2016

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http://hdl.handle.net/10026.1/6758

http://dx.doi.org/10.24382/1060
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**AN ELECTROPHYSIOLOGICAL EXAMINATION OF VISUOMOTOR ACTIVITY ELICITED BY VISUAL OBJECT AFFORDANCES**

By

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A thesis submitted to Plymouth University in partial fulfilment for the degree of

**DOCTOR OF PHILOSOPHY**

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August 2015

*Acknowledgements*

This work was carried out with a studentship from the University of Plymouth.

Thanks to Jeremy Goslin and Rob Ellis for igniting my interest in research as an undergraduate and for their continued support, help and advice during my postgraduate studies. Thanks also to my kind and loving parents, family, godfather and friends for their support and encouragement. Special thanks to my Grandmother, Meme, for all of the lessons she has taught me, and for all of the time we have enjoyed together.

This thesis is dedicated to Samantha Udwin.

## AUTHOR'S DECLARATION

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Sub-Committee.

Work submitted for this research degree at the Plymouth University has not formed part of any other degree either at Plymouth University or at another establishment.

This study was financed with the aid of a studentship from the University of Plymouth.

Publications:

Goslin, J., Dixon, T., Fischer, M. H., Cangelosi, A., & Ellis, R. (2012). Electrophysiological examination of embodiment in vision and action.*Psychological Science*, *23*(2), 152-157.

Dixon, T., Goslin, J., Ellis, R. (2012). Affordance effects in the absence of the intention to act on seen objects. *Cognitive Processing,* 13(1), S39-40.

Presentations and Conferences Attended:

Fifth International Conference on Spatial Cognition, Rome.

Word count of main body of thesis: 76,701

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# An Electrophysiological Examination of Visuomotor Activity Elicited by Visual Object Affordances

## Abstract

A wide literature of predominantly behavioural experiments that use Stimulus Response Compatibility (SRC) have suggested that visual action information such as object affordance yields rapid and concurrent activation of visual and motor brain areas, but has rarely provided direct evidence for this proposition. This thesis examines some of the key claims from the affordance literature by applying electrophysiological measures to well established SRC procedures to determine the verities of the behavioural claims of rapid and automatic visuomotor activation evoked by viewing affording objects. The temporal sensitivity offered by the Lateralised Readiness Potential and by visual evoked potentials P1 and N1 made ideal candidates to assess the behavioural claims of rapid visuomotor activation by seen objects by examining the timecourse of neural activation elicited by viewing affording objects under various conditions. The experimental work in this thesis broadly confirms the claims of the behavioural literature however it also found a series of novel results that are not predicted by the behavioural literature due to limitations in reaction time measures. For example, while different classes of affordance have been shown to exert the same behavioural facilitation, electrophysiological measures reveal very different patterns of cortical activation for grip-type and lateralised affordances. These novel findings question the applicability of the label 'visuomotor' to grip-type affordance processing and suggest considerable revision to models of affordance. This thesis also offers a series of novel and surprising insights into the ability to dissociate afforded motor activity from behavioural output, into the relationship between affordance and early visual evoked potentials, and into affordance in the absence of the intention to

act.  Overall, this thesis provides detailed suggestions for considerable changes to current models of the neural activity underpinning object affordance.

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# *1. Chapter one*

## *Affordance and stimulus-response compatibility*

## *1.1 General introduction*

This thesis considers the synergy between vision and action as espoused in the behavioural SRC affordance literature. The SRC affordance paradigm has been used to demonstrate a two-way relationship between vision and action wherein action possibilities contained in seen objects can have a profound impact on executing motor behaviours, even when the action possibilities are not relevant to the task at hand. From this, deep claims have been made on the nature and layout of neural processes supporting these action effects. These claims will be discussed in the introductory chapters. This thesis seeks to expand this body of knowledge by extending the affordance SRC paradigm to include the use of electroencephalography (EEG) to investigate the timecourse of visuomotor activity associated with the affordance effect under a variety of parameters. In the process, it will examine the veracity of some of the core claims and assumptions of the behavioural literature.

This introductory chapter begins by briefly reviewing the rich historical context in which the present experimental work was undertaken. It will initially consider some of the key studies and principles in the history of the stimulus-response compatibility paradigm, which is at the core of the thesis. After this, the concept of object affordance will be introduced and the relation between affordance and SRC will be considered, followed by some philosophical grounds for the approach taken in this thesis.

## *1.2 Stimulus Response Compatibility*

The paradigm at the heart of this work is the SRC paradigm. This paradigm yields the SRC effect, which is the name given to the increased speed and accuracy with which participants respond to stimulus sets that are similar to their response sets when compared with stimulus sets that are different. The interpretation of the SRC paradigm has undergone a number of revisions and changes and has been used in a wide variety of contexts.

The earliest SRC studies may be found in the work of Paul Fitts, a former US Army Lieutenant Colonel who became an academic studying human movement and human-machine interactions, particularly with a view to improving aviation safety. It was in this context that the now seminal experiments by Fitts and Seeger (1953) provided the first evidence for SRC effects. They presented participants with three different stimulus arrays, each matched with a response array. Stimulus arrays consisted of lights in various positions around the midline of the participants. Only some of the lights would be lit on each trial, and participants were tasked with moving the joysticks in the response arrays towards or away from whatever lights on the array were lit. This forms the parameters for compatibility between stimulus and response and lays out the basic format for all subsequent SRC studies; a dichotomy is created where stimulus and response share or do not share features (such as spatial location) and the trials on which these features are shared are termed compatible and the trails on which they are not shared and termed incompatible. The finding is consistently that responses are faster and more accurate on compatible trials than on incompatible trials. This was an exceptional finding at the time, suggesting that something as apparently simple as stimulus location could interact with responses to yield its own effect, outside of any other experimental manipulations.

Fitts and Seegar extended this in another experiment, having participants either use matched or mismatched stimulus and response arrays to complete the task 32 times over a ten week period. This gave them a great deal of time to practice the relations between the mismatched arrays. Additionally, from the 27$^{th}$ testing session a distractor task was added. It was found that regardless of how practiced a participant was mismatched arrays always produced longer reaction times (RT), with very little change in RT overall. This was also found to be true when completing a distractor task. This led the authors make the claim that is at the core of the SRC literature, that SR translation effects are an integral part of human perception and not something that needs to be learned or that can be easily modified by practice or task complexity. It shows a functional association between what is seen and what is done in a way that had not been seen before.

The next key events in the history of SRC came from the work of J.R. Simon whose eponymous effects are very similar to those of Fitts and Seegar. For example, Simon and Wolf (1963) used similar light displays to those described above that rotated relative to a fixed response location with a sample divided into older and younger participants. The rotation of the stimulus lights was intended to vary the difficulty of the task with a view to identifying an effect of aging however this effect was not obtained. Instead Simon found an effect of stimulus location with up to a 30% RT advantage for the most compatible display (where the stimulus light was rotated closest to response) compared with the least compatible display ( where the stimulus light was rotated furthest from response). Like Fitts and Seegar (1953) this result indicated that there was an interaction between stimulus and response sets occurring in the observer as they performed the task, where motor movements made in the direction of congruent visual stimulation were facilitated simply by virtue of the stimulation.

Simon provided several further demonstrations of this principle and many of the later studies used auditory instead of visual stimuli yet still obtained analogous results and in doing so further expanded the providence of SRC. For example, Simon and Ruddell (1967) presented tones monaurally and had participants make a button press response that was either ipsilateral or contralateral to the tone. Participants had shorter RTs when the button press was ipsilateral to the tone than when it was contralateral, mimicking the visual results above. A similar effect was also demonstrated using verbal commands ‘left’ and ‘right’, presented to left and right ears and responded to with left and right button presses (Simon and Ruddell, 1967). Simon suggested that all of these studies evinced a natural bias to relate our bodies to our surrounding space. To check this interpretation and rule out the possibility of the results being due to a simple isomorphic association, Simon (1969) presented the words ‘left’ and ‘right’ to left and right ears, meaning that on half of the trials the word and the ear were mismatched. It was found that when word and ear were matched, RT was shorter than when they were mismatched. This shows that SRC effects come from information drawn from the stimulus and not a simple 1:1 relation of response hand to stimulus laterality. Simon (1969) provides the final core principle in SRC research by presenting participants with monaural tones and the instruction to move a joystick towards or away from the tone on a per-block basis, altering the task relevance of the tone by predetermining the response. Again, the same effects were obtained.

From the work of Simon and of Fitts and Seegar we can draw out a number of core principles that characterise SRC research and will underpin the experimental work in this thesis:

1. Participants respond more rapidly when stimulus and response are similar than when they are different.
2. This effect is not due to an isomorphic relation between stimulus and response but rather is drawn from the information contained in the stimulus.
3. The effects occur with a wide range of stimulus modalities, including visual, aural and linguistic stimuli.
4. These effects are not a product of learning and are not modified by practice.

### *1.3 Object Affordance*

Affordance is the name given to the potentiation of actions that may be performed with seen objects and shares one of the crucial principles of SRC given above; that information contained within stimuli shapes perception and subsequently shapes behavioural output. One difference between affordance and the studies described above is that with affordance, that information is drawn from objects and the possible actions that may be performed with them rather than from the mere location of the stimulus.

EJ and JJ Gibson first posited this concept after some years of working on perceptual learning (e.g. Gibson & Gibson, 1955), where they were concerned that perceptual learning was characterised as the improvement of amodal, global discriminatory processes which ultimately led to a "decreased psychophysical correspondence between perception and stimulation" (Gibson & Gibson, 1955). In their view, perceptual learning should be more interested in increasing this correspondence because the main challenge in perceptual learning involves dealing with novel stimuli and therefore requires a system that allows high quality interaction with novel stimuli that could only be facilitated by a tighter coupling of perception and stimulation. From this view the notion of affordances flows naturally, representing a mechanism by which observers may detect their relationship with characteristics of their environment, novel or otherwise and so be prepared for real-time interactions with their environment. This is achieved by potentiating action possibilities in observers at the earliest stages of perception in a way that they are not merely products of perception, but rather that their production constitutes a central part of perception itself. In this way, affordances were the forerunner to more modern concepts such as situativity theory (Greeno & Moore, 1993) which states that cognition should be treated as the relationship between agents and their surroundings. It is important to note that the notion of affordance eschews the traditional, behaviouristic mechanics of perceptual input to action output. Instead it creates a loop where perceptual input becomes action potentiation which shapes subsequent perceptual input and where the output is not an independent stage but is rather a conglomeration of the perceptual input to action potentiation loop formed in context of the agent's goals. In this way, the goals and form of affordances are malleable and have been variously debated, reinterpreted and even misinterpreted (*cf*. Greeno, 1994).

The idea of affordance is uniquely suited to investigation by SRC methods because if the principle of potentiating actions to facilitate behaviours is true, then when presenting objects that have properties that are matched or mismatched with response, the SRC effect should be obtained. Indeed a wide variety of research has shown this to be the case and these experiments will be reviewed in chapter two.

*1.4 Looking backwards*

It is interesting to note that well before the work of Fitts, Simon, Gibson and colleagues, philosophers had for some time been appealing to similar ideas when discussing problems with purely computational and representationalist accounts of human function – particularly with respect to how agents could execute their actions in real-time with such success– without appealing to computationally expensive representationalist accounts that would have agents effectively create a 'mirror image' of the world in their mind, necessitating the maintenance of a staggering amount of detailed information in order to execute even the most basic of actions. These representationalist accounts would frame agents as passive observers, however as early as 1927, philosophers such as Heidegger were trying to reframe these agents as active participants in the world around them who had no need to represent in mind the minutiae of their environment, goals and tools, but rather emphasised the functional coupling of objects in context of the agent's goals as the core of intentional action. This is clearly reflected in Gibson and Gibson's (1955) emphasis on increasing correspondence between perception and stimulation. This also speaks clearly to the principles of SRC laid out above, wherein stimulus features (that may or may not be relevant to the task) that overlap with response features facilitate action by virtue of perceptual processes that relate body and intention to peripersonal space, yielding the functional coupling of task apparatus and goal that are a plausible explanation for the SRC effects described above. The importance of functional coupling has also been asserted by more modern philosophers such as Andy Clark (1998) who gives the example of using a hammer to drive a nail; one does not require a rigid representation of the physical characteristics of the hammer, of the nail and of the relationship between these characteristics in order to perform mental calculations of how much force to apply or where to apply it in order to successfully drive the nail home. Instead a more pragmatic coupling of hammer and nail could simply consist of a hammer as an object that is capable of achieving the goal of driving nails.

Another philosophical grounding for the present thesis may be drawn from Merleau-Ponty's work. Merleau-Ponty also wanted to reduce the focus on representational accounts and instead emphasised the synergy of agent and world in an active perceptual loop, where the agent's actions change the world, leading to a modification in the action plan, leading to a change in executed actions, which cause a new change in the world, leading to another modification and so forth. At the core of this notion again is the implicit importance of the relationship between agent and world, just as in Heidegger's ideas and found in the work of Fitts and Seegar, of Simon and of Gibson and Gibson. Although in quite a different context, Merleau-Ponty (1942) gives the excellent example of trying to capture and hold a small, struggling animal, wherein each minute movement of the animal is matched rapidly and evenly by a compensatory movement from the agent holding it, leading to the animal attempting a new and different movement that again changes the agent's grasp on the animal and so forth, in a loop. He suggested that in this way object properties mix with agent intentions to from an entirely new construct and that this new construct is what is useful and relevant to carrying out actions in the world in real-time with any considerable degree of success. As Andy Clark (1998) points out, this idea is not dissimilar to JJ Gibson's (1979) notion of object affordances, described above, which creates a similar loop between perception and action. The similarities are again drawn from advocating the active nature of perception, or what may be called perception for action, wherein merely viewing a stimulus can prepare relevant response in the viewer. Coming full circle, this kind of idea meshes beautifully with the results of Fitts and Seegar (1953) and with the work of Simon and colleagues; the RT advantages obtained in these studies can be explained by an implicit relation between the stimulus and the response that is extracted rapidly on viewing an object, and with almost no interference from external distractors but rather guided by simple rules relating the agent's body to the space around it.

### *1.5 Looking forwards*

The ideas presented above are now often collected under the umbrella of Embodied cognition, a highly collaborative field in which philosophers, psychologists, roboticists, cognitive and computational neuroscientists and others converge with the broad goal of making explanations of cognition that account for the problems and complexities of real-time action by attempting to enact the principles described above. This is achieved by emphasising the role of the body and of the perception of external space in cognition. As mentioned above, this necessitates a move away from computationally expensive representationalist accounts and attempts to pare cognition down to its most essential components by offloading as much computation as possible to the body of the agent and their perception of their surroundings. This is not to suggest that embodied cognition is a single unified notion, for there is surely much debate over quite how body-world-mind interaction might occur and the importance of the different proportions, but it does well express the spirit of the present work and the broad ideas on which it rests. Wilson (2002) identifies six core claims in embodied cognition;

1. Cognition is situated; meaning that it takes place in a body or in the world and takes advantage of that fact and does not occur in an abstracted or homuncular representational space.
2. Cognition is time-pressured; placing limits on what may be computed in time to execute actions successfully and therefore how they may be computed.
3. We offload cognitive work onto the environment; as seen in the functional coupling observed in the SRC work cited above.
4. The environment is part of the cognitive system; Clark (1998) asks the question, if one is working through a maths problem on paper, where does one's mind end?  In one's head, hands or on the page?  This is deliberately difficult to answer with certainty.
5. Cognition is for action; this is a central notion in this thesis, it indicates that goal directed behaviour is what drives cognition.
6. Offline cognition is body-based. This is one of the more contentious claims and is not a central focus of the present work.

These claims are broadly agreed within the field, with a healthy level of debate. They do not espouse a single view point but rather, as suggested by authors such as Anderson (2003), form the principles at the core of a radical revision of the general approach to cognitive sciences and it is this general approach that is adopted by the author. Wilson (2002) states that not every claim is important to all work on embodiment and the claims central to the present treatment are that cognition is time pressured, that this is overcome because cognition is also situated, that the environment (and its relationship with the body) has a central role to play and overall, some broad, positive evidence will be provided that cognition is for action.

*1.6 Chapter conclusion*

This chapter has shown that for the better part of a century, a variety of scientists and philosophers have been converging on the notion of a tight, reciprocal relationship between perception and action with an increasing emphasis on the role of the environment in cognition. They underline the importance of the relationship between observer and environment in agent-world interactions and suggest that there are innate processes in perception that use these relations to expedite behaviour where possible. This has been pursued in the context of learning, in the laboratory and in explaining day to day behaviour. The following chapter will first examine the behavioural research that supports this idea, before introducing come of the complexities underlying these ideas.

## *2. Chapter two*

## *Affordance and embodiment*

### *2.1 SRC, Affordance and Embodiment; a milieu*

Chapter one introduced the phenomenon of SRC in terms of abstract SR relations such as the location of a stimulus (e.g. a light or auditory tone) and its relationship with the spatial characteristics of a response set. Chapter one also introduced the notion of affordances as espoused by Gibson and Gibson (Gibson & Gibson, 1955; Gibson, 1977). As discussed, these two ideas emerged at quite different times and from quite different backgrounds, however they synergise well with each other and with some of the philosophical groundings also given in the previous chapter. The key to this synergy can be found in the structure of the SRC paradigm and in the predictions made by the idea of affordances; SRC results are obtained by the use of matched or mismatched SR pairs, where matched pairs are said to better cue responses than mismatched pairs. The core idea here is that matched pairs are cueing the response in the observers, similar to what Simon described as the natural tendency to respond toward stimulation. Similarly, the notion at the core of the affordance account is that the physical structure of objects prepares the agent for interaction with the objects. In both of these accounts, perceived stimulus characteristics are cueing behaviours. They key difference between Simon's and Gibson's initial accounts are the types of stimuli that they consider, with Simon using abstract stimuli that do not have clear goals associated with them and Gibson and Gibson's (1955) initial focus from their work on perceptual learning being on interaction with novel objects in what would generally be goal directed behaviour. Since this time however, some researchers have brought these ideas together and the SRC notion of matched pairs cueing responses has been extrapolated to use with abstract stimuli that simulate real actions, as well as with real objects. This section will consider some experiments that show how the ideas given in the introduction can be unified and in so doing, will set up the theoretical approach for the experimental sections.

An SRC experiment by Michaels (1988) simulated the affordance of catching by showing computer generated squares moving toward or away from the response location. The square appeared in front of one hand at one response location and moved towards it, or towards the other hand at the other response location. It was found that when squares appeared to be moving toward the response location, participants responded more rapidly than when they appeared to be moving away. This experiment uses the SRC structure from Simon's studies but was designed around and explained by Gibson's affordances; the affordance of catching a moving object was mimicked by having the stimulus moving towards the response location.

Crucially, a second experiment supported this interpretation by systematically varying the response in three locations around the body midline; participants deployed their responses with both hands at a location that was right, left or medial around their body midline to the same stimulus. This exaggerated the correspondence between stimulus motion and response location to show that the results were not due to relative position or motion but rather to the action possibilities conferred by the *destination* of the moving stimulus. It was found that responses were faster at a medial location than at an exaggerated left or right location, confirming that it was the perceived destination of stimulus movement (and the actions it afforded the participant) that yielded the effect, rather than the mere relative position. This is what chiefly supports the affordance explanation, the functional association between stimulus motion and response location, rather than a simple spatial correspondence that is seen in the abstract SRC examples given by Simon. If the effect was stronger due to relative position then an explanation such as Simon's natural tendency may have been a better fit however the information contained within the SR pair here appeared to yield the effect by mimicking the affordance of catching. This study employed the SRC paradigm to demonstrate more than a faster response toward stimulation, it showed that the SRC paradigm can be used to demonstrate the existence and utility of the extraction of functional, action-relevant information from visual stimuli. This is of course, one of the core ideas in affordance.

The link between SRC and affordance in Michael's work has since been expanded by a great many studies and of chief interest to this thesis is the work of Rob Ellis and Mike Tucker, who showed SRC effects with real object stimuli that appear to be solely attributable to the objects affordances. Tucker and Ellis (1998) showed participants images of common household objects that had graspable handles. The objects were pictured in their familiar upright position or were inverted. Object handles were orientated to the left or right of the images and participants were asked to declare whether an object was upright or inverted by using a left or a right button press. This yields the dimension for an SRC effect with a real object; when the required button press is of the same laterality as the orientation of the handle a compatible trial is created and when they are opposite, an incompatible trial is created. An important feature of this experiment is that the orientation of the handle is not part of the task and the role of handle orientation was never made explicit. An SRC effect was found with handle orientation yielding the effect regardless of the stimuli being upright or inverted, with fewer errors and more rapid responses on compatible trials than incompatible trials. This effect was attributed to an affordance effect, where the object affordance was interacting with the planned response to yield shorter RTs. In order to confirm this, a second experiment was conducted in which participants were presented the same stimuli but used a unimanual response, using middle and index fingers to declare the responses. By removing the correspondence between response hand and stimulus rotation and limiting both responses to a single hand the claim of an interaction between bodily position and actions afforded by the stimulus could be falsified. With this manipulation, no effect was detected, supporting the results from the first experiment. This echoes Simon (1969) who also used a unimanual response to show that Simon effects were not due to a simple isomorphic association between stimulated ear and ipsilateral effector. However Tucker and Ellis' (1998) effect is readily distinguishable from a Simon effect. This is due to the central presentation of the stimulus as compared with Simon's lateralised presentations and also to the use of familiar, action-relevant SR pairs instead of Simon's (1968) abstract relationship between auditory stimulus and effector. In Tucker and Ellis' (1998) study, the only changes in lateralisation were the objects handle, which was the same or opposite side as response and always pictured centrally, unlike Simon-like stimuli which are generally pictured on either side of the midline of the stimulus. Tucker and Ellis' (1998) central position means that the effect cannot be explained as a Simon effect and the effect can only be explained by the varying affordance provided by the laterality of the objects handle and its relationship with the response. A third experiment saw a change in the response; participants responded to images of upright or inverted common household objects that were oriented horizontally or vertically, requiring a wrist rotation to interact with them. Participants' forearms rested on an arm rest with their wrists extended past the armrest. A tilt-switch ensured their arm was within 3° of the assigned starting position for each trial, which had their thumb pointing toward the 11 o'clock position; this meant that to grasp a vertical object (e.g. a wine bottle) required a clockwise wrist rotation and to grasp a horizontal object (e.g. a table knife) would require an anticlockwise wrist rotation. Responses consisted of a small wrist rotation and any rotation greater than 9° in either direction was recorded as a response. Compatibility was determined by the relation between required wrist rotation, and the mapping of wrist rotation responses to object categories. The familiar compatibility effect was observed. This third experiment extends the results of the first two by providing another demonstration that the effect is borne of the relationship between response set and the actions afforded by the objects by using a different type of response whilst maintaining the other aspects of the experiment and also shows that these compatibility effects are not limited to lateralised stimulus presentations but also emerge with other relations between body and stimulus.

Although Tucker and Ellis's (1998) results broadly match with the results from Simon and Fitts and Seegar (1953), there are some crucial differences that greatly affect their interpretation. The objects in this study were centrally presented, undermining Simon's 'natural tendency to respond towards stimulation' explanation. Instead, the results are explicable as a functional association between the relative positions of the body and the interactions afforded by the laterality of the objects. Also, the dimension for compatibility was not made explicit, reinforcing the notion of the utility of functional associations connecting perception and action, because responses were influenced by the non-task relevant dimension of the rotation of the graspable parts of the objects simply by viewing the objects. This is a great expansion on the catching affordances from Michaels (1988) because this not only provides an elegant demonstration of the existence of object affordance, it also demonstrates the utility of affordances in relating body to world to facilitate actions with real objects. This also begins to creep into the territory of embodiment, where the implicit stimulus features cued actions and reflect Wilson's (2002) description of cognition being situated and taking advantage of the world around the agent. Furthermore, this result speaks to the allied notion of cognition being time-pressured because the key result here is the reduced RT when object rotation matched with the planned action. This study provides the foundation for the premise of this thesis, that the SRC paradigm may be used to demonstrate the functional association of visual stimulus characteristics with bodily state and that the results appear to best fit an embodied model in which object affordances provide a mechanism for enacting some of the Wilson's (2002) principles of embodied cognition.

The principles demonstrated in Tucker and Ellis (1998) can be extended to other types of object affordance too.  Ellis and Tucker (2000) demonstrated another kind of affordance SRC effect by having participants mimic two grips whilst presenting them with images of objects that required those grips to interact with them.  The first grip was a power grip, consisting of a palmer grip with the digits folded around the object, such as one might use with a hammer.  The second grip was a precision grip, made with thumb and forefinger, such as one might use to operate a key in a lock or to pick up a single grape.  Participants were told which response to make by an auditory tone.  A grip-type compatibility effect emerged, where RTs were shorter and errors were fewer when the response grip matched the grip associated with the objects than when the two were mismatched.  This mirrors the result from Tucker and Ellis (1998) with another kind of affordance, reinforcing the claim that the objects affordance is what yields these effects.  Also, because participants used both response devices in a single hand this supports the claim that the effect is not a simple isomorphic association but really is about the functional association between visual input and available actions.  A second experiment used wrist rotations that were matched or mismatched with the wrist rotations required to interact with the stimuli, similar to Tucker and Ellis (1998) but as in experiment one, had responses cued by an auditory tone. In this experiment, the stimulus had also disappeared before the response was made. Again, this yielded a compatibility effect based on the object affordance and again, this is taken as further evidence that viewing objects potentiates the actions that are afforded by them in the observer, which is the claim at the heart of affordances.  As with the previous study, these results are not attributable to Simon’s claim that humans respond more rapidly toward stimulation because the stimuli were centrally pictured and both responses were made with a single hand.  Ellis and Tucker (2000) note that the size of these effects is small but that this is sensible and necessary to avoid afforded actions disrupting active goal-directed actions, indicating the real-world utility of the phenomenon as preparing and facilitating actions, but not dictating them. Taken together, these studies provide converging evidence from three types of affordance that seen objects, even when not task relevant, appear to facilitate actions or components of actions, that are similar. It appears that some process is rapidly extracting action possibilities from viewed objects and that this influences motor processing very rapidly, likely during the planning stage of making a response and certainly before the participant is able to respond. This hints at a tight link between visual and motor processes where the apparent visual extraction of motoric properties of the stimulus has led some researchers to characterise this system as neither purely visual nor purely motor but instead as a combination of the two; visuomotor. That said, it does not provide direct evidence for such a link and this shall be the part of the goal of this thesis.

The evidence for this position does not only come from SRC studies. Symes, Ellis, Tucker and Ottoboni (2008) conducted a change blindness experiment, a paradigm in which participants are presented with two identical images that switch back and forth, containing one substantial change between each image. Participants are asked to identify the change and it often takes several seconds for them to do so (*cf.* Grimes, 1996; Simons & Levin, 1997). In Symes et al. (2008) participants were shown repeatedly switching images of arrays of twelve objects between which a single object would change. In this case, one of twelve stimuli would be replaced by a similar stimulus, for example a strawberry was replaced by a cherry. These objects were all compatible with precision or power grips and participants were asked to signal their responses by making one grip or another, using the response devices from Ellis and Tucker (2000). Change blindness paradigms are intentionally difficult and response times can be much longer than in conventional RT experiments, such as the SRC paradigm. It was found that when the changing object was compatible with the participant's prepared grip the RT was reduced by an average of 372ms. This provides a different demonstration of the principles outlined above. In some ways this is a more direct demonstration of the visuomotor nature of perception because the preparation of a grip is seen to directly influence how the visual scene is perceived. This also speaks directly to Wilson's (2002) tenets of embodied cognition, with perceptual work being offloaded to the effectors and reducing reaction times greatly.

An older study by Craighero, Fadiga, Umiltà and Rizzolatti (1996) used task-irrelevant primes during a task that involved grasping a bar. The task-irrelevant primes were either congruent or incongruent with the position of the bar that was to be grasped. Primes consisted of drawings of a circle, a rectangle rotated 45° clockwise or a rectangle rotated 45° anticlockwise. The bar was rotated 45° clockwise or anticlockwise, offering a dimension for compatibility with the prime. They found that when the primes were congruent with the bar, responses were facilitated. They described this result as the first evidence for visuomotor priming by irrelevant stimuli, again supporting the notion of integrated visual and motor systems. An interesting feature of this study is that the result is almost the inverse of Symes et al. (2008) with perception of irrelevant drawings influencing the grasp, rather than the prepared grasp influencing the perception of visual stimuli. This again speaks to a reciprocal relationship between vision and action.

Similar evidence for these principles may be drawn from Gutteling, Kenemans and Neggers (2011) who sought to provide direct evidence of the influence of the motor system over early stages of perception. They did this by comparing the results of grasping and pointing to a bar during an orientation discrimination task. Crucially, the bar could slightly change its orientation during the trials. They found increased sensitivity to orientation changes when grasping the bar instead of pointing at it. In a control experiment, the bar remained static and researchers varied the luminance of the bar, a property that is not relevant for grasping or pointing behaviours. When the bar remained static and only luminance varied no effects were found whether gripping or pointing at the bar. The authors suggest that this is the first direct evidence of visual features influencing action preparation, leading on from a large body of indirect evidence such as that cited so far. Gutteling et al. suggest a neuronal feedback explanation for these effects, with motor planning areas feeding into early visual cortex. As suggested above, this study represents another strong piece of evidence for a functional coupling of vision and action and as the authors suggest, it is indeed a direct demonstration of this principle. It is not however, a direct demonstration of their proposed neuronal feedback loop between visual and motor cortices. This claim typifies a trend in the behavioural literature on this connection between vision and action; based on behavioural data alone, researchers offer conclusions about the neural framework underlying their effects. Although these behavioural demonstrations can be elegant and convincing, they rely on inference to reach their conclusions rather than measurement of their target structures.

Further behavioural evidence supporting the reciprocal perception-action link comes from Lindemann and Bekkering (2009) who had participants grasp a response device shaped like the letter 'X' that could be rotated clockwise or anti-clockwise. Upon the delivery of a go signal, apparent motion induced the effect of a rotation in the stimulus. A compatibility effect was found when stimulus apparent motion matched with the planned rotation of the response device. Consistent with the research cited in this section, the conclusion was for a bidirectional relationship between vision and action. Vingerhoets, Vandamme and Vercammen (2009) conducted a series of priming experiments examining the different contributions of physical object properties and conceptual object properties to motor affordances. This is an important caveat to the work cited so far because the affordance account directly claims that the physical properties of an object gives rise to its affordance. They presented a series of familiar and unfamiliar tools as well as simple graspable shapes and had participants respond according to the direction of a centrally presented arrow. When comparing familiar and unfamiliar tools they found that familiarity yields no effect on RT, supporting the Gibsonian notion that affordance could represent a means for interaction with novel objects (Gibson & Gibson, 1955). Interestingly, RTs were shorter for highly graspable (as determined by participant ratings) unfamiliar tools and graspable shapes than for familiar objects. They found that conceptual information such as semantic category or learned associations failed to affect responses in the same way, indicating that the affordance effect was arising from the physical features of the stimuli. Indeed, the largest effects were products of perceived graspability and visual complexity. Vingerhoets et al. (2009) concluded that the brain automatically extracts object affordances based on intrinsic (e.g. shape) and extrinsic (e.g. orientation) object properties in a way that is not achieved by conceptual object properties.

This section has detailed a set of experiments from a variety of laboratories that all reach the same conclusion; that there is a close and reciprocal relationship between vision and action in which action relevant cues from a wide variety of meaningful visual stimuli have influenced a variety of physical responses, even when these cues have been irrelevant to the task at hand. Another common thread in these experiments is the implications of these studies for the organization of visual perception and motor coordination in the brain. It has been suggested that this reciprocal relationship between visual systems and action systems is reflected in the organization of the neural architecture underpinning the task. Over the remainder of the present chapter some attempts to model SRC will be considered, with particular reference to their claims about organisation in the brain. Also, some alternative views on agent-object interaction will be considered.

### *2.2 Attempts to model SRC*

A number of attempts to model SRC have been made, but few of them cover the kind of affordance SRC effects discussed so far. This section will briefly consider two of the most widely cited models and some of the ways in which they differ from some of the principles described above.

The Dimensional Overlap model (DO) by Kornblum, Hasbroucq and Osman (1990) broadly states that SRC effects are explicable as the product of the similarity (overlap) of features (dimensions) of the SR pair. When viewing stimuli they are first checked for DO, if DO is found then stimulus and response are compared. Subsequently, the result of these comparisons feeds forward to influence the generation of a motor program which then accounts for similarities and differences between stimulus and response. This process is conducted in serial. DO provides a taxonomy of SRC effects (table 1) that cover a variety of SR dimensions, both task relevant and irrelevant as well as including stimulus-stimulus (SS) compatibility. The taxonomy allows for DO across stimulus modalities (visual, linguistic and auditory), enabling it to explain abstract SRC effects such as JR Simon's SRC effects or the classic Stroop effect. However, the taxonomy does not make provision for the use of real object stimuli, meaning that even after several revisions (e.g. Kornblum, 1994; Kornblum & Lee, 1995) it offers a poor fit for the stimuli given in the key citations above. In coping with multi-modal SRC effects, the model implies a kind of amodal space for checking SR pairs for DO and integrating them where DO is found. A problem with this method of first checking for DO is that it necessarily reduces the predictive validity of the model because SR pairs need to be checked for DO before they can be integrated in order for the effect to occur. Moreover, necessitating a check for DO before any interaction suggests that this type of system would not be capable of aiding interactions with novel objects in the same way as envisioned by Gibson and Gibson when they suggested the concept of affordance, making this a poor candidate for explaining the kind of effects obtained with affording objects discussed here so far. Another issue with this model in the context of this thesis is the lack of biological referents entailed in its design, with no reference made to brain regions or the role of body/ effectors, undermining embodied ideas laid out above and failing to account for effects such as Tucker and Ellis (1998) that are dependent on body position as much as response type. An assumption from cognitive neuroscience is that various regions function in concert with each other to produce complex behaviours and this is also difficult to reconcile with the serial structure of the model. Simply checking for DO would then mean sending signals to different brain regions associated with the modalities entailed in the task, each of which would have to be sent pending the output of the previous stage of checking. After the modality had been resolved, another region would be required to integrate the output of these stages and check for DO and all of this would have to occur before the response was planned. This would present a computationally expensive and biologically and temporally implausible method of handling SRC effects that does not appear to fit with the principles of embodiment, affordance and cognitive neuroscience that guide this thesis. Hommel (1997) discussed DO's serial approach over three experiments that showed that response-related processes were starting before stimulus-related processes were complete, which is inconsistent with the serial framework laid out in the DO model. This was accomplished by using an SRC task (Simon task) with one of three stimulus-stimulus congruency (SSC) tasks. The DO model would predict an additive

*Table 1.* Taxonomy of SR ensembles in the DO model. Reproduced from Kornblum and Lee (1995). Yes/ no entries describe whether or not DO exists and on what dimension(s).

| | Overlapping Dimensions | | | Examples | | |
|---|---|---|---|---|---|---|
| | SR dimenions | | | Stimulus sets | | |
| Ensemble type | Relevant | Irrelevant | SS dimensions | Relevant | Irrelevant | Response Sets |
| 1 | no | no | no | colours | shapes | digit names |
| 2 | yes | no | no | digits | colours | digit names |
| 3 | no | yes | no | colours | digits | digit names |
| 4 | no | no | yes | colours | colour words | digit names |
| 5 | yes | yes | no | colours | position (left-right) | key press (left-right) |
| 6 | yes | no | yes | position | colours & colour words | key press (left-right) |
| 7 | no | yes | yes | colours | colour words /position (left-right) | key press (left-right) |
| 8 | yes | yes | yes | colours | colour words | colour names |

effect of SSC and SRC however Hommel (1997) showed separate, competing effects of SSC and SRC in each experiment. Hommel (1997) suggests that the DO models serial processes are a poor fit to their data, which showed competing effects consistent with continuous transmission of visuomotor information. This is troubling when considering real objects, which are not properly accounted for in the taxonomy and tend not to appear individually, further testing the serial approach laid out in the DO model.

A more recent model from Hommel, Müsseler, Aschersleben and Prinz (2001) is better equipped to cope with object stimuli in SRC and is known as the Theory of Event Coding (TEC). Hommel (2009) described TEC as based on Hommel's (2000) notion of the *prepared reflex*, which broadly suggests that the major control operations required in SRC tasks are performed before the stimulus is even presented. TEC was intended to model willed actions but is partly based on SRC evidence and so can account for that too. The model suggests that perception and action receive equal representation in common representational medium that consists of cognitive constructs they refer to as event codes, and that event codes are generated according to the action intentions of the observer. The codes account for the physical as well as the functional characteristics of perceptions, and actions. It emphasises the role of the outcome of actions in action selection, and by doing so accounts for action intention. The use of codes as a 'common representational medium' allows for continuous and simultaneous comparison and combination of perceptual and action information gathered through any perceptual modality, all with the goal of producing behaviour in real-time.

The model was intended to bridge a gap between the dominant cognitivist approach, which was suggested to fail to sufficiently account for the impact of action intentions on perception, and the action-orientated approach, which tends to treat action planning as a continuation of stimulus processing. Treating action planning in this way makes TEC a good fit with the concept of affordance, which offers the similar idea that afforded actions are potentiated in observers upon viewing objects and that this potentiation produces the SRC effect as part of continuous and reciprocal visuomotor processing, rather than discrete, serial processing described in the DO model. TEC is defined by three core assumptions; firstly that perception and action share a coding scheme which offers a platform to create representations of the world. Assuming a suitable coding scheme, this provides a *cognitive* mechanism for the integration of real object stimulus affordances and response set affordances, allowing TEC greater explanatory value than DO when dealing with affordance SRC effects. A second assumption is that representing these SR pairs is distributed based on composites of feature codes, with each represented in discrete subsystems. Hommel (2009) describes this by suggesting that the number of features shared by SR pairs defines their similarity and that when considering the tight connections between visual and motor systems, this means that one may also define similarity between perceptions and actions. Hommel et al. (2001) suggested that to plan an action is to consider not only the mechanics of performing the action, but also the effects it may have on the world, recalling the notion of affordance i.e. viewing an object elicits a preparation of actions that are afforded by the object, and these affordances are a means to understand the effect using the object may have on the world, just as described by Hommel et al. (2001). He goes on to say that this view requires perceptual and motor systems work together to define the relationship between the visual input and possible behavioural output in order to compute the effects of those possible actions. The third assumption is that cognitive representations refer to distal and not proximal representations, effectively meaning that it describes the action possibilities and actions that exist in the external world, rather than the plethora of possible actions that could be internally represented. This is both a strength and a weakness; a strength because it reduces the computational expense of the SR translations required and filters out many irrelevant dimensions that are invited when relying on internal representations. However it could be seen as a weakness insofar as it fails to explain how an observer may make the transition between distal and proximal relations or vice versa and so it cannot account for all aspects in generating a particular motor pattern. For example, when interacting with something novel (e.g. a rock climber visualising a way to scale an unfamiliar rock face or watching another climber scale that same novel rock face). As suggested above, TEC's action orientated approach is much closer to the idea of affordance than the DO model and chimes with some ideas in embodiment. Despite the strengths in this approach, it does not make direct or specific predictions about the anatomy or timecourse of neurophysiological events entailed in structuring the coding of external events. In particular the timecourse of visuomotor events underpinning object interactions is a key idea in this thesis. So, whilst the model provides a clear *rationale* for a role for the body in generating codes, it lacks the kind of physiological and anatomical specificity sought to guide this thesis. Additionally, from an embodied perspective it is difficult to see how positing extra processing stages for transforming sensory information into abstract codes offers greater parsimony as an explanation of real time cognition or how and why it is needed in a biological sense. So, despite the clear theoretical rationale it provides for visuomotor processing, the TEC is still not a perfect fit for the ideas in this thesis.

A more recent computational model from Cisek (2007) gives direct consideration to some of the brain regions involved in affordance as well as overturning the idea of serial processing in favour of parallel processes. The Affordance Competition Hypothesis suggests that constant competition exists between current action possibilities and the actual need for action. This idea of competition suggests that agents constantly potentiate actions and select between them, aided by a brain that has evolved to mediate action in real-time. Cisek's (2007) sentiments here echo those of Wilson (2002), Anderson (2003) and others given earlier in this chapter, perhaps reflecting the direct involvement of the concept of affordance in the development of this model.

The affordance competition hypothesis suggests that visual information is processed in posterior parietal cortex (PPC) in parallel with processing in prefrontal cortex (PFC). In this way, this model surpasses any serial models and is a better fit with the fundamentals of cognitive neuroscience, which strongly indicates parallel processing in different brain regions. PPC is seen as being involved in selecting the target and maintaining that selection for subsequent use, which will come from the reciprocal connection with dorsal premotor cortex (dPM). This reciprocal connection allows for online changes of the action plan induced by new targets, but moreover, it allows the product of the PFC processing of action goals and planning of action execution to be communicated back to PPC, via dPM. Aside from the reciprocal connection back to PPC, dPM is divided into three layers in this model with reciprocal connections between each that allow this layer to resolve competition between different inputs from PPC in context of the input from PFC. As Cisek stated, the output of the competition in these layers constitutes the decision of which response to make, however this decision is not deployed before the activation reaches the final node in the network, primary motor cortex, which essentially functions as an output stage.

The brain regions implicated in the model are well supported, for example Anderson and Cui's (2009) review made similar suggestions about the roles of PPC and its links with PFC, particularly in terms of low-level sensorimotor elements being managed by PPC but being moderated by high-level planning and goal-state elements by PFC. The behavioural implications of the model are also well supported by studies such as Tucker and Ellis (1998), Ellis and Tucker (2000) and Michaels (1988). The author himself suggests the biggest weakness to the affordance competition hypothesis; that it does not account for the full panoply of brain regions that have been shown to play a role in action preparation and execution.  This is however, a considerable improvement over other models, such as the DO model or TEC which have been generated without reference to brain areas and instead appear to exist in an abstract space with little to no biological constraint.  Cisek's (2007) model is one of relatively few to consider affordance as being at the heart of real-time decision making and action execution and similarly one of few to consider the brain regions entailed in this too.  His reciprocal connections between parietal and premotor cortices are compatible with the conclusion of many studies from the previous section, studies that invoke a reciprocal connection between visual and motor stages.  That said, although the precise anatomy of visuomotor  processing is up for discussion, Cisek (2007) provides a clear model offered in context of multiple layers of reciprocal, self-referential processing, chiming well with a variety of citations given above (e.g. Ellis, 2009).  This model is not comprehensive however, for example it does not make direct predictions about the role of response preparation (e.g. Symes et al., 2008; Ellis and Tucker, 2000) in detecting affordances or indeed what would happen in the absence of these physical preparations.  It also does not make direct predictions about priming or multiple object presentations.  These themes will be visited in the experimental chapters.

Although we have seen that the SRC paradigm is capable of demonstrating object affordances, particularly with real object stimuli, it appears that the DO model of SRC fails to account for affordance effects.  Whilst Hommel et al.'s (2001) TEC provides a clear rationale for visuomotor coactivation, the coding explanation is fundamentally cognitivist and lacks the neurophysiological specificity sought to guide this thesis. Cisek's (2007) model best describes a neurologically-grounded framework for affordance SRC effects because it has been designed with affordance in mind and moreover that it has been designed with relevant anatomical and physiological constraints in mind.  Cisek's model typifies the kind of approach adopted in this thesis; the integration of behavioural results and cognitive neuroscience with the goal of understanding affordance effects in context of the biological, physical and temporal constraints placed upon the agent.

### *2.3 Other views on the SRC affordance effect*

One alternative explanation of object affordance effects may be drawn from Anderson, Yamagishi and Karavia (2002) who showed participants a series of simulated objects over three experiments and simulated non-objects over two experiments. Stimuli are detailed in in figure 1. They suggest that the SRC affordance effects described above are products of attentional bias by asymmetries within the stimuli. Each experiment had participants complete an SRC-type task, with the stimuli rotated 18° clockwise or anticlockwise determining the hand of response, and the orientation of the objects determining compatibility. Their first experiment saw two of the authors complete this task and rate the salient parts of the stimuli. They rated the hands of the clock, the handle of the scissors and the bowl of the wineglass as the salient features. Interestingly, they found shorter RT but increased errors when the lateralisation of the salient features matched with the lateralisation of the button press response. The increased error rates with compatible stimuli conflict with the findings of Tucker and Ellis (1998) and Ellis and Tucker (2000), who found reduced error rates when stimuli were compatible. The main differences between these studies were the use of black and white object silhouettes as stimuli, compared with Tucker and Ellis' (1998) photographs of real objects or the real object stimuli used in Ellis and Tucker (2000). Their second experiment repeated this with a sample of 21 naïve observers and found similar results. Participants rated the same parts as the authors as being most salient and showed the same RT and error rate effect, except with the scissors. Ten participants rated the handle as the most salient feature of the scissors, ten rated it as the blade and one rated the axis of the stimulus as being most salient. When the data were reanalysed with respect to participants' ratings of salience the results matched with that of the experimenters. The authors concluded that the location of the salient feature was the ‘critical factor’ and stated their assumption that these features induced attentional bias in the observers.  A third experiment saw the object stimuli pictured only in the left visual field and again used only the authors for participants, who used self-report and indicated the salient features as being the same as in experiment one and showed the same shorter RT and increased errors when the salient part was on the same side as response.  In concluding experiment three, they state that their self-report data supports their assumption from experiment two that asymmetry is directing attention.

Anderson, Yamagishi and Karavia (2002) also conducted a series of non-object experiments, with the stimulus consisting of a white circle with two smaller circles pictured on each side (’side-patches’) that gave laterality information (see figure 1).  They again used an author for a participant alongside a sample of 12 naïve observers.  Again, RT was shorter and error rates higher when response was on the same side as the asymmetry (i.e. left response to left-asymmetric stimuli and vice versa). This is consistent with self-reports from observers and authors that the larger side patches were used to judge orientation. They conclude that because the same behavioural data was obtained for object and non-object stimuli (regardless of the nature of the stimuli), an affordance effect may be ruled out.  They then repeat their assumption that stimulus asymmetry is causing attentional shifts and use this assumption to conclude that the RT effect obtains when the attentional shift is compatible with the response and not when handle and response match.  Their final experiment saw one side-patch removed from the non-object stimuli and only two authors for participants.  Again they found shorter RT and more errors when response coincided with stimulus asymmetry.  Overall, they conclude that visual asymmetry in the stimuli induced attentional bias in their participants and that it was an interaction of the attentional bias and the hand of response that yielded the effects here, rather than interactions of handle orientation and response location as suggested in other affordance SRC paradigms.

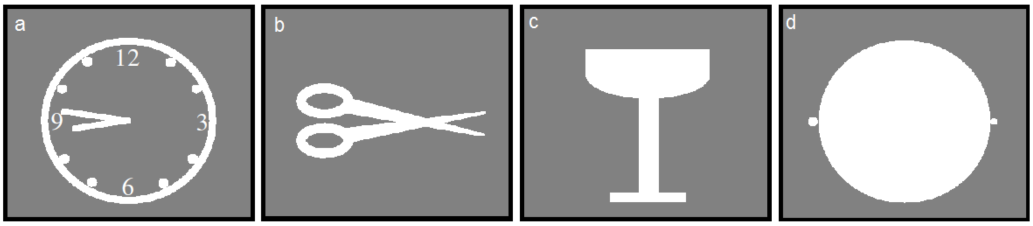



*Figure 1.* Stimuli found in Anderson et al. (2002).a) clock face stimulus, always pictured with hands at 3.15 or 8.45, i.e. orientated left or right. b) Scissor stimulus, could be oriented left or right. c) Wine glass stimulus. d) Non-object stimulus, note asymmetrical 'side patches' that yielded orientation information. All objects were also pictured rotated 18° clockwise or anticlockwise. Stimuli a-c were used in the object experiments 1-3 and stimulus d was used in the non-object experiments. Figure reproduced and edited from Anderson, Yamagishi and Karavia (2002).

There are several problems with this conclusion, mostly arising from the method. Not least among them is the issue of the use of the authors as participants in a study where the analyses were conducted based around the author's own self-reports of the salient features of the stimuli. Naïve observers were only used in two of five experiments and when they were they completed fewer trials than the authors before all of the data were entered into group means. The use of experimenters as participants introduces a possible bias and this notion is supported by the lack of agreement on the scissor stimulus from experiments one and two. Another related issue is the use of assumptions in the study. The authors clearly state in the discussion of object experiments two and three, as well as non-object experiments one and two, that the attentional bias explanation is an assumption and offer no little supporting argument. They also assume that their stimuli are equivalent to affording objects however they were merely monochrome silhouettes of objects (figure 1), only loosely resembling real objects. The objects lacked cues to depth, three-dimensional shape or graspability, something present in Tucker and Ellis' (1998) and Ellis and Tucker's (2000) real object stimuli and critical to object affordance. Additionally, no effort was presented to establish whether the objects would generate an affordance effect, critical to delineate an affordance effect from what they describe as an effect of salience. The monochrome, simulated stimuli (figure 1) used in the study are not comparable to the clear photographs and actual real-object stimuli used in the affordance SRC studys that it seeks to refute (e.g. Tucker & Ellis, 1998; Ellis & Tucker, 2000). For example, the proportions of the scissors are very unusual. Also, because the stimuli are monochrome, they have no texture or colour information to separate functional and graspable parts. Another reason that this study is insufficient to refute the affordance explanation is because it only considers lateralised affordance and does not consider grip-type affordance, such as that seen in Ellis and Tucker (2000). An alternative explanation may be drawn from their use of 'side-patches' suggesting a Simon-like effect may be taking place instead, considering the lack of affording characteristics in the stimuli.

Allied to the issue with authors rating stimuli that they created is the error rate data, the opposite of that found in the affordance SRC literature cited earlier in this chapter, where compatible trials see fewer errors rather than more. Although this is insufficient to draw any conclusions, it suggests that Anderson and colleagues may be dealing with a different phenomenon. These error rate differences could also be related to the analyses, where functional parts (i.e. scissor blades, bowl of wineglass) were defined as the most salient instead of graspable parts (i.e. handles) as in an affordance experiment, however this is difficult to resolve with the RT advantage for functional parts. A key feature of Anderson et al.'s (2002) disagreement with the affordance explanation comes from the use of RT metrics; they claim to refute the affordance explanation by replicating the RT effect with non-object stimuli. However this argument is insufficient; although they replicated the global RT effect, this single point of measurement does not reveal enough about the underlying processing that produced the effect to justify the strength of their conclusion. More convincing would be to demonstrate that simulated objects elicited the same visuomotor activity as real objects. This disagreement supports the use of ERP measures in the present thesis because they would enable a direct test of whether the simulated object silhouette stimuli elicit a comparable visuomotor response to an object affordance, allowing a direct test of the physiology underpinning Anderson et al.'s (2002) claims.

Another alternative position on SRC effects is typified by RW Proctor, who has sought to show the equivalence of many different kinds of SRC effects, whether with affording objects, words, numbers, abstract visual or auditory stimuli. More specifically, Proctor describes affordance SRC effects as object-based Simon effects (e.g. Cho & Proctor, 2011) and relates all other forms of SRC to Simon effects too (e.g. Proctor, Miles & Baroni, 2011), where they define a Simon effect very generally, as a compatibility effect of an irrelevant stimulus dimension. However, Proctor does not suggest that these effects are all identical, conceding that different factors may be at work. For example, in Proctor, Miles and Baroni (2011) it is suggested that an object-based Simon effect would require additional semantic processing when compared with abstract Simon effects, implying that there are many different kinds of Simon effects. The critical difference between Proctor's approach and the approach in the present thesis is the application of an affordance explanation. Proctor has repeatedly found against the affordance account (e.g. Cho & Proctor, 2010; Proctor & Vu, 2006), generally by failing to replicate results from other labs (e.g. Lien, Gray, Jardin & Proctor, 2014).

Proctor and Miles (2014) identify two versions of affordance at large in the literature; traditional Gibsonian affordance, also called the direct-perception account, and representational affordances, which they describe as a blend of ecological and information processing accounts. Proctor comes from an information processing background and so is against the direct perception account because it removes several processing stages that would normally be considered important by an information processing model. On the representational affordance account, Proctor and Miles suggest that there is no value to be gained by introducing the concept of affordance, a concept from ecological psychology, into the information-processing dominated SRC literature. They reason that by uniting ideas from the different fields the resulting amalgamation will fail to satisfy either the typical affordance or the typical information processing accounts. For instance, they see insufficient justification for introducing ecological concepts into the information processing model, which they deem sufficient to account for all SRC phenomena, regardless of the source of the effect. They also suggest that the ecological model is less useful in a laboratory setting than the information processing model, given its real world orientation and the relatively barren arrangements seen in the lab as compared with the real world. Another key factor in this disagreement is the stage at which the effect is occurring. With Simon effects simply due to spatial correspondence it is sufficient for these to occur at the stimulus identification stage, however, because an affordance SRC effect depends on the combination of specific features of stimulus and response, it has been suggested to occur later, at the response selection stage (Hasbroucq & Guiard, 1991; Tucker & Ellis, 1998). That said, Lu and Proctor (1994) also put the effect at the response selection stage and claimed that it arose from the application of the translation rule, from the relevant to irrelevant stimulus dimension, used for completing the task. This highlights again the problems in trying to use behavioural data to reach deep conclusions about neural processing; all three positions are supported by a considerable number of experiments, but are at odds with each other. A critical issue here is that Proctor and colleagues do not recognise the argument that the centrally presented object stimuli constitute a sufficiently different class of stimuli –as compared with lateralised presentation of non-objects, arrows, abstract symbols or tones– to warrant their own class of explanation. They do not see the action information suggested by the affordance explanation as anything more than a task-irrelevant stimulus feature and so are happy to lump the effects in together.

A number of behavioural studies have successfully disentangled affordance and Simon effects; Symes, Tucker and Ellis (2005) show that it is possible to elicit both effects in the same paradigms by varying the attentional demand placed on participants. By varying the location of lateralised affording objects around fixation, they found it was possible to produce a Simon effect of stimulus location that was dissociable from an affordance effect of handle orientation. They argued that that for an affordance effect to occur, the objects must be represented at the level of objects. This is similar to the findings from Tipper, Paul and Hayes (2006) and Pellicano, Iani, Borghi, Rubichi and Nicoletti (2010) (described in greater detail below) who also disentangled Simon and affordance effects using behavioural methods; they showed participants affording stimuli that were depicted in different colours. They found that when asked to respond to the colour of an object, they obtained a Simon effect, but when asked to respond to the category of the object, they obtained an affordance effect. Similar to Symes, Tucker and Ellis (2005) they argued that this is a matter of how attention is directed to the object, and what object features are attended. However, despite these (and other) experiments Proctor and colleagues (e.g. Proctor & Miles, 2014) have continued to argue that affordances do not represent a special case for SRC.

Michaels and Stins (1997) provide an excellent discussion on this; they suggest that RT data is so crude and stimulus properties so arbitrary that the interpretation of the majority of SRC experiments depends as much on the constructs that the authors begin with as the results they find, perhaps explaining the persistence of this disagreement despite the evidence. When similar RT and error data are obtained using the same paradigm but different stimuli, it is intuitive to seek to unite these notions. However, as described in Ellis (2009), a great many SRC experiments use abstract stimuli that have little or no relationship with the response, and these responses often fail to mimic an action. Proctor's information processing approach makes this into a minor concern by simply focussing on the RT effect of the relevant/ irrelevant stimulus properties, regardless of stimulus class and ignoring nuances of stimulus presentation and/ or response set. However, coming from an affordance background the different stimulus and response classes become a huge concern because the affordance account stands and falls on its assumption of the overlap of action relevant information and available action possibilities. The nature of the affordance account means that experiments around it must use stimuli that contain action possibilities and that effects found with stimuli that lack these action properties must be measuring a different construct. As Ellis (2009) suggests, new questions must be asked and new paradigms devised in order to end this disagreement. This is a key motivator for the present thesis; one possible means to build on the behavioural literature that has attempted to disentangle these possibilities (e.g. Symes et al., 2005; Tipper et al., 2006; Pellicano et al., 2010) would be to directly measure the visuomotor activity elicited in the presence of each effect using cognitive neuroscience methods (such as event-related potentials, ERPs). Due to their high temporal resolution, ERPs are particularly well suited to address the question of the stage at which affordance effects are exerted. Also, the Lateralised Readiness Potential (LRP) offers an ideal tool to directly investigate motor activity afforded by object stimuli, an issue discussed above. Understanding the motor processing entailed in each effect using LRPs might differentiate more clearly the information processing and affordance accounts.

*2.4 Conclusion*

This chapter has seen a wide variety of evidence for and explanations of affordance SRC effects. Those studies used behavioural methods that have consistently implicated visuomotor processing, suggesting that this approach could benefit from directly measuring visuomotor activity. The following chapter will consider evidence from cognitive neuroscience on affordance SRC and consider whether these methods may better elucidate the disagreements laid out so far.

## *3. Chapter three*

## *Cognitive neuroscience and affordance*

### *3.1 Affordance, SRC and cognitive neuroscience*

The first two chapters introduced the idea of affordance and gave some evidence to support the notion that affordance effects develop based on overlap in SR pairs due to a reciprocal visual and motor processing best described as visuomotor. However, it also saw considerable dispute between different points of view on affordance when compared with Simon effects or effects of salience and where affordance effects fit in with SRC effects in a wider sense. Those chapters suggested that one way to attempt to clarify this is by that employing deeper metrics may help to choose between these differing views. In order to do this, the present chapter will consider the evidence from cognitive neuroscience on the question of the linkage, timecourse and automaticity of object perception and action processes, particularly the affordance SRC effect. First for consideration are two replications of studies discussed in the previous chapter in Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) followed by some further evidence demonstrating the role of the motor cortex in perception. Following this is a discussion of the temporal factors, beginning with evidence from single cell recordings and moving on to more recent ERP, LRP and Transcranial Magnetic Stimulation (TMS) investigations. Finally, some reasoning for some of the temporal differences shall be presented.

### *3.2 Spatial evidence*

This section will focus on evidence for the spatial arrangement of brain activity underlying visuomotor processes seen in SRC and affordance experiments to see if evidence from the spatial domain may help to resolve some of the issues from chapter two, such as how to assess the motor effects of looking at objects and the equivalence of behavioural results for affordance and Simon effects. This evidence will be drawn from methods such as fMRI and PET. As mentioned above, some of the results that are central to this work have been replicated and extended by using neuroimaging methods, such as Grezes and Decety (2002) who used PET in an experiment similar to Tucker and Ellis's (1998) first experiment. Again, they had participants make a left or right button press in order to declare whether a stimulus was in its normal orientation or was inverted. The stimuli also had graspable parts that were oriented left or right, creating the axes for a lateralised affordance SRC effect. There was also a motor imagery task, consisting of an object presented every three seconds to which participants were instructed to imagine grasping and using each object before making a left or right handed keypress dependent on the orientation of the object. A silent object naming task was employed, with participants instructed to silently name an object presented every three seconds before making a keypress dependent on the objects orientation. A silent verb generation task was employed, in which participants silently named the verb associated with each tool before making a keypress response. To form a baseline, non-objects were presented in a separate condition. The core result that was observed here was that there was a common network serving each of these tasks; the inferior parietal lobule (IPL), premotor cortex (PMC), inferior frontal gyrus (IFG) and the supplementary motor area (SMA) with an additional activation in MT/V5. Interestingly, whilst there were bilateral activations associated with all conditions, the areas primarily associated with the perception of tools were right hemisphere dominated and included inferior and middle frontal gyri (rIFG/ rMFG), middle temporal gyrus (rMTG), right putamen and right cingulate gyrus. The authors suggest that their results are consistent with the ventral/ dorsal distinction as described by Goodale and Milner (1992) with projections from primary visual cortex following the prescribed route. They also suggest that eliciting activation in motion-sensitive visual area MT/V5 is characteristic of the dorsal processing stream in the presence of action-relevant stimuli. They went on to suggest that stimulus motion is a sufficient but not a necessary condition for activating the dorsal stream but that the presence of a cue to action in the stimuli is a necessary condition for eliciting this kind of dorsal stream activation. The authors conclude that affordances are a precondition for dorsal activity, and that this study provides neurophysiological evidence to support the notion of object affordance and its automaticity, based in similar reasoning as Tucker and Ellis (1998) regarding the lack of relevance the object affordance has to the task. On the point of the visuomotor nature of perception from previous chapters, the action of visual motion area MT/ V5 in concert with activation in motor cortices in resolving this object affordance task speaks the visuomotor account of object perception. MT/ V5 is suggested by Grezes and Decety (2002) to be the first area of the dorsal processing stream, which is implicated in the detection of movements and movement-related stimuli and object affordances are intrinsically linked with guiding movement to or with an object. This, in conjunction with activation in action planning areas PMC/ SMA implies evidence for visuomotor interpretations. However, due to the poor temporal resolution available in PET it is impossible to know whether these areas were activated concurrently or not, which would need to be true for the assertion would be properly supported. This shows a limit of using spatially-orientated techniques to answer questions about the nature of processing.

Another core experiment discussed in chapters one and two was replicated and extended by Grezes, Tucker, Armony, Ellis and Passingham (2003), who replicated the grip-type affordance SRC experiment presented in Ellis and Tucker (2000) using fMRI. As described above, this was a grip-type affordance SRC paradigm, in which participants mimicked a power and precision grip by holding two manipulanda. One had them make a precision grip with their thumb and index finger and the other had them make a palmar grip. Half used the precision in the right hand and power in the left and the other half used the opposite combination, representing a small deviation from the original design. They found a significant behavioural interaction between object grip and response grip, signifying a compatibility effect as in Ellis and Tucker (2000). This behavioural effect was accompanied by left hemisphere dominated compatibility effects that correlated with the behavioural compatibility effect in left dorsal premotor cortex, left anterior parietal cortex, left superior parietal lobe, left inferior frontal sulcus and left temporal sulcus. The left premotor cortex activation in particular supports the notion of automatic motor activation by seen affordances. This brings us back to the question from the first chapter of whether we can reasonably expect the same processes to occur under two quite different affordance SRC paradigms because this experiment does not show activation in the same locations as Grezes and Decety (2002). Some are shared, such as the premotor cortex activation however there are some considerable differences. Most obviously, the processing in this grip-type study appears to be confined to a left hemisphere network and no activation was detected in the temporal cortex, fitting broadly with Cisek's (2007) proposed network detailed in the previous chapter. In Grezes and Decety, there were bilateral activations in some areas as well as a series of right hemisphere dominant effects associated specifically with tool perception, located in rMTG, rIFG, rMFG, right cingulate gyrus and right putamen. Furthermore, no activation was detected in IPL which is quite irregular, considering that some researchers have suggested that this area may be the seat of affordance processing (*cf.* Arbib, 1997; discussed below). No cingulate gyrus activity was reported here either, which is surprising both due to it being enlisted in the previous study and given the multifunction nature of cingulate cortex, featuring in both motor function as well having been implicated in a link between task performance and motivation (*cf.* Torta & Cauda, 2011). This cannot however be taken as a final indication. fMRI analysis techniques are notorious for the wide degrees of freedom and dependence on analysis parameters affecting the significance of activation and Grezes and Decety (2002) used PET instead of fMRI and so used very different thresholds and techniques, leaving weak grounds for a direct comparison. However it does provide some tentative evidence towards the proposition that processing underlying different affordance effects may indeed differ at a neuroanatomical level. Although merely speculation, the lack of IPL activation may reflect the maintenance of the grips during this experiment as part of the possible scaffolding of affordance processing discussed above, however that possibility has not been directly tested and remains conjecture.

These two studies from Grezes and colleagues –two revisions of well-known experiments in the area– show a possible difference between grip-type and lateralised affordance that is completely unavailable when using behavioural methods alone. This supports the rationale for the use of techniques from cognitive neuroscience by showing the depth of information they offer and returns us to the question of what new knowledge may be gained by the application of these techniques to the relatively old and familiar SRC paradigm. In order to elucidate this possible difference between types of affordance, further PET and fMRI results will be considered. There is also some theoretical support for a difference too, with evidence on the prospect of a difference at a neurophysiological level from a proposed network for grasping, suggested initially by Arbib (1997). This study was extensive and used comparative studies with rats and monkeys to generate conclusions about the network and emphasised the interaction of anterior parietal cortex with premotor cortex and prefrontal cortex, as well as interactions between hippocampus and parietal cortex in rat navigation. The assertion most pertinent to this thesis was that affordances appeared to be resolved in monkeys in a parietal-premotor portion of the proposed network. We have already seen in Grezes and Decety (2002) that images of affording objects preferentially activated IPL and precentral gyrus but not postcentral gyrus. Further support for this notion may be drawn from Rizzolatti, Fadiga, Matelli, Bettinardi, Paulesu, Perani and Fazio (1996) who used PET to isolate brain regions associated with grasping that matched well with those proposed by Arbib (1997) and with the findings of Grezes et al. (2003). They used three conditions, one in which participants watched the experimenter making grasping movements on common objects, one in which participants grasped the same objects and a final condition that consisted of merely viewing the objects, used as a comparison. For the grasping condition, they found activation in precentral and postcentral gyrus, left inferior parietal cortex and cingulate gyrus. The use of real objects in obtaining these effects makes for compelling evidence for two reasons; firstly because the stimuli are appropriate for what they sought to test (avoiding problems from Anderson, Yamagishi and Karavia, 2002, cited in chapter two). Secondly, it is compelling due to the good fit with the work from Grezes and colleagues, Arbib (1997) and Cisek (2007). This is interesting because if there really is a specialised network for grasping in the way this suggests, then grip-type affordances should presumably entail the use of this network. However a lateralised affordance effect does not share the same grasping characteristics as a grip-type study, again supporting the possibility of a difference in processing, or minimally in the supporting brain regions. Combine this with the large overlap between the left hemisphere dominated results of Grezes et al. (2003) and those seen in Rizzolatti et al. (1996) as compared with right hemisphere dominated results from Grezes and Decety (2002) and the evidence begins to mount for a difference in processing different classes (e.g. grip-type vs. lateralised) of affording stimuli.

The results of Castiello, Bennett, Egan, Tochon-Danguy, Kritikos and Dunai (2000) provide further support to this novel juxtaposition of grip and lateralised affordance processing by evidence from neuroscience methods. Castiello et al. (2000) used PET with four conditions, mouth grasping movements, finger grasping movements, imagined mouth grasping and passive viewing, for subtraction analysis. During this, the experimenter moved a piece of food (a small sweet) on a fork towards the participant's hand or mouth. Participants were instructed to open or close the mouth or hand as if they were to grasp the morsel. Due to use of finger grasping as a response, these data clearly speak more to the grip-type study of Ellis and Tucker (2000) or Grezes et al, (2003) than lateralised studies like Tucker and Ellis (1998) or Grezes and Decety (2002). The core reason for this is that in order to respond here, the participants execute a prepared grip just as in the other grip-type citations given above. There is also greater consistency in the relationship between stimulus and response amongst these grip-type studies, where they use whole-object level features to determine compatibility instead of relying on the affordance of *components* of objects (i.e. handles) as is the case with lateralised affordance experiments. As described above, a left-hemisphere dominant network emerges that enlists both pre and post central gyri and again enlists cingulate gyrus, something not observed in the lateralised studies. Castiello et al. (2000) also found activation related to hand grasps were left-hemisphere dominated. For the mouth grasp condition, bilateral pre and post central gyri activations were observed, however for hand movements these were dominated by left hemisphere activity. IPL activity was observed here too, as predicted by Arbib (1997) and by the results of Rizzolatti et al. (1996), which also mesh beautifully with these data. Left cingulate gyrus activity was observed here too, the opposite pattern to that from Grezes and Decety (2002) who used lateralised affordances instead of Castiello et al.'s grip-type stimuli, further reinforcing a difference between processing different classes of affordance. Taken on its own, it would be easy to explain away the left hemisphere dominance as simply being an artefact of the right handed responses, however the left hemisphere dominated network has been described above for grasping movements. Castiello et al. (2000) focussed on the role of IPL in affordance generation here, however the overall lateralisation is also pertinent to the present discussion. This selection of studies indicates that grip-type and grasping studies are particularly left hemisphere dominated and that lateralised studies appear to be right hemisphere dominated. There are some ambiguities however, such as why the cingulate gyrus is not enlisted in Grezes et al. (2003), but are in

Rizzolatti's and Castiello's work, although there are clear task differences, such as the constant maintenance of the grasp in Grezes' studies.

Expanding the notion of automaticity visited in the previous chapters, an interesting dual method experiment from Handy, Grafton, Shroff, Ketay and Gazzaniga (2003) used ERPs and fMRI to show that when viewing graspable objects, spatial attention is automatically courted by the graspable features and that this effect is strongest in the lower visual field and the right visual field. Handy et al. characterised the lower and the right visual field as being dominant in visuomotor processing and their experiments provided evidence of this. They did so by presenting a task-irrelevant tool object and a non-object (e.g. animals) in the upper visual field to the left or right of fixation before one would be replaced by a target. They used the P1 component to assess their results, as it is known to be associated with orientating spatial attention to non-foveated areas. A second experiment did the same but orientated the images above and below fixation. These two experiments show that visual field asymmetries are integrated with visuomotor processes, with right handed participants showing a stronger effect for right visual field and lower visual field presentations and a greater P1 activation for tools presented in the right visual field. This shows that early stages of visual perception appear to have some relationship with action-properties, a key consideration in using P1 and N1 in the experimental chapters. A third experiment used fMRI and found that the attention grabbing effect was only obtained when the target was a tool pictured in the right visual field and that this was accompanied by dorsal premotor and prefrontal activations, areas that Handy et al. assert are critical to action planning. Handy et al. characterised the right visual field (of their right-handed participants) as being specialised for visuomotor processing and suggest that this is why the fMRI effects were only found with tool targets presented in the right visual field. This innovative approach shows that not only should authors consider the asymmetry within the brain, but they should also be mindful of asymmetries that exist long before visual information is processed.  One of the most interesting results however, and one that is troublesome to the discussion of the role of intention (see above and below) in the affordance effect is that this effect occurred on trials when participants responded, as well as when they did not respond, supporting the case for automaticity over intention. This interaction between the fundamental rules of visual fields in the earliest stages of visual input and the output of the motor response or a neural response provides a another angle that supports the visuomotor nature of perception and the notions that vision is for action and also that vision is mediated by action.

To round out this section, the last study for consideration shall be a review from Lewis (2006) that was comprised of a meta-analysis of 64 studies of tool use skills and knowledge.  Overwhelmingly, the results pointed to shared circuitry for viewing, interacting with or pantomiming interaction with objects, fitting well with an embodied approach to cognition as described in previous chapters.  There was a particular emphasis on the IPL and the dPMC for these purposes, with premotor cortex particularly entailed in accessing, preparing and maintaining the intention to perform an act and how to translate the preparation into a sequence of motor commands, with IPL associated with the preparation of these motor commands in the effectors, including selecting the correct effector.  Ventral premotor cortex (vPMC) was more concerned with the execution of actions in what we shall see over the following sections are later stages of visuomotor processing.  Another key result found here was that in effectively all reviewed aspects, both hemispheres were enlisted for different purposes but that the left hemisphere was always dominant in this, something else that we shall see fleshed out in the electrophysiological data presented below.

From examining the studies presented in this section it appears that the application of neuroimaging techniques is highly elucidative for the area of object and affordance processing. The spatial evidence on SRC and object use appears fairly consistent, with left hemisphere dominance exhibited for most action preparations and stimulus classes, whilst maintaining the classical contralateral control of effectors and still allowing the right hemisphere a considerable role to play, as shown by Grezes and Decety (2002). That said Grezes and Decety and Grezes et al. (2003) also show up a considerable inconsistency in the hemispheric asymmetry associated with lateralised as opposed to grip-type affordance SRC paradigms. Although there is no apriori significance to particular patterns of hemispheric asymmetry (Hellige, 1993) this is of potentially great theoretical significance, particularly to affordance orientated models such as Cisek (2007) because this represents one of the first indications of a fundamental processing difference between different classes of affordance that appear to behave identically when examining the behavioural data. Overall however, the evidence agrees that on the questions of response preparation that the SRC paradigm is geared to, the dorsal premotor cortex is the main candidate for further investigation. Evidence from Handy et al. (2003) also illustrates the importance of considering the role of visual fields, particularly with lateralised tool stimuli. Perhaps most importantly, Handy et al. (2003) also showed that early visual ERP component P1 may also be elucidative of the visuomotor nature of these response preparations, providing a motivator towards the use of ERPs over spatial methods in the present thesis. This is again of great theoretical significance, with early visual components generally thought of as not being influenced by task parameters (discussed in more depth below). One problem with the use of spatial techniques is that whilst we might see what areas are entailed in particular tasks, the lack of temporal resolution means that it can be difficult to assert what stages of processing the different areas are activated, and so what their functions are. For this reason, this chapter will now proceed to examine what new information on object affordance may be found by the use of techniques with great temporal resolution but poor spatial resolution.

### *3.3 Temporal evidence*

Whilst the evidence from imaging techniques such as PET and fMRI are informative in the spatial domain, as discussed above their lack of temporal resolution means that it is difficult –if not impossible– to accurately infer function by correlating blood flow with behaviour. Instead, techniques with high temporal resolution allow us to expand on localisation studies by understanding the order in which areas become activated, when and for how long they are activated, whether they are activated serially or in parallel and these things allow researchers to make much deeper inferences about the processing at work and do not simply rely on correlation. This section is particularly pertinent as the studies in the experimental chapters all made use of electrophysiological measures in order to improve upon the specificity of behavioural measures and the temporal limitations of fMRI and PET, as discussed above. First, some comparative studies will be considered, followed by some evidence from human electrophysiology, with a view to establishing the timing of the effect of objects and object affordances in motor cortex.

#### *3.3.1 Single cell recordings*

Some of the earlier evidence on the timecourse of object processing and action preparations may be drawn from single cell recordings, in which the firing of single neurons or small populations of neurons are monitored intracranially by microelectrodes. These studies provide evidence of very early motor activation arising from compatibility effects. However, due to their invasive nature, they are also almost exclusively comparative studies, conducted on primates instead of human participants. Due to the use of primates, the paradigms are more like spatial SRC than affordance SRC simply because primates do not share the same relationships with objects that humans do. That said, such studies still show converging evidence on temporal aspects of action initiation and motor activation during SRC.

A frequently cited study from Georgopoulos, Kalaska, Caminiti and Massey (1982) provides a good starting point. They recorded 606 cells in motor cortex related to proximal arm movements, focussing on 323 cells that were most activated by the task. Four rhesus monkeys were trained to move a manipulandum from a central position to one of eight target positions marked by LEDs, meaning that this was not a typical SRC paradigm as there were no incompatible trials, however the task closely resembles the format for compatible trials. As well as single unit recordings, electromyograms (EMG) and electrooculargrams (EOG) were recorded. EOG revealed that monkeys made saccades to foveate the target around 150ms after stimulus onset. Taken with a mean RT of 265ms, this illustrates how rapidly (at approximately 100ms) the visual information was translated into a motor programme that was executed. EMG revealed that muscle activity was detectable 80ms before movement onset, leaving around 20ms between foveating the target and the earliest detectable muscular response. This could not have been due to a predictable trial structure due to a 2 second jitter, again indicating that these visual to motor translations can occur extremely rapidly. However, as suggested in Requin and Riehle (1995, reviewed below) with their own data, the implications of these studies depend greatly on the constructs one postulates to explain the data, meaning that it is very difficult to infer the nature of the processing (particularly cognitivist discrete stage versus continuous transmission accounts) based solely on these impressive rapidity of the effects. The frequency domain analysis revealed orderly variation of cell direction with movement direction, however Georgopoulos et al. did not identify discrete populations of cells specific to a particular response direction. Instead, they found that different directions were signalled by *combined* activation of neurons that were tuned to the characteristics of the required movement. Put another way, different cell populations were found to activate in concert to produce responses in different directions and no cell populations were identified that related solely to a single direction. This study shows the depth of information available when working outside of the behavioural RT domain by observing not only the rapidity with which visual information interacts with motor processes but also hinting at the interaction of the visual system, the motor cortex and the musculoskeletal system through the use of single unit recordings, EOG and EMG data. Although not interpreted this way, the temporal proximity of the effects in the different metrics employed here hint strongly at an integrated visuomotor system, rather than discrete visual and motor systems.

This proposition is supported by Rizzolatti and Gentilucci (1988) who found that the same canonical neurons in the vPMC fire during both the presentation of an object and during the execution of actions associated with that object, in agreement with the meta-analysis by Lewis (2006). This supports the embodied notion of scaffolding discussed in previous chapters because it shows physiological evidence for the interrelation of perceptual processes and action processes in neuronal populations that are not specific to either process, but rather support both. This speaks to the notion of scaffolding because action areas are supporting perception and moreover, this favour is returned during action execution. This also suggests that the traditional cognitivist distinction between action and perception or input and output may be flawed, because the evidence shows little to distinguish between the two at a neurological level, with similar populations recruited for both, shown in electrophysiology and spatially by Lewis (2006). Rizzolatti and Gentilucci (1988) suggest that the activation of these canonical neurons under both conditions indicates a basis for the automaticity of SR translations. However this is questionable because presumably each action must also be served by other neurons in a similar way that Georgopoulos et al. (1982) did not find neuronal populations specific to particular directions but instead found that combinations of different populations signalled particular directions in a way that is more diffuse than simple 1:1 relationships between neurons and behaviours. If this is the case, then this does not provide sufficient evidence for a claim of automaticity, because it does not consider what other neurons are required to complete the behaviour. The authors conclude that the vPMC neurons they measured provided a kind of vocabulary of grip-types in PMC based on the principles described above and suggested that this would be monitored by anterior parietal neurons, fitting well with the spatial evidence given above. Given the necessity of visual area activation to these results with viewed objects, these principles of distributed processing again support the visuomotor account of perception.

Further to Georgopoulos et al. (1982), a compelling body of evidence for early motor cortex effects caused by visual and auditory compatibility may be drawn from the work of Requin, Riehle and colleagues. Requin and Riehle (1995) collected intracranial data from motor cortex with two monkeys over two experiments. The first was a mixed go, no-go and two-choice paradigm in which one monkey was trained to align a pointer with visual targets (LEDs) by using unimanual flexion/ extension wrist movements. It was found that motor neurons responded to the signal very early, between 113ms and 173ms. Overall, similar effects were observed in the go and no-go trails, with the effect most pronounced when time-locked to the movement onset. The authors interpreted this experiment as showing that the motor component of sensorimotor neurons is activated by directional information, with this activation peaking at around 150ms. This was strongest in the go trails but was still clearly detectable in the no-go trials. The timing of these effects coincide well with the data from Georgopoulos et al. (1982) who found effects commencing before 200ms in a slightly different paradigm.

In their second experiment, Requin and Riehle (1995) examined the temporal overlap of perceptual and motor processes in a fairly typical SRC paradigm. This is an interesting question for any visuomotor account because these accounts claim that the work of perception and action is shared so temporal factors should be able to elucidate the way in which the work is shared by showing when different systems make their contributions. To assess this, they used a variation on their first task, this time with compatible and incompatible trials that were determined by the colour of the visual target. They found a behavioural SRC effect (shorter RT and shorter movement time for compatible trials than incompatible trials) and a neural correlate of this SRC effect in 114 neurons in primary motor cortex. More interestingly, they found that the earliest motor cortex activity associated with the stimulus was the same for compatible and incompatible stimuli. That is to say the initial phase of activity was facilitatory for both compatible and incompatible trials, however this was brief and incompatible trials yielded opposite activity to compatible trials soon after. The authors suggested that the visually triggered motor cortex neurons appear to be targets for response relevant information and so their activation provides direct evidence for the automatic activation of compatible responses. They went on to say the these neurons appear to play quite a different role to those in primary sensory areas, despite their activation by visual stimuli and that one could argue either way for their status as sensory or motor neurons. This conclusion gets to the core of the embodied viewpoint, functionality can be almost impossible to put into discrete categories and so it becomes more important to consider synergy. This study provides excellent evidence that visual information selectively activates motor cortex. It also shows that the selective components of this activation are preceded by non-selective activation that appears to spring automatically from the perception of the stimulus.

Zhang, Riehle, Requin and Kornblum (1997) conducted another SRC study using Rhesus monkeys who were trained to align a pointer with coloured LEDs that required an extension or a flexion of the wrist, similar to Requin and Riehle (1995) and used the same LED arrangements. Both RT and MT were measured, as was activity in 154 neurons in motor cortex. It was found that initial motor activation correlated with the side of the LED, with differential activity between the trial types peaking early at 160ms. Differences between neuronal responses to the mapping rule were observed to peak at around 260ms, around the same time as the compatibility effect. Average RTs were 336ms (SD 33ms), indicating that each trial was resolved extremely quickly and reinforcing the notion that the speed of responses indicate a rapid link from vision to action. This study provides a result that is inaccessible to behavioural studies too; it was found that after the response had begun, the differences associated with the compatibility effect persisted. One limitation of these data is that as well as being interpreted as the result of SR compatibility, the compatibility effect observed at 260ms could also be interpreted as SS congruence between LED colour and location, because the LED colour indicated the response location. This cannot be resolved because the authors only analysed the correct trials. However they suggest that whether SR compatibility or SS congruence the neurons still belong to a generic class of SR association neurons that translate the visual stimulus into a behavioural response and so are still doing the kind of visuomotor transforms that are pertinent to this thesis. Overall, this study provides evidence that SR translation processes have a dynamic timecourse in motor cortex in which stages are not discrete but motor activity changes based on the simple visual input being parsed and then filtered through the mapping rule, implying continuous processing as well as a role for the task in the transformations. That said, the average overall RT is shorter than in many of the human studies cited in the previous chapter so the timecourse may not be perfectly reflected in humans, however the demonstration of the principle of rapid and selective motor activation by visual stimuli remains clear.

Two further SRC experiments conducted by Riehle, Kornblum and Requin (1997) found a systematic motor cortex effect based on the mapping rule and supported the conclusions from Zhang et al. (1997). Two Rhesus monkeys were presented with stimuli on the left and right that were compatible or incompatible with left or right movements, with movements signalled by high or low pitched tones that were presented to the left or right ear using similar apparatus to Requin and Riehle (1995). The procedure for their first experiment was as that of Zhang et al. (1997) but using two Rhesus monkeys. In their second experiment equipment and procedure were almost identical except that the laterality of the stimulus presentation was irrelevant to the mapping rule, with three white LEDs used to show the locations with which to align the pointer and the laterality of the response was signalled by a high or low tone. Using a tone closely resembles the manipulations seen in Simon and Ruddell (1967) and Tucker and Ellis (1998). 154 neurons in primary motor cortex were monitored in monkey one and 123 in monkey two. Behaviourally they found the typical SRC effect, with shorter RTs on compatible trials than incompatible. Their intracranial recordings identified several populations of neurons that were associated with different aspects of the task, with a population for the side on which the stimulus was presented, a population that varied with the response rule and one that varied with the response side. These populations also showed considerable overlap, supporting the idea that the visuomotor transformations entailed in this kind of paradigm are continuous rather than discrete. Examining the figures in this experiment, these effects were observed to occur very rapidly with effects observed in cell populations related to response peaking as early as 100ms and not later than 200ms, with incompatible trials persisting until up to 400ms, around 150ms longer than in compatible trials. They also found a good deal of overlap between these factors, showing that the transformation of visual information to motor information is not a discrete process but rather a continuous one, representing a problem for the information-processing models in chapter two. Revealed by these continuous changes is an interesting result; the data suggest that the increased reaction times observed in incompatible trials may be due to an automatic activation of compatible responses that need to be overridden in order to supply the correct (incompatible) response as indicated by the longer activations observed for incompatible trials as well as the large overlap of different populations of neurons in the observed effects, as in Zhang et al. (1997).

These data are supported by Riehle and Requin (1995), where two monkeys were trained to rotate a handle using wrist flexion/ extension movements in order to signal a response in a movement precueing RT task whilst intracranial data were recorded from 411 neurons in primary motor cortex, premotor cortex, somatosensory cortex and parietal cortex. Movement direction and required force were precued by different coloured LEDs, in a similar arrangement to the other studies cited here. They found different populations of neurons associated with stimulus onset, response and compatibility, similar to those studies cited above. The populations behaved differently during different stages of the preparation (when processing the precues) and execution (MT and RT) of the response. Some of these differences clustered around the precuing of direction and force, with primary motor cortex found to respond most strongly to both. Different regions were seen to be differentially influenced by the stage of processing, interacting with how much (if any) information was cued on movement direction and force, again indicating a continuous flow of visual to motor translations, this time under cueing conditions, with the LED display interacting with the response rules to yield primary motor cortex activation associated not only with the execution but also the preparation of responses. Upon the presentation of a cue, activation rapidly increased with a component lasting around 100ms reflecting the nature of the cue, again showing the rapidity with which the visual input *selectively* activates motor cortex and with which the input is resolved into motor preparations and outputs.

Further evidence for the timing and duration of these effects may be drawn from a wide pool of research, such as Weinrich, Wise and Mauritz (1984) who found an effect at 138ms or Johnson, Ferraina, Bianchi, Caminiti (1996) who found an effect of an instructive stimulus in motor cortex at 166ms. However, these single unit studies have been included not only because the method gives a very direct sense of what is happening in motor cortex during compatibility effects, when it is happening and how long it is happening for but also because they show that the kind of processing that is implicated from human SRC appears to hold in primates too. This is interesting because one of the principles espoused by the proponents of embodiment is that comparative studies can evince the nature of the heuristic processes that allow real time interaction (*cf.* Clark, 1998), with the emphasis on heuristics. However, the use of primates introduces a problem too; primates do not share the same relationships with objects as humans and as such many of the studies cited here used spatial SRC rather than affordance SRC paradigms. This means that whilst the comparison may be valid at a neural level, it is not necessarily the same at a behavioural level. This is of little concern to the present thesis however, as these hallmark studies in the early SRC literature provide an excellent foundation in the physiology of visuomotor transformations as well as showing the utility of temporally-acute methods for understanding SRC processes.

As discussed above, rapid and reliable but fairly brief changes occurred between 100ms and 200ms upon presentation of a stimulus (or precue) just as hypothesised from the behavioural evidence presented in chapter two, with some effects commencing even before 100ms. Other studies showed premotor cortex concurrently activated with visual areas in this time period, again indicating the visuomotor nature of perception, in the vein of Georgopoulos et al.'s (1982) demonstration that directional effects were produced by combinations of neuronal populations acting in concert. A remarkable finding is that there appears to be an automatic component where the ipsilateral response is briefly activated before the rule-based responses are processed. This shows the additional power in physiological investigations and provides part of the rationale for the use of electrophysiological measures in the experimental chapters. To complete this review and rationale and to further elucidate the temporal dynamics of compatibility effects, human electrophysiological evidence in SRC will be considered.

*3.3.2 Electrophysiological evidence*

The previous section has demonstrated the usefulness of high temporal resolution in understanding the processing underlying the SRC phenomenon, however it was limited by the use of non-human participants. So, this section will now consider temporal evidence from human participants gained by the use of the Event-Related Potential (ERP) technique. Compared with single-unit recordings, ERPs have the advantage of being able to monitor activity at several sites across the scalp and so can monitor more regions in a single session and is completely non-invasive, however this comes at a cost to spatial acuity.

When dealing with lateralised motor preparations, another ERP-based technique can be employed that focuses on just two sensors, one in each hemisphere positioned over precentral gyrus, typically C3 and C4 in the 10/20 system. Due to the contralateral control of the effectors, potentials from one hemisphere can be subtracted from the other, removing any noise associated with the testing environment or resting state activity from the signal and leaving only activity related to motor preparation; the Lateralised Readiness Potential (LRP). Using this technique, movement preparations are characterised by negative-going waves and potentials are larger when contralateral to the employed effector (*c.f.* Vaughn, Costa & Ritter, 1968; Kutas & Donchin, 1980). LRP measures selective response preparation and removes noise by using a subtraction procedure; ipsilateral motor activity is subtracted from the contralateral motor activity for one response hand and the same calculation is then performed for the opposite hand. Or in the Coles (1989) derivation, the contralateral activity is subtracted for the ipsilateral activity for the opposite hand, producing a positive-going wave. Then, the output for one response hand is subtracted from the other, with the process yielding much smaller values than the initial input. These smaller values reflect only differences in response preparation between hands and theoretically should have very little noise. This procedure is given in the following equation (from Osman, Bashore, Coles, Donchin and Meyer, 1992):

Left hand (C3 – C4) – right hand (C3 – C4)

LRPs are widely accepted as selectively monitoring motor activity and make an ideal method for cognitive neuroscience orientated investigations of SRC and visuomotor processing. This section will consider the ERP and LRP results from SRC-type paradigms, considering particularly the timing of response preparation effects in motor cortex, as well as issues related to the automaticity and selectivity of these effects.

Some relatively early evidence for the rapidity of spatial affordance effects may be drawn from Osman, Bashore, Coles, Donchin and Meyer (1992), who used LRPs in a mixed paradigm consisting of choice RT combined with a go/ no-go paradigm. They also recorded RT and EMG. In the first experiment, participants held a joystick in each hand and were briefly presented (50ms) with a command signal that appeared to the left or right of fixation, not dissimilar to Michaels' (1988) as discussed above. If the signal was a letter, participants moved a joystick towards the letter (a go trial), which joystick was determined by the side that the signal appeared on (choice RT). If the signal was a digit, they did not move their joystick (a no-go trial). It is important to note that both the choice RT and go/ no-go component were dependent on different characteristics of the presentation. The LRPs revealed that initial activation was not statistically different for the go and no-go trials, with large components elicited from 100-200ms after stimulus onset for both trial types. After this period, the LRPs for the two trial types began to diverge, with go trials eliciting larger amplitudes (~9µV) and no go trials eliciting some negative amplitudes (~-2µV). On go trials, EMG revealed large potentials commencing 200-300ms after the presentation of the command signal, indicating that the fundamentals of the response had already been computed.  Importantly, no EMG activity was observed on correct no-go trials meaning that the LRP results could not be due to small undetected movements.  These two results have an interesting implication; the lack of EMG on no-go trials indicates that participants did complete the go/ no-go discrimination before response preparation. However, if response preparation occurred after this in a serial fashion then one might not predict the detected LRP effects because the authors hypothesised that the brief presentation (50ms) of the stimulus would only convey partial information that they suggested would decay very rapidly.  They argue that this strongly indicates parallel processing, with serial limits evinced by the lack of an EMG effect.  The depth and specificity of these claims illustrate the power of neuroscience methods in addressing questions of response preparation, particularly methods with great temporal resolution.  In order to rule out an alternative explanation, a second experiment was conducted that was identical but this time dissociated the location of the signal and the identity of the signalled response, employing elements from an SRC paradigm. As in the first experiment, the response hand was determined by the location of the signal however compatibility was determined by condition. Compatible and incompatible trials were determined by a response rule that asked participants to either respond with an ipsilateral (as in experiment one) or contralateral button press with alternating blocks of each.  This tests whether the LRP results observed in experiment one were specific to the response hand or command signal.  The use of SRC-like conditions was also reasoned to affect preparation time, given the RT advantage usually observed for compatible over incompatible trials.  A significant behavioural compatibility effect was obtained.  As in experiment one, EMG revealed little activity in the no-go trials and was not statistically different from zero.  For go trials, EMG peaks commenced at around 300ms, again indicating the rapidity with which the task information was computed.  LRP data again revealed effects becoming significant from 100-200ms; at 150ms after stimulus onset for compatible no-go trials and 160ms for compatible go trials with a long delay before significance was reached on incompatible trials, with 260ms for incompatible go trials and 270ms for compatible no-go trials. It is important to note that t-tests against a baseline of zero revealed that no-go trials were significantly different to baseline and so did show an effect. When examining the difference waves for go and no-go trials for compatible and incompatible mappings, a startling effect emerges; the waves can be seen to diverge even before 100ms, although they do not reach significance until after 100ms this is still impressively early. The authors concluded that experiment two replicated and extended experiment one, again showing LRP for no-go trials in the absence of EMG activity and again showed a dissociation of different stimulus properties in the onset and divergence of the LRP. Overall, the authors suggested that the latencies observed in this experiment indicate parallel processing of the features of the command signal that indicated whether it was a go or no-go trial and what side to make a response because each component of the command signal appeared to exert a different effect of the waves, but at the same latency; the polarity of the potential appeared to vary with the lateralisation of the command signal, but this did not interact with spatial compatibility. Spatial compatibility instead appeared to interact with the go/no-go signal, with similar latencies emerging for both that were affected by spatial compatibility between command signal and response. That said, it is easy to reconsider these data in an affordance framework wherein stimulus onset yields an affordance (albeit a spatial, rather than an object affordance), explaining the highly similar early activity in go and no-go trials, before the response rule takes over and yields the divergence observed in LRP. This does not trouble Osman et al.'s interpretation on parallel processing, but rather compliments it by giving a basis for the early effects. The timing of the effects here is extremely interesting to the present work, meshing well with the claims from the behavioural affordance SRC literature on the rapidity of the affordance effects. Overall, this study provides LRP timings that broadly coincide with those seen in other studies cited in this thesis even though Osman et al. did not use real object stimuli like other studies discussed here. That said their experimental set-up was similar to Michaels' (1988) abstract catching affordance experiment, meriting the relation to an affordance explanation. Moreover, this study provides an insight into the parallel nature of the early stages of visuomotor processes, with EEG directly demonstrating parallel activation just as suggested in the previous chapters and with the rapidity suggested in previous chapters.

Direct support for Osman et al. (1992) may be drawn from Miller and Hackley (1992). They employed the same mixed forced choice and go/ no go paradigm as Osman et al. (1992) and found highly comparable results. Although slightly later, very early LRP components again support the rapidity of visuomotor transformations for both trial types. A particularly interesting result here was the role of stimulus size and shape; it was found that readily recognisable information on stimulus shape reliably cued motor preparation based on the response rule, speaking directly to the grip-type studies cited above where stimulus size and shape is highly salient. This result also shows the rapidity with which the visual information is not only parsed but also how early the response rule comes to bear on processing the stimulus. However it was also found that once the stimulus size had been parsed, the motor preparation based on stimulus shape could be aborted rapidly. This again supports the possible distinction of grip-type and lateralised affordance SRC because the shape of handles in lateralised experiments and the associated binary choice shows less variation than the continuum of different size and shape information in a grip-type experiment, particularly when accounting for practical concerns such as visual angle, where a larger object may end up subtending a similar angle to a smaller object in order to maintain a balanced stimulus set.

Miller and Hackley (1992) also replicated the finding that no-go trials show no EMG activity despite similarities in the LRPs up to around 200-250ms. As above, the null result in EMG for no-go trials dissociates different stages of response preparation, with the earliest stages of response preparation which were begun by simple stimulus features such as shape and size, confined to motor cortex. When taken with EMG peaks emerging at around 200-350ms after stimulus presentation in Osman et al. (1992) and Miller and Hackley (1992). One curious result (that shall prove pertinent in the experimental chapters) was that once the LRPs diverged at around 250-300ms, they remained that way until the end of the experiment. This replicates not only Osman et al. but is also supported by comparative single-unit recordings from Requin and Riehle (1995). This result was extended here by pointing out that because there were no EMG potentials on no-go trials that motor activation does not necessarily lead to motor output or muscle preparation in the effectors and so the early activation may be aborted according to task demands, providing it is before neuro-muscular activation. Overall, this study lends further support to parallel accounts of visuomotor processing and contradicts fully discrete explanations (e.g. DO model, described in ch.2) by again demonstrating that partial information is sufficient to commence motor preparation but does not support fully continuous models either because when stimuli only varied in size, there was no evidence of preliminary response preparation. This study also further bolsters the evidence for the role of intention in SR translation and in so doing provides further support for questioning or constraining the claims of automaticity put forward in the literature.

More recent support for these points may be taken from Hohlefeld, Nikulin and Curio (2010) who set out to explore the difference between overt and covert movements (e.g. motor imagery) and in the process, found an early effect of visual stimuli in motor cortex using LRP. 18 participants were shown the letters ‘L’ and ‘R’ presented centrally, indicating the hand of response whilst ERPs were recorded. Effectively, this experiment was comprised of compatible trials in an abstract compatibility task in which participants related the identity of the stimulus to a response hand. Participants were instructed to make an overt thumb movement in the overt movement condition, to imagine the same movement in the motor imagery condition and to make the smallest possible thumb movements for a quasi-movement condition, in order to make the movements barely detectable by EMG whilst still having participants make a response of some kind. The key result was a motor component in LRP arising at 120ms but only for overt and not for covert movements, where no effects were found. Similarly, activation on overt movement trials clustered over sensors C3, C4, C5, C6, FFC5h/6h and CCP5h/6h however these areas did not differ significantly from baseline on the covert movement trails. This is interesting on its own because covert movements are generally considered to share the same characteristics as a real movement contraction including sharing the same circuitry, up to the point of the final muscle contraction. This shows another advantage of the temporal sensitivity of electrophysiological measures, because based on the spatial evidence presented in Lewis (2006) one would predict the same populations being enlisted for overt and covert movements. Perhaps instead, the temporal sensitivity here shows that whilst these areas may become active, they are not active at the same time on equivalent trials. In terms of this thesis however, the timing of the component is most interesting. 120ms is extremely early for a visual stimulus to activate motor cortex in what are effectively compatible trials. One might predict, based on Osman et al. (1992) or on the behavioural literature, that incompatible trials may show a later effect, however this is not substantiated here. This study does however provide an interesting caveat, particularly when considering automaticity in SR translation; when viewing the same stimuli a motor effect was only observed for the overt movement condition and not the covert condition and the authors concluded that this provides evidence for the role of intention in the SR translation process because there was no intention to make a response on the covert trials, hence there being no motor activation. Conversely, on the overt trials where there was the intention to act a motor preparation was observed. This questions the notion of automaticity in SR translation because if one has no intention to make an overt response to the stimulus, this early motor component does not obtain. The picture is not completely clear however, with the authors stating that later activations can be shown to be functionally equivalent. The authors offer some suggestions as to why other studies have not obtained effects quite as early, attributing much to the sensitivity of their particular LRP method in dealing with components of variable polarity that would be averaged out in typical LRP/ ERP studies. They also suggest a difference may be drawn from the overt movement being a simple thumb abduction, rather than a button press as in comparable studies, meshing nicely with the arguments presented above around the response having an effect not only on reaction time, but also on the processing serving the RTs. The authors suggest that the early component may reflect hand selection processes, however this is not supported by the no-go trials from Osman et al. (1990), wherein an early effect was obtained even without the necessity of a movement. Both studies shared abstract letter/digit stimuli and although Osman et al. effectively had a Simon paradigm, overall this points towards the response shaping the way stimuli are perceived. This supports the distinction of response types suggested from the behavioural citations above, as well as providing direct evidence for the role of intention in SR translation.

Another approach comes from an investigation of motor activity elicited by masked stimuli that was conducted by Eimer and Schlaghecken (1998). They set out to find whether motor activation would be affected by masked stimuli presented for extremely short durations, such that they were almost imperceptible. Over three experiments they found that masked arrow primes (i.e. >> or <<) that indicated the hand with which to execute a button press (same side in compatible condition and opposite side for incompatible condition) selectively influenced motor cortex, however it was not in the predicted direction. They found a negative compatibility effect, with slower RTs on compatible trials than incompatible trials. Their LRP analysis showed a pattern similar to that described above, where the earliest stages (~200ms after prime onset) appeared to show the partial activation of a compatible response based solely on the visuomotor transformation before being countermanded at around 300ms after prime onset and yielding a negative compatibility in LRP, supporting the behavioural negative compatibility effect. This is interesting as it shows the same overall effect as Osman et al. and the supporting citations given above; the earliest stages of response activation seem to be based solely on the visual input, but this seemingly automatic early effect swiftly changed, exhibiting the opposite pattern of results. An extremely interesting feature of this investigation is the inclusion of neutral trials, something that many SRC studies do not include. These neutral trials allowed Eimer and Schlaghecken (1998) to conclude that not only was there a reversal of the effect, but also that this reversal was due to the inhibition of compatible responses. They were able to conclude this because the compatible trails showed a performance cost relative to neutral trials and incompatible trials showed a performance gain compared to neutral trials. The LRP effects observed in this experiment were a little later than those cited above, however this is likely due to the use of a masking procedure and the described reversal of the effects. This experiment supports the idea that the task and stimulus presentation can constrain and modify the apparently automatic activation of compatible responses. This is a possible candidate for the mechanism by which human agents are able to make goal-directed actions on affording objects, without the interference of conflicting affordances from non-goal objects. If task parameters and stimulus presentations were not constraining the automatic activation of compatible responses then there would be a great deal of interference from task-irrelevant stimuli in routine activities. This expands on the idea of the role of intention in affordance SRC as discussed so far by showing that the intention to act on the object still yields an effect, even with a brief presentation. Moreover, it allies the idea of intention with the selective activation of motor cortex by action relevant stimulus features by showing that incompatible responses are inhibited according to the response rule, meaning that intention to act is also interacting with the response rule.  Were it not, then we would not predict inhibition on incompatible trials.

On the point of selectivity, there is some evidence that man-made objects are a special case for visuomotor processes, showing differential processing to animals in a study by Proverbio, Del Zotto and Zani (2007).  Participants were presented vertically arranged pairs of images of common man-made objects, animals or mixed pairs of both.  They were instructed to make a categorical judgement on the stimuli and to withhold their response when a mixed pair was presented.  No effects were found in the P1 or C1 time periods, however the most striking result was that posterior N1 at occipito-temporal sites (electrodes O1, O2, OL, OR, T5, T6) were preferentially activated from 130-180ms, with greater amplitudes elicited by images of animals than objects.  The inverse pattern was found when measuring frontocentral (electrodes F3, F4, C3, C4) N1 from 130-160ms, with preferential activation by objects over animals.  At the same sites, from 200-260ms the frontocentral N2 component was more negative for objects than animals.  They also found a smaller P300 component to objects than animals from 300-400ms.  This study is striking because it appears to show that natural and manmade objects are processed quite differently, with selective effects emerging as early as 130ms after stimulus onset.  The differential pattern across visual and motor sites speaks to the kind of visuomotor processing suggested above, with manmade objects having greater action relevance and so showing greater motor activation, with posterior sites appearing to differentiate the nature of the different stimulus categories, forwarding action relevant visual information selectively to motor cortex.  The authors suggest that the preferential posterior N1 activity to animals is related to the animate, homomorphic nature of the stimuli, indicating a perceptual representation compared with the more functional representation of tools, resolved in motor cortex.

Interesting evidence may be drawn from Proverbio, Adorni and D'Aniello (2011), who found quite different latency in their study whilst employing a quite different design that entailed presenting manipulable stimuli. They showed participants images of manipulable tools, non-tool objects and plants whilst recording ERPs. Participants were only asked to respond to images of plants, which numbered 25 out of 325 possible stimuli, effectively forming a passive viewing paradigm with plant stimuli as catch trials. They found an effect of action affordance within 250ms of stimulus onset. A larger anterior negativity was observed to tools than objects from 210-270ms as was a larger centroparietal P300 observed from 550-600ms. The authors used low-resolution electromagnetic tomography (swLORETA) to localise the source of the effects to left precentral gyrus and bilateral premotor areas, with a leftward hemispheric asymmetry. The authors explained this as showing automatic and rapid access to motor properties of stimuli, even when attention is devoted to other stimulus categories. Given that no response was required for the tools this is particularly interesting because most SRC effects are explained as an interaction between stimulus and response. However this study shows an effect much later than other studies presented here and in the absence of a response may not be so easy to combine with the other citations given here. That said it is quite difficult to draw clear divisions and there are several reasons that these different studies do converge on the same point; the latency difference is possibly attributable to a lack of imperative to provide a rapid response or maybe to an effect of attention or an interaction of these two factors. Another possibility may be suggested based on Miller and Hackley's (1992) intimation of a role for intention in generating these effects, perhaps the lack of intention to respond to these stimuli was responsible for a sort of 'de-tuning' of the system to such stimuli or rather, perhaps the intention to respond to the plant stimuli was responsible. It is also interesting to note that the trials in this experiment were longer than others cited here, perhaps also reflecting another potential source of tuning of the system, based in the same reasoning behind the widespread use of jittered trials in psychology experiments; if trials are predictable, participants adapt to that and predictability may from a part of their response strategies. The authors claimed that these data suggest that manipulable tools command a stronger capacity to capture attention than other objects of equal familiarity, and that this capacity is attributable to their affordance and biological relevance and it is difficult to suggest that this study is not congruent with the SRC literature, whilst still couching SRC effects in an affordance framework as this thesis seeks to do. To that end, although the effects observed here were later than comparable experiments cited here, given that there was no explicit motor output, it represents one of the strongest demonstrations of affordance and of visuomotor processes in premotor cortex. This study also shows one of the best reasons to use neuroscience methods to examine object affordance; it is possible to gather data even when there are no responses made and indeed entire paradigms may be designed around this fact to yield data that would be difficult to infer from behavioural experiments alone because they always require a response, necessarily conflating the notion of action preparation by seen objects with the action preparation necessitated by executing the behavioural response. With electrophysiology in particular we are able to see the divergence of different stimulus conditions in time, making apparent the role of selectivity and intention in what has been characterised as simply automatic by much of the behavioural literature.

So, a motor cortex effect in the absence of a response led Proverbio et al. (2011) to suggest an attention based explanation, however the link was also made by Allport (1987) with the selection for action hypothesis, which broadly states that attention shapes visual processing according to the action intentions of the observer. On the face of it, this seems like quite a plain statement, but there are considerable ramifications in the context of different sources of affordance. By this hypothesis, attention would be directed by the response set because it represents the action intentions/ possibilities, so a lateralised button press response would increase the salience of lateralised handles on objects and maintaining particular grips would prime the observer for detecting similar grips. A compelling example of this may be drawn from Van Elk, Van Schie, Neggars and Bekkering (2010), who investigated the selection for action hypothesis by showing participants objects and asking them to either point at or grasp them, with alternating blocks of each. ERP data showed an increased N1 response to grasping compared with pointing. N1 is not typically associated with particular task demands but rather is expected in any visually evoked potential to any visual stimulus, so this task-influenced N1 effect is remarkable. Moreover, it shows the visuomotor processes that have been touted so far by examining motor cortex effects also obtain in visual cortex because the motor component of the task showed a detectable difference in visual cortex. This result allies well with the behavioural results from Symes et al. (2008) in the previous chapter, where visual search was shown to be speeded by maintaining a particular grip. These and the other citations showing a role for intention in affordance generation and visuomotor processing all support the selection for action hypothesis. The hypothesis also provides a complimentary notion to that of affordance, giving a mechanism by which relevant affordances can be extracted and acted upon. Moving into the experimental work, this hypothesis and the discussion of the role of intention in affordance effects will be increasingly significant. The studies cited in this section clearly demonstrate the depth of explanation available when examining SRC affordance effects using methods that have high temporal resolution. The SR translations happen so rapidly that great temporal acuity is required in order to understand the processes and the order of events.

### *3.3.3 A note on support from transcranial magnetic stimulation*

As we have seen from the electrophysiological data, both human and primate premotor cortex appear to respond to visual stimuli within 200ms of stimulus onset and sometimes even before 100ms. The converging evidence on this point is convincing and yet more may be drawn from another source of evidence; the temporally-orientated neurophysiological technique, TMS. TMS makes use of the relationship between electrical potentials and magnetic fields in order to trigger the firing of cells in a desired location with high accuracy. This is often used in concert with structural MRI data in order to locate the stimulation in the desired brain region. Schluter, Rushworth, Passingham and Mills (1998) employed this technique during a choice RT study which saw participants respond with a button press from either middle or index finger on one hand, signalled by the appearance of a large circle or small rectangle for one response and a small circle or large rectangle for the other response. This manipulation meant that neither size nor shape defined the response, a measure taken in order to lengthen the RTs. Subjects were stimulated during this task in premotor cortex or primary motor cortex, contralateral to the hand of response. As one may expect from the electrophysiological data given above, stimulation of premotor cortex from 100-140ms disrupted action selection and led to longer RTs overall. Similarly, primary motor cortex stimulation from 300-340ms also delayed the response, attributed to disrupting response deployment. In a second experiment, ipsilateral premotor and primary motor cortices were stimulated. In this case, RTs were only slowed for left handed responses. This was taken as supporting a left-hemisphere dominated network governing action selection, compatible with some of the results given above (e.g. Grezes et al. 2003). The timing seen in this experiment comes from a third neurophysiological technique and converges well with other sources of evidence presented in this chapter, providing strong support. Similar effects at similar latencies have also been observed with manual responses to auditory stimulation with right primary motor cortex stimulation at 25ms intervals from 50ms to 125ms showing no preference for which hand was affected, with a contralateral effect emerging from 150ms (Koch et al., 2006). In stroke patients with right hemiparesis, TMS applied at 100ms to left premotor cortex slowed RTs by 12%, showing that the principle of rapid motor access by visual stimuli for the preparation of responses holds, even when dealing with systems that have been damaged and restructured (Johansen-Berg et al. 2002).

TMS has also been shown to yield quite unexpected results in SRC paradigms, even leading to shorter RTs on incompatible trials than compatible when stimulating motor cortex at 200ms after stimulus onset (Koski, Molnar-Szakacs & Iacobonia, 2005). This is interesting because it appears that the TMS pulse has disrupted the influence of the affordance on the process of generating a response and this will become pertinent during the experimental chapters. The overall effect in this study was to slow responses compared with baseline RTs, however early (50ms or 100ms) stimulation of left hemisphere was shown to facilitate responses made with the contralateral effector. It is extremely interesting that stimulation at 50ms would exert such an effect because this is much earlier than any of the timings seen in any other method discussed here, and indeed is earlier than one would predict for a motor cortex effect. This study does provide some caution however, stating that nonspecific factors of stimulation appeared to contribute to producing the RT increases, as evidenced by a slower response on sham TMS trials compared with baseline trials. Sham trials involve the use of equipment that appears to be the same as that which delivers the TMS, but does not actually provide the stimulation and is intended to control for any effects of the experimental procedure. For this reason and given the volume of support for this core point on timing, the current section will be curtailed, having demonstrated good support for the electrophysiological data from another angle.

### *3.4 Chapter conclusions*

This chapter has considered evidence from cognitive neuroscience on the generation of spatial and object affordance effects. One of the key themes is the rapidity of the affordance effect, with converging evidence from ERP, TMS and single-cell recording all indicating that effects commonly emerge at around 100-150ms and sometimes even earlier (e.g. Riehle, Kornblum & Requin, 1997; Koski et al., 2005; Georgopoulos et al., 1982). It has also been shown that effects may occur much later, up to 250ms (Proverbio et al., 2011) and a connection has been suggested between the pressure to provide a rapid response (as a function of trial duration and the frequency with which target stimuli appear) and the latency of the effect, with earlier effects appearing with shorter trials and with more go trials. This appears to be connected with and indeed is part of the intention to act on the objects (e.g. Hohlefeld, Nikulin & Curio, 2010), however some reports suggest that intention is irrelevant and upon viewing an object its affordances are automatically parsed (e.g. Proverbio et al., 2011). This point shall be considered again in the experimental chapters. All of the converging TMS, single-cell recording, fMRI and PET evidence presented here indicate that premotor cortex is the seat of these early response preparation effects, with primary motor cortex more strongly implicated in response execution and inferior parietal lobule implicated in the translation of early response preparation into execution, apparently as a function of the response rule (e.g. Grezes et al., 2003; Cisek, 2007). Some evidence has also been presented that suggests that early visual ERP components may have more of a role to play than typically assumed, with stimulus-orientated effects in N1 and P1 seen in different studies (Van Elk et al. 2010; Proverbio, Del Zotto, Zani, 2007), although not widely reported.

Of the citations given here, effort has been made to provide as many as possible that deal with real objects, however the available evidence is limited and as seen in the previous chapters, direct comparisons between different stimulus classes in SRC are difficult to avoid. Also, many experiments have been conducted with quite different parameters and this has been suggested above to influence the latency of the results in ERPs. So, the experiments in the following chapters will only use full colour photographs of real objects as stimuli and will tightly control presentation parameters in order to avoid any potential confounds and achieve a consistent comparison across datasets. An addendum to this also revisits the issue of localisation; behavioural and neurological evidence suggests that grip and lateralised stimuli may be served by different networks, different processes and exhibit different latencies and so a comparison of grip-type and lateralised affordance effects will be attempted under controlled presentation conditions in order to attempt to understand the difference between these experiments.

Moving into the experimental chapters, the emphasis on localisation will decrease given the converging evidence presented above. Instead, the following experiments will focus on the latency and timecourse of different affordance classes in LRP and VEPs P1 and N1, as well as the assumptions underlying so much affordance behavioural SRC work.

*4. Chapter four*

*The core SRC affordance effects*

## *4.1 Outline*

This chapter describes two experiments based on the familiar SRC affordance studies by Tucker and Ellis (1998) and Ellis and Tucker (2000). These studies (among others discussed above) have demonstrated that when objects and responses share characteristics such as size or orientation, reduced RT and error rates are observed. This chapter will expand on this by examining the timecourse of the visuomotor processes suggested to underpin this effect. The first experiment will use the lateralised affordances from Tucker and Ellis (1998), having participants make a categorical judgement on the stimuli and declare their response with a bimanual button press. The second experiment will use the grip-type affordances from Ellis and Tucker (2000) with response devices that simulate interacting with the stimulus objects. Unexpected differences are observed between these different affordance classes.

## *4.2 Experiment one – lateralised affordance SRC*

### *4.2.1 Introduction*

The previous chapters have described a burgeoning literature on SRC affordance effects, however the overwhelming majority had been conducted using behavioural methods (e.g. Michaels, 1988; Michaels, 1993; Thorpe, Fize & Marlot, 1996; Hommel, 1997; Stins & Michaels, 1997: Tucker & Ellis, 1998; Ellis & Tucker, 2001; Creem & Proffitt, 2001; Craighero et al., 2002; Derbyshire, Ellis & Tucker, 2006; Pappas & Mack, 2008; Van Elk, et al., 2010; Pellicano et al., 2010; Girardi, Lindemann & Bekkering, 2010; Borghi, Di Ferdinando & Parisi, 2011; Galpin et al., 2011; Recent review: McBride et al., 2012). The claim from such studies is broadly that the action relevant properties of the stimuli cue a particular kind of visuomotor preparation in the observer, regardless of their task-relevance, although the precise mechanism has been the subject of some debate, particularly in terms of differentiating from the Simon effect (see chapters one and two). This notion suggests that there should be a detectable event in motor cortex that is associated with the SRC affordance effect. As discussed in chapter three, the Event Related Potential (ERP) technique is an ideal candidate to assess this idea, with sub-millisecond temporal resolution offered by the measurement of electrical activity in human subjects through the recording and subsequent segmentation of a continuously recorded electroencephalogram.

This experiment sought to observe neural markers, originating in visual and motor cortices that signify the behavioural advantage observed in the SRC literature that has led to these processes being characterised as visuomotor. It is predicted, based on the behavioural claims that this effect ought to be detectable rapidly after stimulus onset. This is because the effect is seen in forced choice experiments with reaction times of approximately 500ms (e.g. Tucker & Ellis, 2001), suggesting that this effect must be exerted very early given the time taken to compute the affordance, compute the response and convert the computed response into a motor program to be sent downstream for execution by the effectors.

In order to establish the neural marker of the compatibility effect, the first experiment consisted of a typical SRC experiment that used lateralised objects and lateralised responses as the dimension for compatibility, similar to Tucker and Ellis (1998). Participants performed a categorical judgement task in which the laterality of the objects and the responses were not task relevant. In order to control for the Simon effect, the same objects were featured in both left and right rotations and Lateralised Readiness Potentials were calculated that compared objects like for like.

### *4.2.2 Method*

*Participants*

70 students (26 male) from the University of Plymouth were recruited. All were right handed, aged 18-28 (mean = 20 years, *SD* = 1.60), with normal or corrected vision and no known history of neurological or dermatological problems. In all experiments in this thesis, handedness was determined by self-report and checked by a simplified version of the Edinburgh handedness index. A total of six participants were rejected due to excessive artefact, defined as greater than 35% of segmented data rejected due to ocular, muscular or environmental artefact in the EEG. This led to a total of 64 participants' data entering into the averaging procedures

*Stimuli*

Participants viewed a single image at a time from a pool of 84 colour images photographed from a total of 42 objects graspable handles which could be categorised as either kitchen or tool items, with 21 objects of each category. Note that whilst there were different examples of the same kind of object (e.g. small and large frying pans) no single object image appeared any more than another. Each object was photographed twice; once with the handle at 45° to the right and once with the handle at 45° to the left, producing 42 right-oriented and 42 left-oriented objects for the grand total of 84 images. Each image appeared 6 times in the course of the experiment, three times in each rotation, with each rotation presented once in each of 3 blocks. The presentation order was randomised within each block and was different for all participants. E-prime's E-studio (Psychology Software Tools, Inc) was used to generate the script and present the experiment. Responses were recorded using the associated Serial Response Box.

*Procedure*

Images were viewed on a 21" Viewsonic P227f CRT monitor at 20 degrees viewing angle at a resolution of 1280x1024 and a refresh rate of 100Hz. A fixation cross ('+') appeared in the centre of the screen for 1000-1200ms before ceding to a randomly selected image from the pool described above for up to 2000ms or until a button response was made. Following this a blank screen appeared for up to 400-600ms until a symbol (' (-) (-) ') appeared for 1400ms instructing the participants that it was possible for them to blink. This 'blink break' was included to keep the participants from blinking during the trials and to therefore reduce the rejection of segments due to EOG artefacts. See figure 2 for a visualisation of the timecourse of each trial.

Participants were asked to categorise the images as either kitchen items or tools and signify their response by a speeded bimanual button response using a left or right button press. This creates two possible combinations of category and button laterality or 'response mappings'; half of the participants responded first with a left button press to signal that an item was a tool and a right button press to a kitchen item whilst the other half of the participants completed the opposite response mapping; a left button press to a kitchen item and a right button press to a tool. All participants completed both response mappings and to ensure that there was no influence of order the first mapping undertaken was counter-balanced across participants. As described above, all responses may be classified as either compatible or incompatible based on the lateralisation of the handle and the button press; a compatible response would be a right button press to a right-oriented handle or left button to a left-oriented handle and an incompatible response would be a left button press to a right-oriented handle or a right button response to a left-oriented handle.

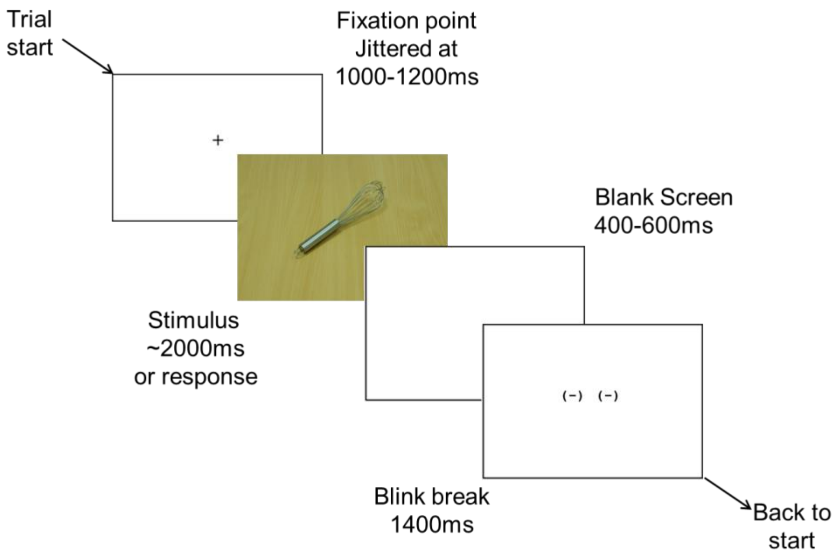



*Figure 2.* Visual representation of the timecourse of each trial, with each frame representing a change in what is displayed. Each trial consisted of four such changes and lasted up to a maximum of 5200ms and was repeated 84 times per block, with a different stimulus presented on each trial.

Before beginning the experiment, participants completed 15 practice trials to give them a chance to get used to the experimental conditions, primarily use of the blink break. Participants were asked to repeat this up to three times, or until a minimum of 14 out of 15 trials were answered correctly and without EOG contamination.

*EEG Acquisition*

The ERP data was acquired using 29 actively amplified Brain Products Acticap Ag/AgCl electrodes in a 32 channel montage (figure 3) arranged according to the international 10/10 system, with an implicit left mastoid reference (A1) and ground (AFz). There were also two channels recording EOG and a right mastoid electrode (A2) that was averaged with A1 offline to form a reference. Data were recorded at electrode locations FP1, FP2, F7, F8, F3, F4, FT7, FT8, FC3, FC4, FCz T7, T8, C3, C4, Cz, TP7, TP8, CP3, CP4, CPz, P7, P8, P3, P4, Pz, O1, O2, Oz.

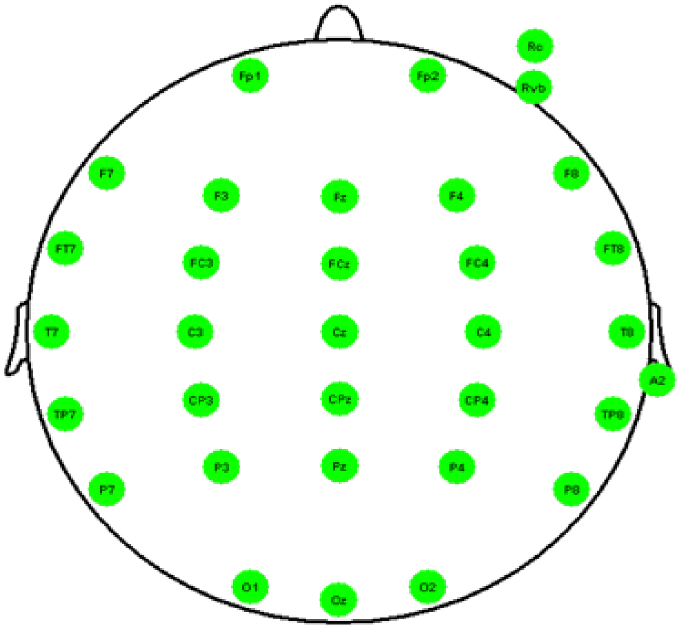



*Figure 3*. Showing the montage for experiment one consisting of 34 electrodes arranged according to the International 10-10 system.  Not pictured here is the implicit reference at A1 and ground at AFz.

Electrode impedance was maintained below 20kΩ. The signal was amplified by two 32 channel Brain Products MR series amplifiers and digitised at 2.5kHz.  Any trials that contained a response before 200ms or after 1200ms were rejected, as were any trials that contained ocular, muscular or any other artefacts.

ERP Analysis

Using Brain Vision Analyser (Brain Products GmbH), the data were then downsampled offline to 500Hz before a 0.5-40Hz Butterworth filter was applied and notch filter was applied at 50Hz to remove mains noise.  The data were then referenced offline to a reference of the average of the two mastoids and a baseline correction was applied taken from the 200ms prior to stimulus presentation.  A semiautomatic artefact rejection procedure was conducted on all of the segmented data from scalp and EOG electrodes using the inbuilt module in Brain Vision Analyser with an amplitude criterion range of -80µV to 80µV and a gradient criterion of 50µV/ms in order that the procedure only marked artefacts.  The output of this process was manually checked for all participants to ensure that no good segments were removed and that no bad segments were allowed into the averaged data. Where more than 35% of segmented data was rejected, the participant was removed from the analysis to avoid falsely inflating the sample size.

### *4.2.3 Results*

*Behavioural data*

Participants correctly categorised 93.62% of stimuli. Responses less than 200ms and more than 1200ms after stimulus onset were excluded in order to remove any accidental responses. RTs greater than 2.5SD from the mean cell value were excluded from the analysis to remove any remaining outliers. Repeated measures ANOVA were conducted, using factors of object category (kitchen vs. tool) and object compatibility (compatible vs. incompatible). This yielded a significant effect of compatibility ($F$ (1,64) = 6.53, $p$ = 0.012) as well as an interaction between compatibility and object category ($F$ (1,64) = 16.81, $p$ < .001).

The typical stimulus-response compatibility effect was observed, with faster responses to compatible pairings (542ms) of object and response than incompatible pairings (547ms). The interaction revealed a difference in the behaviour of the two categories of stimuli with an effect (10.32ms) in the tools ($F$ (1,64) = 6.53, $p$ < .001) and no effect for the kitchen items ($F$ < 1). No such interaction was observed in the errors ($p$ > 0.5).

*LRP data*

LRPs were calculated using the Coles (1989) derivation for compatible and incompatible trials:

$$\frac{[\text{Mean}(C4 - C3)_{\text{left responses}} + \text{Mean}(C3 - C4)_{\text{right responses}}]}{2}$$

With this derivation, potentials recorded in each hemisphere are subtracted separately for conditions where the correct response is left or right handed, removing any symmetrical activity. The resulting values index asymmetric activity. These values are then averaged together to create the LRP. The LRP for compatible trials was calculated by averaging the product of subtracting the C3 potential from the C4 potential for left orientated objects requiring a left handed response with the product of subtracting the C4 potential from the C3 potential for right orientated objects requiring a right handed response. The LRP for incompatible trials was calculated by averaging the product of C3 subtracted from C4 for left handed responses to right orientated objects with the product of C4 subtracted from C3 for right handed responses to left orientated objects. These calculations mean that the resulting LRPs will have a positive going waveform indicating preparation of an incorrect response and a negative going waveform to indicate preparation of a correct response. The LRPs may be seen in figure 4. Compatible LRPs were calculated as:

$$\frac{[\mathrm{Mean}(\mathrm{C4}-\mathrm{C3})left\ response\ to\ left\ handle + \mathrm{Mean}(\mathrm{C3}-\mathrm{C4})right\ response\ to\ right\ handle]}{2}$$

And incompatible LRPs were calculated as:

$$\frac{[\mathrm{Mean}(\mathrm{C4}-\mathrm{C3})\mathrm{l}eft\ response\ to\ right\ handle + \mathrm{Mean}(\mathrm{C3}-\mathrm{C4})right\ response\ to\ left\ handle]}{2}$$

Averaged LRPs were analysed in five 100ms epochs from 0 to 500ms after stimulus onset using a factor of compatibility (compatible vs. incompatible) and of object category (kitchen vs. tool). In order to control for the familywise error rate a Bonferroni correction was applied by dividing the standard alpha level by the number of comparisons (0.05/5), so the corrected $\alpha = 0.01$. The only significant effect was observed between from 100 to 200ms (all other *F* 's< 1) in which congruent trials led to the preparation of the correct response hand and incongruent trials led to the preparation of the incorrect response hand ($F$ (1,64) = 24.84, $p$< .001).

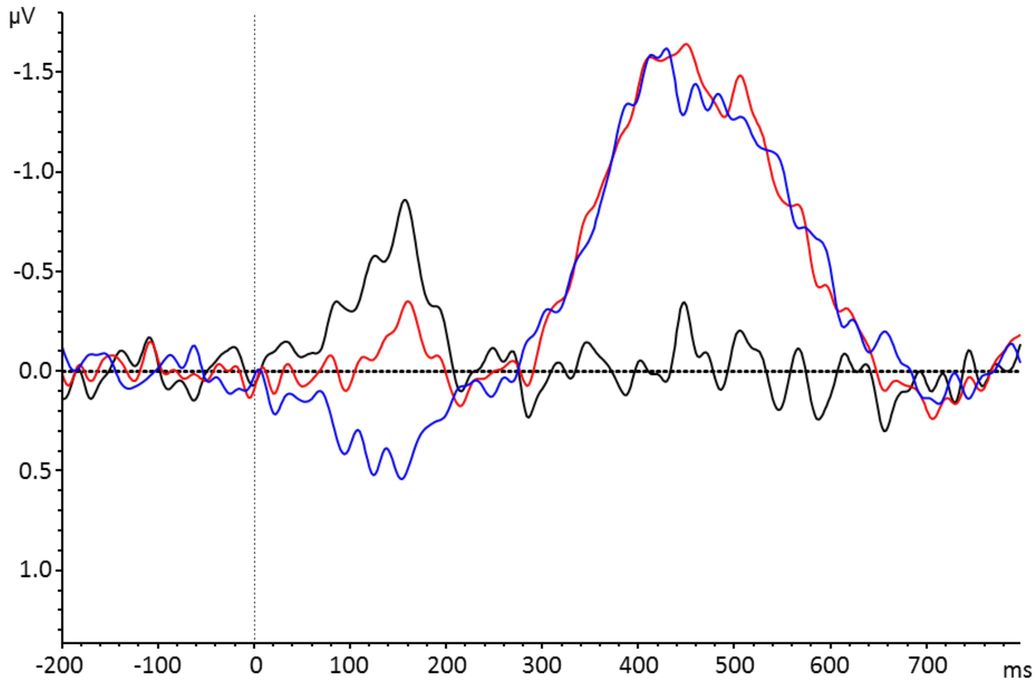



*Figure 4.* LRP results for experiment one. The LRP's were calculated separately for compatible trials (when the handle on the stimulus was orientated in the same direction as the button press) and for incompatible trials(when the handle was orientated in the opposite direction to the button press). The red trace plots the grand average for compatible trials, the blue trace plots the grand average for incompatible trials and the black trace plots the difference of the two.

*ERP data*

Figure 5 shows average ERPs across parietal and occipital electrodes P7, P8, O1, and O2 for compatible and incompatible trials. Average ERP amplitudes were calculated for the visual P1 from 70 to 100ms and N1 from 120 to 170ms after stimulus onset. Repeated measures ANOVA was used with factors of response hand (left vs. right), handle orientation (left vs. right), electrode hemisphere (left vs. right) and electrode group (parietal vs. occipital).

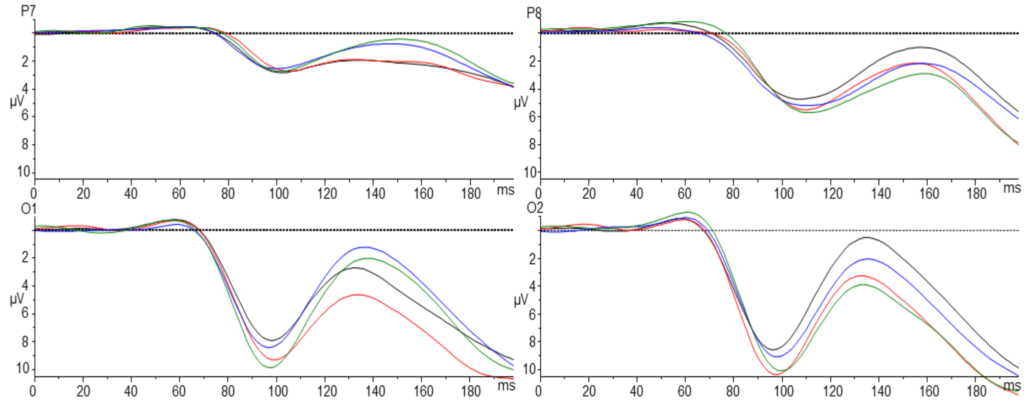



*Figure 5.* Averaged ERPs for electrodes P7, P8, O1 and O2. Separate waveforms are displayed for each combination of handle orientation and hand of response. The black trace plots left-orientated handles and left handed responses. The red trace plots left-orientated handles and right handed responses. The blue trace plots right-orientated handles and left handed responses. The green trace plots right-orientated handles and right handed responses.

An interaction between hemisphere and handle orientation was observed in P1 ($F$ (1,64) = 5.98, $p$ = 0.017) and N1 ($F$ (1,64) = 100.87, $p$ < .001). There was also an interaction of handle orientation and response hand in P1 ($F$ (1,64) = 6.91, $p$ = 0.011), with compatible responses eliciting greater positivity. The same interaction of handle orientation and response hand was found in N1 ($F$ (1,64) = 5.49, $p$ = 0.022), with greater negativity for compatible responses. These compatibility effects in visual components show that not only is there a detectable motor component associated with affordance SRC paradigms, but there are also detectable visual effects that mirror the motor effects, supporting the notion of visuomotor integration described in the literature review over the notion of discrete visual and motor systems. Following the behavioural finding of a stronger effect for tools than kitchen items, a further ANOVA conducted within object categories showed that the compatibility effect between handle orientation and response hand was only significant in the tool category –as in the LRP data– for P1 ($F$ (1,64) = 10.99, $p$ = 0.001) and N1 ($F$ (1,64) = 12.40, $p$< .001). Overall, these ERP data closely resemble the LRP data.

*4.2.4 Discussion*

This experiment found the typical behavioural SRC affordance effect seen in the behavioural literature but also demonstrated novel effects in motor cortex and visual cortex that appear to provide a neural basis for the well-known SRC affordance effect. These data support the notion from embodied cognition that vision and action are tightly linked (e.g. Ellis, 2009), as described in the introductory chapters. The electrophysiological data reveals that within 100ms of stimulus onset neural activity occurred that varied systematically with the affordance of the objects in both motor and visual cortices. The rapidity of the concurrent visual and motor effects suggests very early (~100ms) interaction of visual and motor systems prior to object categorisation and therefore well before response selection that matches the idea of visuomotor processing described above. The rapidity with which the effects were detected suggests that the visuomotor effects are not produced by relating object affordances to the response rule, because semantic access with objects has been shown to occur much later, from 300-600ms, marked by the N400 component (e.g. Goto et al., 2010; Van Elk, Van Schie & Bekkering, 2010; Balconi & Caldiroli, 2011; discussed in detail later). Currently, the findings appear to represent the very early extraction of action relevant properties from the visual information however this requires further confirmation over the following experiments.

Unexpectedly, they show that even low-level visual evoked potentials P1 and N1 are modulated by the relation between the actions associated with an object and the action intentions of the observer. This is remarkable considering the literature on P1 and N1 which states that these components will be detected whenever there is visual input (e.g. Van Voorhis & Hillyard, 1977 evoked P1 using only flashing lights) and suggests that they are not selective of particular visual properties (e.g. Luck, 2005).

These findings support the notion of a visuomotor system that is critical to human perception in the way described in the embodied literature given in the introduction. This does not mean to say that all affordances operate in this way. Semantic affordances for example, such as those seen in Tucker and Ellis (2004), who found that object names also potentiate actions, clearly operate in a different way given their basis in language. Rather, these data demonstrate a direct link between visual and motor systems, fitting with more traditional notions of affordance and providing a neural basis in rapid, concurrent visual and motor activation and so supporting key results in the area, such as Tucker and Ellis (1998).

The most surprising results here are the effects in the visual components, N1 and P1. These components have typically been thought of as markers of visual attention, varying only with non-task stimulus properties such as luminance (e.g. Johannes, Münte, Heinze & Mangun, 1995) or due to non-task influences such as the participant's state of arousal (e.g. Vogel & Luck, 2000). However, these components showed an interaction of handle orientation and response hand, forming a compatibility effect. Visual effects occurred contralateral to the object handle, evoking larger N1 and P1 amplitudes. This is remarkable because action intention appears to be guiding the earliest stages of visual perception in order to produce this interaction, recalling Symes et al.'s (2008) result where preparing a particular grip reduced visual search times for compatible objects. So, it appears that object-based attention is giving rise to these affordance SRC effects, just as described by Ellis (2009) but that this is also interacting with available action possibilities, as described by Symes et al. (2008). It also appears that the overall affordance SRC effect is not purely motoric, but is rather a composite of visual and motor activation just as posited by the embodied account given above. Interestingly, all effects were stronger for tools than kitchen items in visual and behavioural data. Although this category effect is of no theoretical significance it does imply that the effects observed are closely related, because each shows the same pattern across conditions.

One interpretation of the visual effects is that the visual asymmetry of the objects was shifting attention laterally, similar to that seen with spatial cuing (e.g. Handy & Mangun, 2000; Luck & Hillyard, 1995; Mangun & Hillyard, 1988). These effects cannot be attributed to visual properties of the stimuli because the analyses ensured that comparisons were between the same stimuli and all that changed was the response mapping and with it, the participant's expected motor responses.

Less radical but still of some interest was the observed interaction of hemisphere and handle orientation, indicating that the composition of the object appeared to be modulating these conventionally independent components similar to spatial cuing (e.g. Handy & Mangun, 2000; Luck & Hillyard, 1995). This is not completely beyond expectations (see Hillyard, Vogel and Luck, 1998) but it is difficult to resolve when considering the work of Wascher, Hoffman, Sänger and Grosjean (2009). These authors showed that laterally presented stimuli (similar to our centrally presented, lateralised stimuli) may elicit an earlier N1 component of greater amplitude, detectable contralateral to the stimulus laterality when compared with centrally presented symmetrical stimuli. Wascher et al.'s (2009) results predict those here but were attributed to a spatial attention shift that occurred well before 300ms. The present data is insufficient to strongly conclude for either object or spatial attention and this is not the focus of the present thesis, but it is sufficiently interesting to note that lateralised object stimuli can recreate Wascher et al.'s (2009) results.

This experiment offers two core conclusions; firstly it provides a neural basis for affordance SRC effects in motor cortex at around 100ms and also implies the involvement of a visuomotor loop from motor to visual cortex. Moreover it provides first evidence for an influence of action possibilities on early visual components, a previously unforeseen result. The next experiment will examine grip type affordances and look at whether similar effects are observed.

### *4.3 Experiment two – grip-type affordance SRC*

#### *4.3.1 Introduction*

Experiment two will consider another prominent dimension for compatibility seen in the literature, referred to here as grip-type compatibility. This refers to the kind of compatibility observed in Ellis and Tucker (2001) where participants were tasked with declaring presented stimuli as organic or man made using bespoke response devices that forced participants into making precision or power grips. The objects were all either compatible or incompatible with power or precision grips based on their overall size, lending the moniker grip-type compatibility because grips were either compatible or incompatible with size and shape of objects.

When considering the behavioural literature, the dimensions for compatibility seen in experiment one are difficult to separate from others, such as grip type compatibility, simply because they show the same effects in the same metrics, i.e. reduced RT and error rates for compatible compared with incompatible SR pairs. Some authors (e.g. Zhao & Zhu, 2013) have posited the possibility of a difference in the handling of grip and lateralised affordances, but little direct evidence on this distinction is available. The present approach is well suited to providing such direct evidence and this forms the rationale for the present experiment; to determine whether the behaviourally equivalent compatibility effects that arise from lateralised affordance and grip type affordance are underpinned by the same or similar electrophysiological events. These effects may be described as behaviourally equivalent because SRC studies using behavioural metrics are only able to report the global reaction time and the error rate and these metrics report the same findings for both affordance classes, however the use of lateralised readiness potentials (LRPs) will allow the present investigation to determine whether these different sources of affordance are treated in the same way in motor cortex by investigating the timecourse of the neural response as with lateralised affordances in experiment one.

It is difficult to make predictions beyond the behavioural compatibility effect, because no work has replicated Ellis and Tucker (2001) in ERP. In a typical embodied cognition framework it can be said that the similarity of response devices should facilitate responses, however it is difficult to predict what effect this will have on the affordance component observed in experiment one. Furthermore, it is difficult to account for the difference between unimanual (as in Ellis and Tucker, 2000) and bimanual use of the grip devices, as will be employed here in order to allow for the calculation of LRPs.

A lack of data on the similarities and differences between different sources of affordance make it difficult to offer predictions. That said, theoretical grounds for a difference may be drawn from embodied cognition, which would suggest that physically maintaining a grip would scaffold perception in the way shown by Symes et al. (2008) in their change blindness paradigm where grip compatibility saw a large RT advantage emerge. This perceptual scaffolding was unavailable to the lateralised object stimuli used in experiment one, where participants viewed objects with handles whilst holding a response box that did not resemble the handles of any of the objects.

### *4.3.2 Method*

*Participants*

35 participants (18 females) were recruited, all University of Plymouth students. All were right handed, aged 18-28 (mean = 21, *SD*= 3.25), with normal or corrected vision and no known history of neurological problems. Two participants were removed from the analysis

due to corrupted files and eight participants were removed for excessive artefact, defined as greater than one third of segments rejected due to ocular, muscular or other artefact.

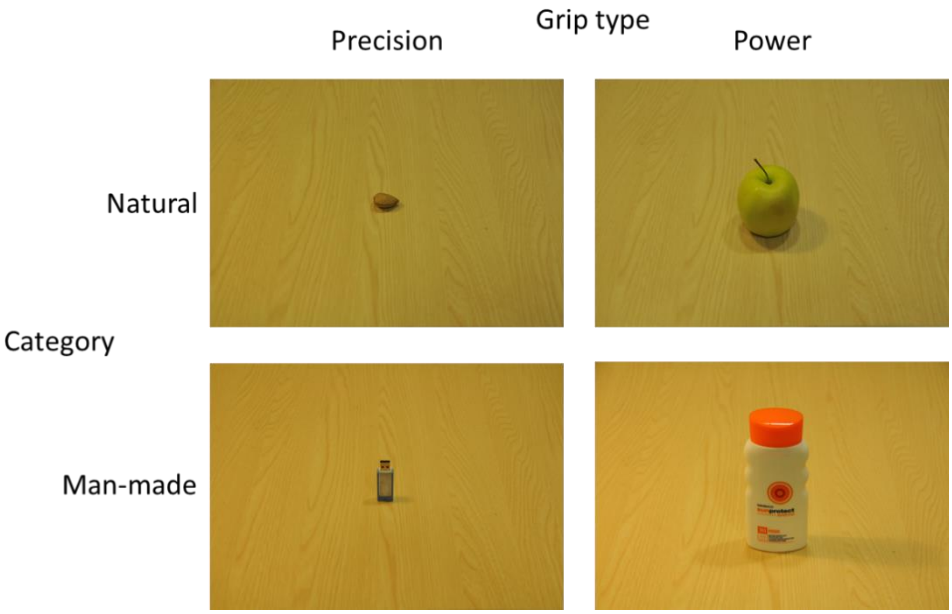



*Figure 6*. Example stimuli depicting the 2x2 design. Objects compatible with precision or power grips (columns) were chosen based on their classification (rows) as natural (e.g. almond, apple) or man-made (e.g. USB pen, sun cream). Compatibility existed between grip required to interact with the object and grip required by the response devices and the response rule determined which grip participants made to which category. Response devices are depicted in figure 7.

*Stimuli*

Stimuli consisted of colour photographs of 96 objects, classifiable as natural or manufactured. Natural objects consisted of organic items such as fruits, vegetables and stones. Manufactured objects consisted of an array of common household objects. Of each of the two types of stimulus 50% of items required a precision grip to interact with them and 50% required a power grip to interact with them. A precision grip is defined as the use of a thumb and index finger to manipulate an object, such as turning a key or picking up a coin. A power grip is defined as the use of the full palm and fingers to pick up an item, such as one would to use a hammer or to grasp a door handle when opening a door. Care was taken to ensure that the stimuli did not contain any lateralised information such as handles to avoid contamination by the Simon effect or lateralised affordance effects. Each object was presented three times, once in each of three blocks for a total of 288 trials per participant.

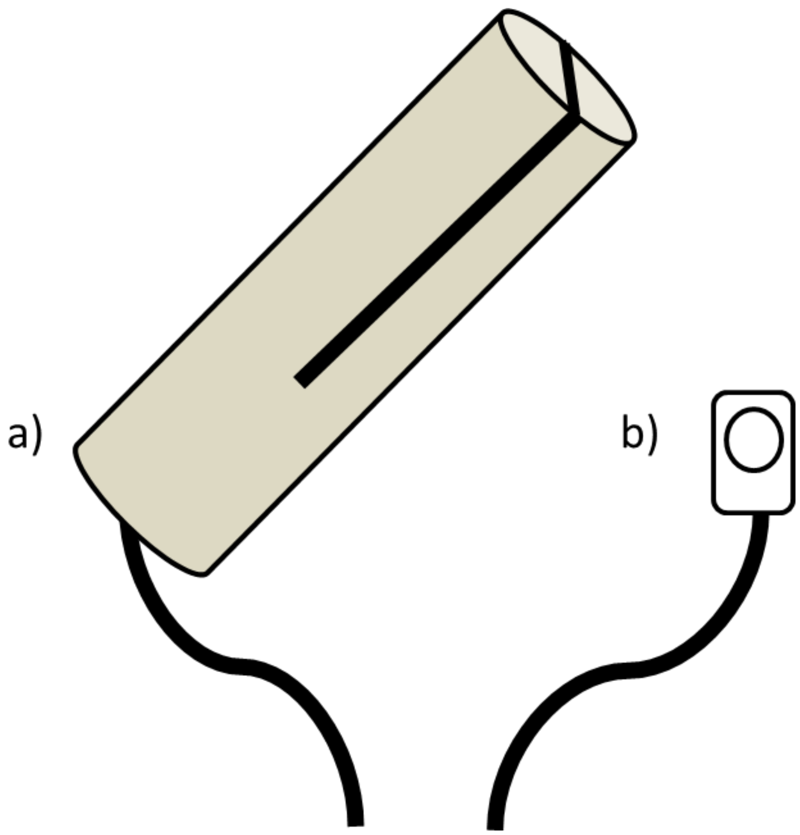



*Figure 7.* Response devices used in experiments two and four. Devices ran into a Psychology Software Systems Serial Response Box that recorded RTs before sending them on to the computer. a) Participants grasped this device with a palmar grip, wrapping all four fingers around the cylinder to grasp the device with the thumb holding it in place. This grip is classed as a power grip. The cylinder had a cut running down the middle, in which a microswitch was positioned to register the responses. Responses were executed by squeezing the cylinder. b) This simple microswitch was of the same kind as in the cylindrical power grip response device. It was grasped between thumb and forefinger and responses were made by squeezing the device between these digits.

*Procedure*

The experiment was presented using the same equipment as experiment one, with the same trial format and durations (figure 8). Participants completed the same practice procedure as in experiment one in order to familiarise themselves with the procedure. The only changes were to the stimulus and response set (detailed below and in figure 6), which led to a slightly greater number of trials overall (288 trials).

Participants responded to objects using grip devices that forced the participants to mimic a power grip or precision grip, depicted in figure 7. Precision grips were replicated using a small switch held between thumb and forefinger and a power grips were replicated by the use of a cylinder that required the whole hand to grip. These devices were seen in Tucker and Ellis (2001) where participants used both devices in one hand. In the present experiment participants used the precision grip device in their right hand and the power grip device is their left hand. This allows for the calculation of comparable LRP's to those seen in the lateralised affordance experiments reported here.

Participants held these response devices throughout the experiment whilst they viewed images of objects that were either compatible or incompatible with the grip devices and made categorical judgements on whether the objects were natural or manmade, declaring their answer with the response devices. Response mappings were counterbalanced across participants to ensure that there was no mapping effect. Half of the participants declared objects to be natural with a power grip and the other half did so with a precision grip, and vice versa for declaring objects to be manmade. Half of the objects in each category were power or precision grip compatible, meaning that on some trials, objects would be of a different grip to the response device, generating an incompatible trial. Otherwise, the presented object would match the grip-device used to declare the judgement, generating a compatible trial.

*EEG Acquisition*

Continuous EEG was recorded using Brain Vision Recorder and Brain Products MR plus series amplifiers (Brain Products GmbH) at a sampling rate of 500Hz from 64 Ag/AgCl electrodes in the following montage, conforming to the 10/10 system consisting of FP1, FP2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C3, T8, FCz, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, Rc, O1, Oz, O2, Rvb, AF7, AF3, AF4, AF8, F5, F1, F2, F6, FT9, FT7, FC3, FC4, FT8, FT10, C5, C1, C2, C6, TP7, CP3, CPz, CP4, TP8, P5, P1, P2, P6, PO7, PO3, POz, PO4, PO8. Rvb and Rc were used to monitor EOG for the purpose of rejecting segments with excessive ocular artefact. Electrode impedance was maintained below 25kΩ. EEG was referenced to a left mastoid reference electrode online.

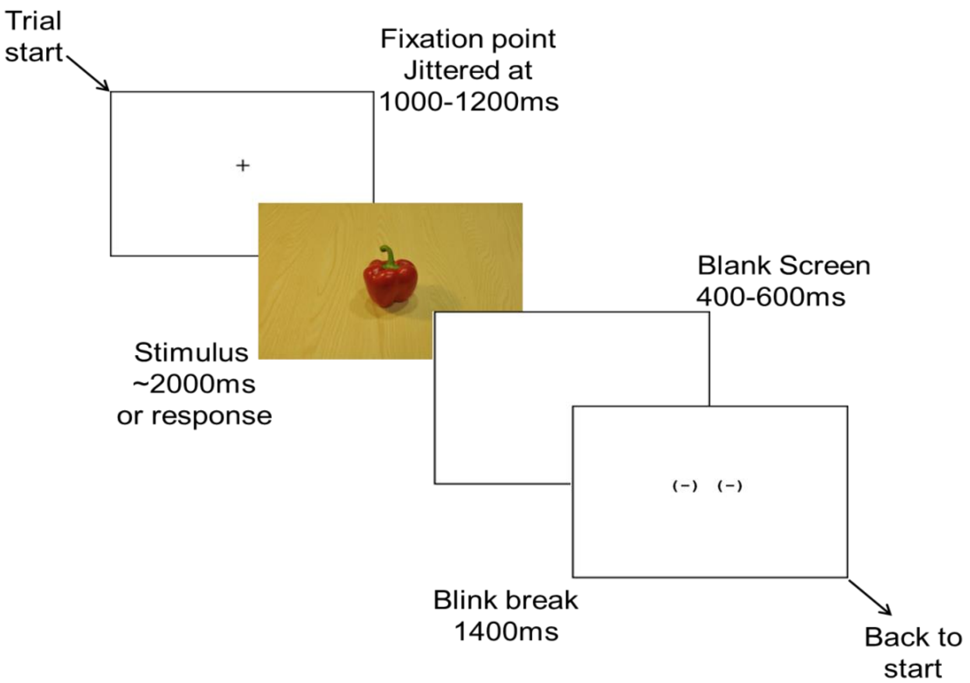



*Figure 8.* Visual representation of the timecourse of each trial in experiment two, with each frame representing a change in what is displayed. Each trial consisted of four such changes and lasted up to a maximum of 5200ms and was repeated 96 times per block for a total of 288 trials per participant, with each stimulus being displayed three times over the course of the experiment.

*ERP Analysis*

Brain vision Analyser 2 (Brain Products GmbH) was used first to filter the data using 0.1-40Hz bandpass filter, with a 50Hz notch filter to remove mains noise. A baseline correction was applied based on 100ms of data immediately before stimulus onset and the data were re-referenced offline using an average of the two mastoids. The data were divided into 700ms segments from -100ms to 600ms before and after stimulus onset. An automatic artefact rejection procedure was applied with an amplitude criterion range of -80µV to 80µV and a gradient criterion of 50µV/ms and the output of this process was manually checked to ensure that no artefacts were kept and no good data were rejected.

*4.3.3 Results*

*Behavioural data*

Trials with reaction times longer than 1200ms or shorter than 200ms were excluded from the analysis, as were trials with RTs that fell beyond 2.5SDs from the mean. The error rate was 2.9% with no significant differences in the errors (p's > .2). Mean RT for compatible trials with manmade objects was 622ms, and for incompatible trials with manmade objects were 13ms slower at 635ms. Compatible trials with organic objects were the shortest RTs, with a mean of 594ms and incompatible trials with organic objects had a mean RT 18ms slower, at 616ms.

Repeated measures ANOVA was conducted with factors of object size (power vs. precision) and response (power vs. precision). An interaction of object size and response indicated a significantly faster response for compatible trials than incompatible trials ($F$ (1,24) = 40.52, $p$< .001), indicating the typical compatibility effect observed in Ellis and Tucker (2000). No main effects were observed for object size ($F$ (1,24) = 1.659, $p$ = 0.210) or response ($F$ (1,24) = 0.795, $p$ = 0.381). Additional tests revealed that the compatibility effect was stronger for organic objects ($t$ (25) = -4.152, p = 0.001) than for man-made objects ($t$ (25) =

1.973, $p$ = 0.06), which only showed a tendency towards compatibility. Additional tests also revealed that power responses (610ms) were significantly faster ($t$ (25) = -3.952, $p$ = 0.001) than precision responses (625ms).

*LRP Data*

LRPs were computed using the Coles (1989) derivation as above, with separate LRPs for compatible and incompatible trials. LRPs were computed as the averaged potential on the electrode ipsilateral to response subtracted from the averaged potential on the electrode contralateral to response. For left handed responses this meant that the LRP was calculated as C3 subtracted from C4 and for right handed responses as C4 subtracted from C3.

The LRP is depicted in figure 9. Repeated measures ANOVA with a factor of compatibility (compatible vs. incompatible) were conducted from 0-500ms at five 100ms intervals, with a sixth interval (225-400ms) based on visual inspection of the differences between the waveforms for each condition. A Bonferroni correction was used to control the familywise error rate for the six comparisons, generating an alpha criterion of (0.05/6) $\alpha$ = 0.0083. RM ANOVA revealed a borderline effect of compatibility from 200-300ms ($F$ (1,24) = 4.347, $p$ = 0.048) and becoming significant with the Bonferroni corrected $\alpha$ from 300-400ms ($F$ (1,24) = 5.339, $p$ = 0.003). Based on visual inspection of the data another epoch was defined, yielding a significant effect of compatibility from 225-400ms ($F$ (1,24) = 8.993, $p$ < .006), demonstrating greater negativity when SR pairs were matched than when they were mismatched.

Additional $t$-tests revealed the 225-400ms effect was primarily borne of facilitation, with the compatible LRP differing significantly from baseline ($t$(24) = -6.413, $p$ < .001) and the incompatible wave failing to differ significantly from baseline ($t$(24) = -1.890, $p$ = 0.071).

This fits with assertions from studies such as Galpin et al. (2011) that affordance SRC is driven by facilitation rather than inhibition. However, from 300-400ms both compatible ($t(24) = -6.600$, $p < .001$) and incompatible ($t(24) = -3.074$, $p = 0.005$) waves were significantly different from baseline indicating a delay in developing the motor activity for the rule-cued response on incompatible trials. However during this period the polarity of the LRP for incompatible trials was negative, indicating the preparation of the correct response hand. As incompatible affordance driven would be typified by positive LRP (as in Experiment 1), it would appear that this deviation is likely associated with motor preparation associated with the execution of the rule-cued response.

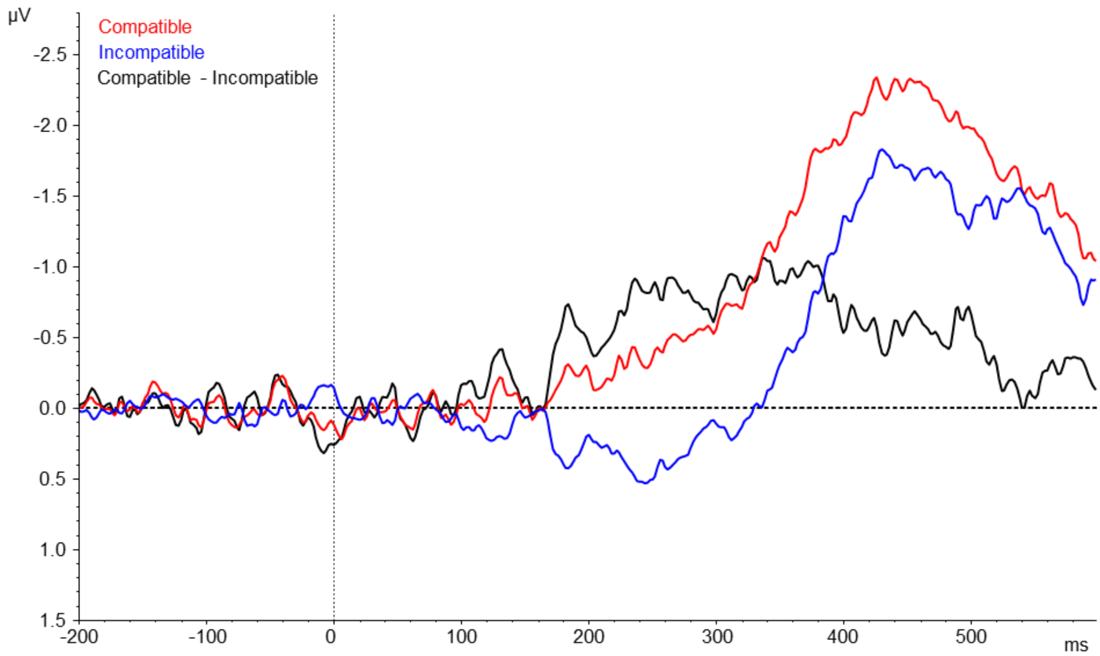



*Figure 9.* LRP results for experiment two. The LRP's were calculated separately for the compatible trials, when stimulus and response grips were the same, and for the incompatible trials, when stimulus and response grips were different. The red trace plots the grand average for compatible trials, the blue trace plots the grand average for incompatible trials and the black trace plots the difference of the two.

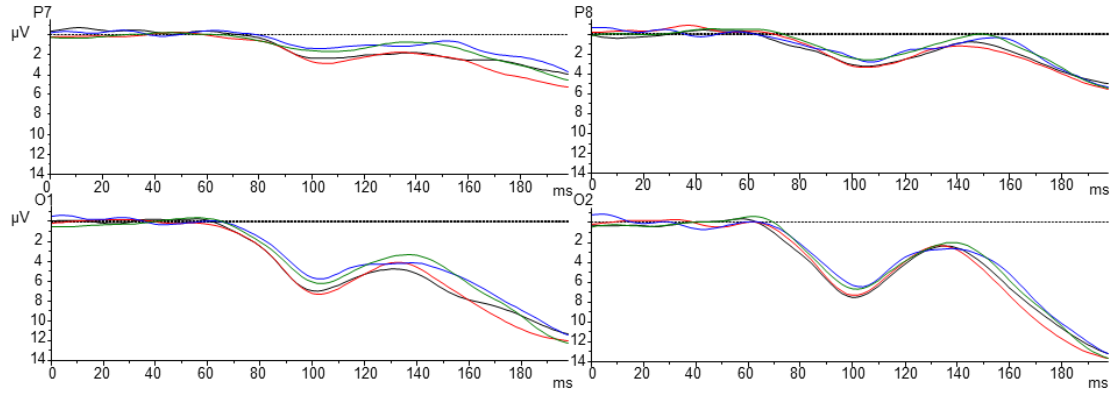



*Figure 10.* Depicting the activity on sensors P7, P8, O1 and O2 for visual P1 and N1. The black trace plots the data for power-grip objects with power-grip responses. The red trace plots the data for power-grip objects with precision-grip responses. The blue trace plots the data for precision-grip objects with power-grip responses. The green trace plots the data for precision-grip objects with precision-grip responses. Unlike the previous experiment, ANOVA revealed no effects of compatibility in P1 or N1, and only main effects of object category.

*ERP data*

Average ERP amplitudes were calculated for the visual P1 from 70 to 100ms and N1 from 120 to 170ms after stimulus onset, depicted in figure 10. Repeated measures ANOVA was used with factors of object size (power vs precision), response (power vs precision), electrode hemisphere (left vs. right) and electrode position (parietal vs. occipital).

Analysis of P1 revealed no compatibility effects, unlike the previous experiment. Analyses of P1 did reveal a significant main effect of object category ($F$ (1,24) = 7.903, $p$ = 0.010), which is unsurprising considering the variation in the stimulus sets. A main effect of electrode position ($F$ (1,24) = 76.235, $p$ < .001) was observed, indicating a preference for occipital sensors. Perhaps most interesting was a main effect of response (F *(*1,24) = 5.074, $p$ = 0.035), supporting the idea advanced in Symes et al. (2008) that maintaining particular grips affects the perception of object stimuli. No significant interactions were found that would indicate any compatibility effects in P1. No effects of mapping were found (all $p$'s < .141).

Analysis of N1 also failed to reveal any compatibility effects. However a main effect of response was also found in N1 ($F$ (1,24) = 7.487, $p$ = 0.012), lending further support to the idea that response (and the actions they cause participants to prepare) affects object perception, just as suggested by Symes et al.'s (2008) visual search task. A significant effect of electrode hemisphere was also detected ($F$ (1,24) = 7.525, $p$ = 0.012), indicating greater activation in the left hemisphere. A significant effect of electrode position was also detected ($F$ (1,24) = 15.921, $p$ = 0.001), which showed greater activation on occipital sensors than parietal.

#### *4.3.4 Discussion*

The typical RT effect was observed, in line with Ellis and Tucker (2000) and Tucker and Ellis (2001), indicating faster responses when stimulus and response shared grip-type characteristics compared with when they did not. A matching compatibility effect was observed in LRP from 225-400ms, with compatible responses eliciting greater negative amplitudes than incompatible responses. This signals rapid activation of motor cortex when viewing affording objects. These results support the typical interpretation that SRC affordance effects represent motor facilitation by overlap between action characteristics (i.e. affordances) of SR pairs.

However, no compatibility effects were detected in visual components, questioning the assertion from Ellis and Tucker (2000) and others that grip-type compatibility effects represent visuomotor processing. When examining visual and motor activation during the task, no effect of compatibility was observed in P1 or N1 where they were observed in the lateralised SRC affordance experiment (one). That said, a main effect of response was detected in both P1 and N1 which recalls the findings from Symes et al. (2008) who used the same response devices as the present experiment and demonstrated that visual search is speeded when the target object shares a grip-type affordance with the response device.

This was suggested to indicate a two-way relationship between vision and action where vision guides action but is also guided by action. In the present experiment and in Symes et al. (2008) participants maintained grips throughout the experiments, holding the response devices which kept the grips stable throughout. This begins to offer a potential explanation for the observed differences; the main effect of response in the visual data may represent a marker of the role of the response in shaping perception of the objects. Although at this stage this is conjecture, it represents a credible explanation based in similar research and questions why the role of response has not received greater attention in previous treatments of SRC, which typically tend to focus on the relationship between stimulus and response without considering the physical aspects of response.

### *4.4 Chapter discussion*

Both experiments demonstrated the typical SRC affordance effect that is familiar from the behavioural literature. When stimulus and response were similar, RTs were shorter than when stimulus and response were dissimilar for both affordance classes. However, unexpected differences were observed between experiment one and two. Although both experiments demonstrated the typical SRC affordance effect in RT, the electrophysiological data revealed quite different timecourses in motor cortex and very different results in visual cortex.

The lateralised affordance experiment elicited an LRP effect 125ms sooner than the grip-type affordances, at 100-200ms compared to the grip-type experiments 225-400ms effect. This indicates a potential difference in terms of how these different affordance classes were handled. Lateralised affordances elicited motor effects more rapidly than grip-type affordances and the duration of the effect was shorter. The visual effects were also very different, with the lateralised experiment detecting effects of compatibility (an interaction between response and handle orientation) in both P1 and N1 but the grip-type experiments detecting no compatibility effects in these components. Instead, grip-type affordances yielded an effect of response in P1 and N1 that did not interact with the action possibilities contained within the stimuli to yield a compatibility effect.

Two possible explanations present themselves. The different findings may be due to the different SR relationships, with grip-type SR pairs representing a continuum of size and lateralised SR pairs representing a binary choice between left and right. That said, response devices ensured that participants' grips remained the same throughout the grip-type experiments and the grips required to interact with the stimuli were deliberately unambiguous and based on common household objects, effectively making this a binary choice in practical terms. An alternative view was introduced above; perhaps the response was affecting the perception of the stimuli in the way demonstrated by Symes et al. (2008), who showed that visual search times are reduced when participants prepare a grip that is compatible with the target object. This argument is supported by the main effect of response in P1 and N1 in the grip-type stimuli, which indicates that responses were affecting the earliest stages of processing the visual features of the stimulus. Maintaining the response grip activates the neuronal populations that would support the affordance, which is merely a sub-threshold preparation of the action that is compatible with the object and this may explain the differences between grip-type and lateralised results in terms of their responses.

That said, before this may be discussed further it is important to confirm that observed differences are accurate because they were observed using two separate samples of participants. This leaves open the possibility that these findings were due to the samples so experiments three and four will attempt to expand on this by conducting two similar experiments using one sample in order rule out this possibility and also to confirm the findings of experiment one and two.

## *5. Chapter five*

## *The effect of masking on the EEG timecourse of object affordance*

### *5.1 Outline*

The experiments from chapter four demonstrated some unexpected differences between grip-type and lateralised affordances in terms of the latency of motor effects and the presence of visual P1 and N1 effects, which is surprising considering the equivalent behavioural facilitation demonstrated by both classes of affordance in behavioural studies. Understanding these differences motivates the present chapter, which aims to explore the differences using a backward masking paradigm and a single sample. Using a homogenous sample allows us to rule out the possibility that differences between affordance classes observed in experiments one and two were due to individual differences. More interestingly, the use of backward masking will allow these experiments to probe the differences observed in chapter four by determining whether the negative compatibility effects observed in RT in the literature will be reflected in LRPs or ERPs. As we shall see, backward masking experiments have offered some of the only evidence suggesting fundamental differences in the processing of affordances in lateralised and grip-type SRC experiments, making it an ideal paradigm with which to examine the differences between lateralised and grip-type SRC.

Of the limited evidence to explain the differences observed between affordance classes in chapter four, one indication of a difference may be drawn from the behavioural literature by comparing the findings of Tucker and Ellis' (2004) masked grip-type study with Vainio et al.'s (2011) lateralised study with briefly presented objects and Koch's (2009) masked lateralised study:

Tucker and Ellis (2004) used the same sort of grip-type stimuli and response devices as experiment two, Ellis and Tucker (2000), Tucker and Ellis (2001) and Symes et al. (2008).

They presented these stimuli in a backward masked SRC paradigm, with masking appearing at various stimulus onset asynchronies (SOAs) of 20ms, 30ms, 50ms, 150ms and 300ms. They found only a non-significant trend towards negative compatibility at the shortest (20ms) SOA, however all other SOAs (30ms, 50ms. 150ms & 300ms) indicated a typical compatibility effect. This is in sharp contrast to Vainio et al. (2011) who employed a brief presentation paradigm with lateralised SR pairs, similar to the stimulus from experiment one and Tucker and Ellis (1998). Vainio et al. (2011) observed a negative compatibility effect at SOAs of 30ms, 70ms and 170ms. Indeed only at their longest SOA (370ms) did Vainio et al. (2011) detect a typical, positive compatibility effect. It is important to note that Vainio et al. (2011) suggest that their negative compatibility effect may be partially explained by the use of a brief presentation procedure instead of a backward-masked, brief presentation procedure, citing Koch (2009) to suggest that backward masking might elicit a weaker negative compatibility effect, or possibly none at all. Koch (2009) conducted a mixed dual-task and single-task paradigm, however only the single-task results are relevant here. They found no compatibility effect in their lateralised, backward-masked, single-task blocks, indicating that no RT effect may be detected with the present use of backward-masking. On blocks with strong crosstalk with audio signals they did find a compatibility effect, however there are no such audio signals in the present experiments so it is difficult to make predictions on the RT effect for masked, lateralised affordance SRC given the mixed findings in the literature. Nonetheless, that these different affordance classes would produce opposite or different behavioural compatibility effects at similar SOAs supports the suggestion from experiment one and two that processing grip-type and lateralised affordances may elicit different processes. Whilst these findings do little to specify these different processes, they do support the rationale to investigate them and suggest backward masking as a method to do so.

Based on the differences between affordance classes presented in Tucker and Ellis (2004), Koch (2009) and Vainio et al.'s (2011) masked experiments, this chapter will present backward masked versions of experiments one and two whilst using a single sample. This is intended to explore the differences between affordance classes observed in experiments one and two by following the example of the masked experiments by Tucker and Ellis (2004), Koch (2009) and Vainio et al. (2011), who also found quite different effects with different affordance classes. Backward masking is a good paradigm for this because Tucker and Ellis (2004), Koch (2009) and Vainio et al. (2011) showed roughly opposite effects with grip-type and lateralised affordances, with Tucker and Ellis (2004) detecting a positive compatibility effect at most SOAs and Vainio et al. (2011) detecting a negative compatibility effect at most SOAs and Koch (2009) failing to elicit any RT effect. This suggests that backward masking these experiments will elicit different behavioural effects and therefore offer insight into the different LRP and VEP effects elicited by different affordance classes. The two experiments will be presented separately for clarity, however it is important to note that the order in which they were presented to participants was counterbalanced and that no order effects were observed ($p < .4$).

*Determining backward-masking SOA*

The differences observed by Tucker and Ellis (2004) and Vainio et al. (2011) at similar mask SOAs appear to be factors of the stimuli, so the different SOAs used in these experiments become an important constraint for the present chapter, which seeks to elicit this difference again at the same SOA for both affordance classes, whilst recording ERPs. Tucker and Ellis (2004) found a typical SRC affordance effect at all SOAs over 30ms suggesting that any SOA greater than that should elicit the typical effect. Vainio et al. (2011) found a negative compatibility effect at SOAs up to 170ms, with their only typical compatibility effect occurring at 370ms, indicating that any latency below 170ms should be sufficient to elicit the same effect. Together these studies establish an initial range of 30ms to 170ms for potential mask SOA. The other consideration for determining masking SOA in this experiment is the latency of the peaks in experiments one and two, with a goal of masking between the peak of the LRP effect in experiment one (approximately 150ms) and the onset of the LRP effect in experiment two (200ms) in order to examine any differential effects on RT and LRP effects from the previous experiments and from each other. This was achieved with reference to VanRullen and Thorpe (2001), who demonstrated that visual stimuli produced detectable ERP differences 75ms after stimulus onset. This is supported by Tucker and Fitzpatrick's (2006) comparative study that used intracranial recording to find that visual information became available in visual cortex 50-75ms after stimulus onset. Tovée (1994) also supports this, showing that the early stages of visual processing take roughly 20-40ms per stage, putting the earliest activity in visual cortex at around 60-80ms. Finally the visual effect observed in the previous experiments commenced at around 80-90ms. This convergent evidence suggests that masking at between 90ms and 100ms should lead to masking disrupting the processing of the affording stimulus from 160-200ms. Given the 75Hz monitor refresh rate this yields a mask onset in the middle of this estimate at 94ms, meaning the stimuli in both experiments were displayed for seven frames before ceding to the mask. As will be demonstrated, the success of this procedure was confirmed by the LRP effect becoming nonsignificant at 150ms, shortly after the peak of the effect in experiment one.

## *5.2 Experiment three – masked, lateralised affordance SRC*

### *5.2.1 Introduction*

This experiment sought to examine the timecourse of neural events underpinning a masked, lateralised affordance SRC experiment. The findings of Vainio et al. (2011) predict a negative compatibility effect for these lateralised SR pairs, however there is insufficient data to predict how this will translate into the LRP and visual effects. Also, as discussed above, Koch (2009) found mixed results with backward-masked lateralised stimuli, suggesting that no compatibility effect may be detected with the use of the present backward-masking procedure. The same sample was employed in the present experiment and in the following one, ensuring parity between experiments and allowing a comparison of the affordance classes employed in each experiment in order to explore the notion that different neural events underpin the processing of different affordance classes.

### *5.2.2 Method*

*Participants*

33 participants (14 male) the University of Plymouth took part. All were right handed, aged 18-28 (mean = 22, *SD* = 2.70), with normal or corrected vision and no known history of neurological problems. Three participants were removed from the analysis due to problems with the recording or excessive artefact, defined as greater than 35% of segments rejected due to ocular, muscular or other artefact. This was determined as 35% of segments across both experiment three and four, which used the same sample in two different paradigms.

*Stimuli*

To ensure parity between experiments, participants viewed the same lateralised affordance stimuli as in experiment one and the same grip type affordance stimuli as in experiment two. There were also 44 masks of coloured Gaussian noise with similar colour distributions to the images of affording objects used to backwards mask the stimuli.

*Procedure*

Participants completed a masked version of the lateralised affordance experiment seen in experiment one. Participants were asked to make the same categorical judgement to the same stimuli with the same response. The central difference is that each stimulus was backwards masked by coloured Gaussian noise. These masks were generated based on the overall colour distribution in the stimuli to minimise artefact from colour changes in the stimuli.

Trials were structured as depicted in figure 11 and as follows; a fixation cross appeared on the screen for 1000-1200ms including a jitter, followed by the stimulus image for 94ms. The stimulus then ceded to the mask for 1900ms, followed by a blank screen for 1000ms and finally by a blink symbol (described in experiment one) for 1400ms. Overall, trail duration remained the same as in experiments one and two and total trials were the same at 252 trials per participant, presented in a randomised order over three blocks.

A single response mapping was used, in which participants made a left handed button press to kitchen items and a right handed button press to tools. This was a practical consideration to prevent participants becoming fatigued over the course of a long experiment containing two full SRC paradigms and was deemed acceptable because experiment one revealed no mapping differences.

EEG Acquisition

Continuous EEG was recorded using 64 actively amplified electrodes, (ActiCap, Brain Products GmbH) arranged in a montage conforming to the 10/10 system consisting of FP1, FP2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C3, T8, FCz, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, Rc, O1, Oz, O2, Rvb, AF7, AF3, AF4, AF8, F5, F1, F2, F6, FT9, FT7, FC3, FC4, FT8, FT10, C5, C1, C2, C6, TP7, CP3, CPz, CP4, TP8, P5, P1, P2, P6, PO7, PO3, Poz, PO4, PO8. The EEG was digitised at a sampling rate of 2500Hz and amplified using a Brain Products MR Plus amplifier. As before EOG was recorded at Rc and Rvb for excluding segments with oculomuscular artefacts. Electrode impedances were maintained below 20KΩ.

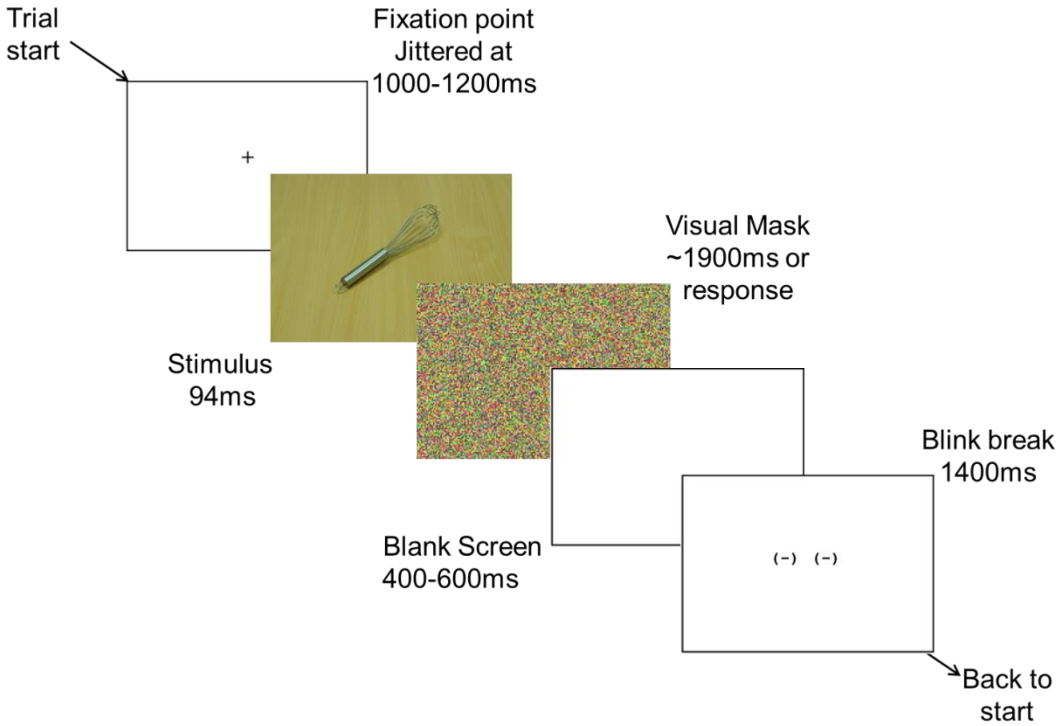



*Figure 11.* Visualisation of timecourse of trials in experiment three. Each pane represents a change in the display. Each trial consisted of five such changes and lasted up to a maximum of 5194ms and was repeated 84 times per block for three blocks for experiment four and 96 times per block for three blocks for experiment five. Detailed in the procedure.

*ERP Analysis*

Using Brain Vision Analyser 2 (Brain Products GmbH) the data were filtered with a 0.1-40Hz Butterworth filter and a notch filter at 50Hz to remove mains noise. The data were then re-referenced offline to a reference consisting of the average of the left and right mastoid, and a 200ms baseline correction was applied. An automatic artefact rejection procedure was conducted on all of the segmented data from scalp and EOG electrodes using an inbuilt module in Brain Vision Analyser 2. The artefact rejection procedure used an amplitude criterion range of -100µV to 100µV and a gradient criterion of 50µV/ms and was manually checked for all participants to ensure that no good segments were removed and that no bad segments were present in the averaged data. Segments were defined as intervals from -200 to 600ms.

### *5.2.3 Results*

*Behavioural*

Participants correctly categorised 93.7% of stimuli, so the global error rate was 6.3%. As in experiment one, RTs shorter than 200ms or greater than 1200ms were excluded in order to remove any accidental responses or outliers, resulting in 48 correct trials being excluded across the entire sample. Mean RT for compatible trials was 435.67ms and for incompatible trials was 438.66ms. Repeated measures ANOVA was conducted with within-subjects factors of object lateralisation (left vs. right) and response (left vs. right). No significant effects were detected for Object lateralisation ($F$ (1,29) = .885, $p$ = 0.355), response ($F$ (1,29) = .005, $p$ = 0.944) or the interaction ($F$ (1,29) = .084, $p$ = 0.774).

No significant behavioural compatibility effect was observed, similar to the findings from the single task, low crosstalk condition from Koch (2009), which consisted of a backward-masked, lateralised affordance SRC task. This is in line with the suggestion from Vainio et al. (2011) that backward masking may not elicit a behavioural effect with lateralised stimuli, whilst their brief presentation (without backward masking) at similar SOAs elicited a negative compatibility effect in RT.

*LRP data*

LRPs were calculated separately for compatible and incompatible trials using the Coles (1989) derivation, as detailed above. The compatible LRP was calculated as C4 minus C3 for objects with a left orientated handle that required a left handed response and C3 minus C4 for right orientated handles and right handed responses. The incompatible LRP was

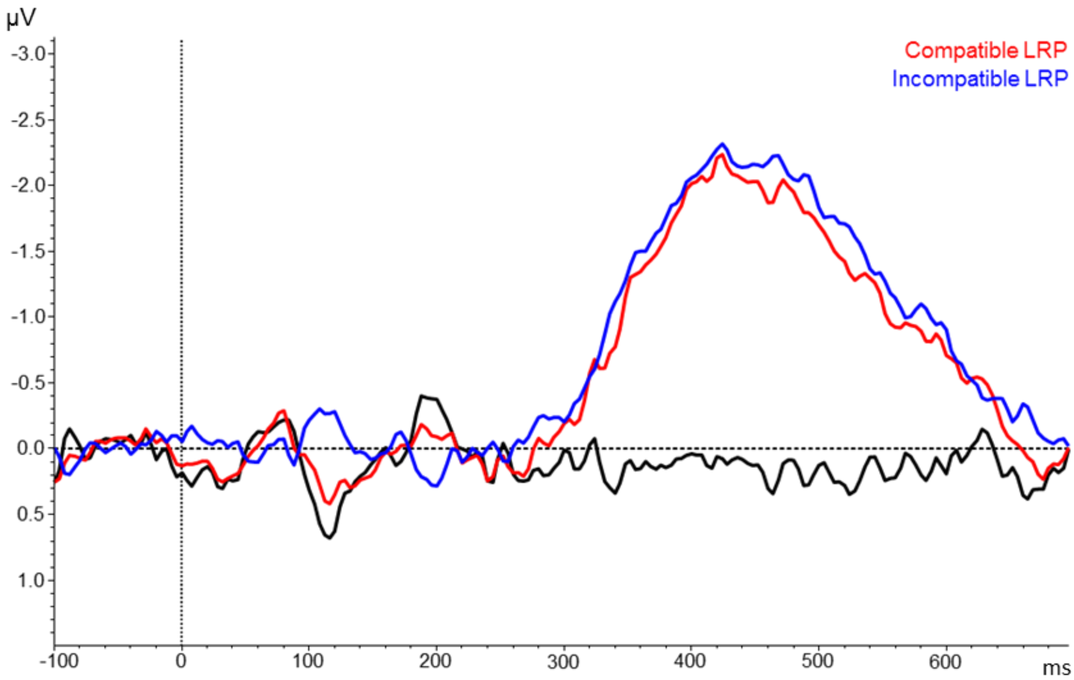



*Figure 12.* LRP results for masked, lateralised experiment three. The LRP's were calculated separately for the compatible trials (when the handle on the stimulus was orientated in the same direction as the button press) and for the incompatible trials (when the handle was orientated in the opposite direction to the button press). The compatible wave is marked in red and the reversed compatibility effect is visible from 100-200ms by the positive inflection in the compatible wave and the negative inflection in the incompatible (blue) wave, a reversal of the effect from the unmasked experiment.

calculated as C4 minus C3 for left handed responses to right orientated objects and C3 minus C4 for right handed responses to left orientated objects. As in previous experiments, these calculations will result in a positive going waveform for incompatible response hand and a negative going waveform for the preparation of the compatible response hand. The LRP was analysed in five 100ms epochs at 100ms intervals from 0-500ms. Based on the timing of the masking procedure and visual inspection of the waveform, a sixth epoch was defined from 100-150ms and a seventh from 150-200ms. In order to control the familywise error rate across these seven comparisons, a Bonferroni correction was applied (0.05/7), generating an alpha criterion of $\alpha = 0.0071$. The LRP is depicted in figure 12.

ANOVA was conducted with a factor of compatibility (compatible vs. incompatible), revealing a single significant effect from 100ms to 150ms ($F(1,29) = 9.524$, $p = .004$) with a positive going peak in the compatible LRP for this time period indicating the preparation of the uncued response hand, the opposite effect as that detected in previous experiments. This is remarkable considering the lack of a behavioural effect for this experiment, suggesting that LRP effects do not *necessarily* produce a behavioural effect and that intervening factors –such as the backward mask– can disrupt the production of a behavioural effect, even when the affordance having already elicited corresponding visuomotor activity. The 100-200ms effect from the previous experiment was not significant ($p = .325$) however this is due to the masking procedure interrupting motor processing during this epoch as intended; the 150-200ms epoch was analysed following the significant effect from 100-150ms (i.e. before backward-masking interrupted visual processing) and revealed no significant effect ($p = .601$), indicating that the masking procedure was interrupting visual processing as described in the experimental introduction.

Additional tests were conducted over the same time period (100ms to 150ms) using a one-sample t-test to determine whether the experimental conditions were statistically different from zero, to determine the source of the effect; compatible trials were found to be significantly different from zero ($t(29) = 2.790$, $p = 0.009$) and incompatible trials were not found to be statistically different from zero ($t(29) = -1.238$, $p = 0.226$). This suggests that the source of the effect is the deviation from baseline of the wave for compatible trials, with incompatible trials remaining at baseline levels until response. This indicates that backwards-masking procedure elicited the suppression of the compatible preparation.

*ERP data*

Figure 13 shows average ERPs across parietal electrodes P7, P8 and occipital electrodes O1 and O2. Average ERP amplitudes were calculated for the visual P1 from 70-120ms and for N1 from 120-170ms. Repeated measures ANOVA was employed with factors of Response hand (left vs. right), handle orientation (left vs. right), electrode hemisphere (left vs. right) and electrode position (parietal vs. occipital).

For P1, a main effect of electrode position was observed ($F$ (1,29) = 4.769, $p$ = .037) that indicated greater amplitudes on occipital sensors than parietal. The only compatibility effect observed in P1 occurred in a three-way interaction of electrode hemisphere, handle orientation and response hand ($F$ (1,29) = 22.808, $p$ = .017), indicating a compatibility effect in P1 was restricted to the left hemisphere only. No further significant effects were detected.

For N1, main effects were detected for electrode hemisphere ($F$ (1,29) = 5.950, $p$ = .021), indicating a left hemisphere preference overall. A main effect of electrode position ($F$ (1,29) = 57.129, $p$ < .001) indicated greater amplitudes on occipital electrodes than parietal. A Main effect of response hand ($F$ (1,29) = 6.102, $p$ = .020) was also detected, suggesting that prepared responses were affecting the viewing of the stimuli, as suggested following experiment two. The main effect of response hand interacted with the main effect of electrode position ($F$ (1,29) = 12.330, $p$ = .001), indicating greater occipital activity associated with the effect of response hand. The only compatibility effect detected in this analysis interacted with electrode hemisphere in a three way interaction of electrode hemisphere, handle orientation and response ($F$ (1,29) = 7.714, $p$ = .010). No other significant effects were detected. It is noteworthy that the main effect of response hand was detected in N1, in line with the suggestion from the grip-type experiment of a link between early visual processes and available action possibilities.

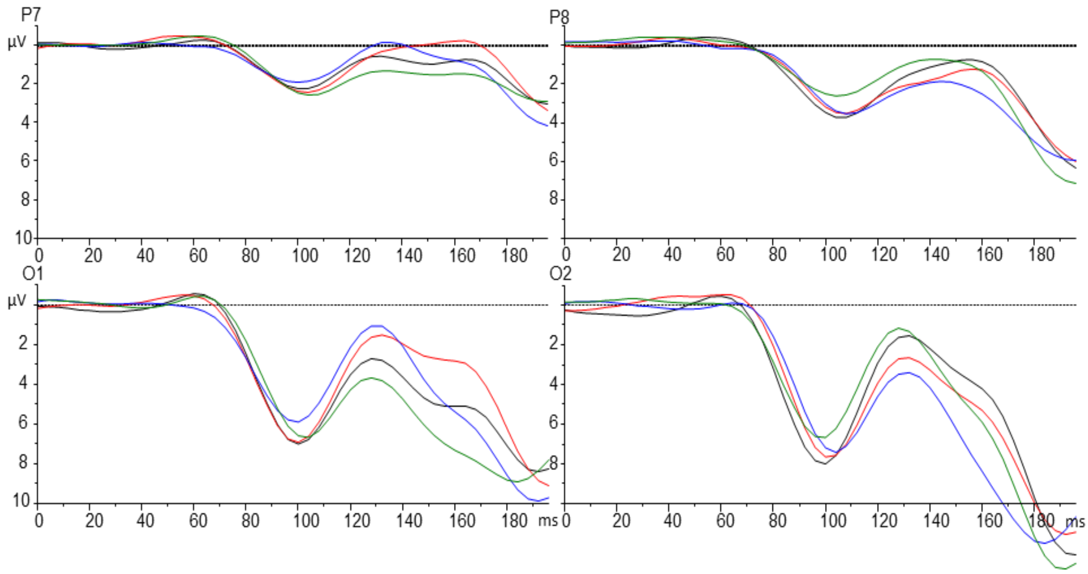



*Figure 13.* Averaged ERPs for electrodes P7, P8, O1 and O2 for visual P1 and N1. Separate waveforms are displayed for each combination of handle orientation and hand of response. The black trace plots left-lateralised kitchen object and left handed responses. The red trace plots right-lateralised kitchen object and left handed responses. The blue trace plots left-lateralised tool object handles and right handed responses. The green trace plots right-lateralised tool object handles and right handed responses.

*5.2.4 Discussion*

The backward-masking procedure elicited quite different results compared to experiment one. This experiment found no effect in RT and a reversal of the LRP effect from experiment one, demonstrating a dissociation of afforded motor preparation and response. A compatibility effect was again detected in P1 and N1, however in this experiment it was only significant in an interaction that indicated the compatibility effect was restricted to the left hemisphere.

As discussed in the introduction, it was difficult to make predictions on the direction of the behavioural effect given limited evidence that showed different effects with different affordance classes, as well as different effects with briefly presented and briefly presented backward-masked stimuli. Vainio et al.'s (2011) brief presentation lateralised SRC affordance experiment demonstrated a negative compatibility effect in RT (i.e. same direction as present LRP) however as they cautioned in their study, Koch (2009) failed to demonstrate the same effect when backward-masking lateralised affordance SRC. The present RT data fit with Koch (2009), not obtaining a behavioural compatibility effect with masked, lateralised SRC and so supporting Vainio et al.'s (2011) suggestion that backward-masking brief presentations has an additional effect compared to brief presentations alone, with the mask apparently 'overwriting' the stored visual information in the absence of the stimulus. This did not seem to occur in Vainio et al.'s (2011) experiments, where instead they detected a reversal of the effect which was interpreted as representing the suppression of the affordance effect in the absence of the affording stimulus. Although this was not the focus of the experiments, it is interesting nonetheless.

The reversed LRP effect (compared to experiment one) mirrors the negative compatibility effect found in Vainio et al.'s (2011) RT data, but did not yield any behavioural effect in RT. The reversal of the LRP effect is similar to Koski et al. (2005), who demonstrated reversed LRP effects when TMS pulses interrupted processing 200ms after stimulus onset, similar to the present masking procedure. This provides a novel demonstration of a dissociation of afforded motor activation and behavioural output and this dissociation was caused by the masking procedure. Indeed the only difference between experiments one and three was the use of the backward-masking procedure, with all other factors remaining the same. So, the backward-masking procedure was sufficient to overwrite the action-relevant information and produce a null effect, in line with Koch (2009). This supports the suggestion from Vainio et al.'s (2011) brief presentations, which still yielded a negative compatibility effect in RT because the action-relevant information was still able to exert an influence in the absence of a new, visually complex stimulus that was without action information (i.e. the mask). The idea of the mask overwriting the action-relevant information is supported by the LRP effect becoming nonsignificant at 150ms in this experiment, just as the mask was intended to be detectable in ERP (*cf.* VanRullen & Thorpe, 2001; Tucker & Fitzpatrick, 2006). This also indicates that the masking procedure was working as intended. Overall, the 100ms LRP effects in experiments one and three suggest that the motor activity detected from 100ms in LRP does represent an effect of the afforded action, but that this is subject to change by, for example, a backward masking procedure, speaking to the notion of affordances as rapidly and automatically generated in order to aid real-time actions, but also as decaying rapidly too (e.g. Hommel, 1994a; 1994b; Ellis & Tucker, 2000).

Examining figure 5 and figure 10, the direction of the compatibility effects in P1 and N1 appears overall to be the same as in experiment one despite only being significant in left-hemisphere. The left-hemisphere locus of these effects recalls the networks proposed by Cisek (2007) and Johnson-Frey, Newman-Norlund and Grafton (2005) that suggest that planning tool use and other object-directed behaviours elicits predominantly left-hemisphere activity (discussed in detail in chapter three). The detection of a left-hemisphere bias in these early effects speaks to the idea advanced above that compatibility effects in P1 and N1 may represent a previously unreported action-sensitivity in these early components, recommending a reconsideration of the factors affecting P1 and N1 amplitudes. Moreover, the P1 and N1 effects have consistently demonstrated stronger activation over occipital electrodes, recommending reconsidering the role of occipital cortex in action planning and object directed behaviour, because that region is conspicuously absent from Cisek (2007) and Johnson-Frey et al.'s (2005) networks.

### *5.3 Experiment four – masked, grip-type affordance SRC*

#### *5.3.1 Introduction*

As described above, this experiment used the same presentation parameters and the same sample but with a different affordance class, using grip-type SR pairs instead of lateralised. This is in order to assess whether the differences observed between LRP, P1 and N1 effects in experiments one and two were real differences or by-products of the samples used. It is also intended to help elucidate the differences between masked grip-type studies (e.g. Tucker & Ellis, 2004) and masked lateralised studies (Koch, 2009) or brief presentation lateralised studies (e.g. Vainio et al., 2011). So, as above, this experiment was a masked version of experiment two, with identical presentation parameters other than the masking procedure. The use of the same sample from masked lateralised experiment three also allows for direct comparisons of the effects.

### *5.3.2 Method*

#### *Participants*

To ensure parity between experiments, the same sample was used as in experiment three.

#### *Stimuli*

The same grip-type stimuli were used as experiment two. The masks were the same as experiment three.

#### *Procedure*

To ensure parity between experiments, the same procedure was employed as experiment three. The only difference was the use of the grip-type response devices from experiment two. With these devices participants completed a single response mapping, with power grips executed by the left hand and precision grips executed by the right hand. Three blocks of 96 trials saw a total of 288 trials.

#### *EEG Acquisition*

ERPs were acquired with the same montage and parameters as experiment three.

#### *ERP Analysis*

The ERP data were subjected to the same transformations and analyses as in experiment three.

### *5.3.3 Results*

*Behavioural results*

The global error rate was 6%, with participants correctly categorising 94.00% of stimuli. Mean correct responses for manufactured objects with a power response was 94.63% and for manufactured objects with a precision response was notably less at 88.89%. Mean correct responses for organic objects with a power grip was 95.56% and for organic objects with a precision response was 96.85%. ANOVA revealing no significant differences between conditions in the errors ($p$ = 0.474) but revealed a borderline significant effect of object category ($F$ (1,29) = 4.331, $p$ = 0.055). This reflects significantly more errors for manufactured objects, with manufactured objects eliciting 91.81% correct responses and organic objects eliciting 96.20% correct responses.

Global mean RT was 467.12ms, with mean RT for manufactured objects with a power response at 488.26ms, manufactured objects with a precision response at 527.63ms, organic objects with a power response 422.06ms and organic objects with a precision response at 430.53ms. Mean RT for manufactured objects was 507.94ms, considerably longer than for organic objects at 426.30ms. Power responses elicited a mean RT of 455.16ms and precision responses 479.08ms.

RM ANOVA was conducted using within subjects factors of object size (power vs. precision) and response (power vs. precision). This revealed significant main effects of object size ($F$ (1,29) = 102.419, $p$ < .001), indicating significantly longer RTs for manufactured objects, and response ($F$ (1,29) = 43.237, $p$ < .001), indicating significantly longer RTs for precision grip responses than power grip responses. A significant interaction of object size and response ($F$ (1,29) = 9.608, $p$ = 0.004) revealed a significant behavioural compatibility effect, with compatible trials eliciting a significantly faster response (mean RT 459.32ms) than incompatible trials (mean RT 474.85ms), indicating the typical behavioural compatibility effect, as predicted by Tucker and Ellis (2004) at this SOA.

*LRP Data*

LRP's were calculated as in experiment two and with the same analysis parameters as in the lateralised affordance LRP analysis. No significant differences were observed from 0-600ms (all $p$'s <0.19). This indicates that the masking procedure has effectively overwritten the motor activation by introducing new visual input to the visuomotor system. This overwriting may occur as part of the process of checking new visual input for action possibilities however this intuitively attractive idea is merely conjecture without further, better targeted investigation. Some support for this may be drawn from Ellis' (2009) characterisation of the visuomotor system as a tightly bound loop where a change in visual input before the development of the motor component may result in the apparent absence of an LRP effect.

*ERP Data*

Average ERP amplitudes were calculated for the visual P1 from 70 to 110ms and N1 from 110 to 160ms after stimulus onset. Repeated measures ANOVA was used with factors of object size (power vs precision), response (power vs precision), electrode hemisphere (left vs. right) and electrode position (parietal vs. occipital).

Analysis of P1 revealed no significant compatibility effects ($p$ < .513), similar to the earlier grip-type experiment, experiment two. Analysis revealed a significant main effect of response ($F$ (1,29) = 6.145, $p$ = 0.019), indicating that response, which in the grip-type experiments also constitutes a planned action, was influencing the earliest stages of visual

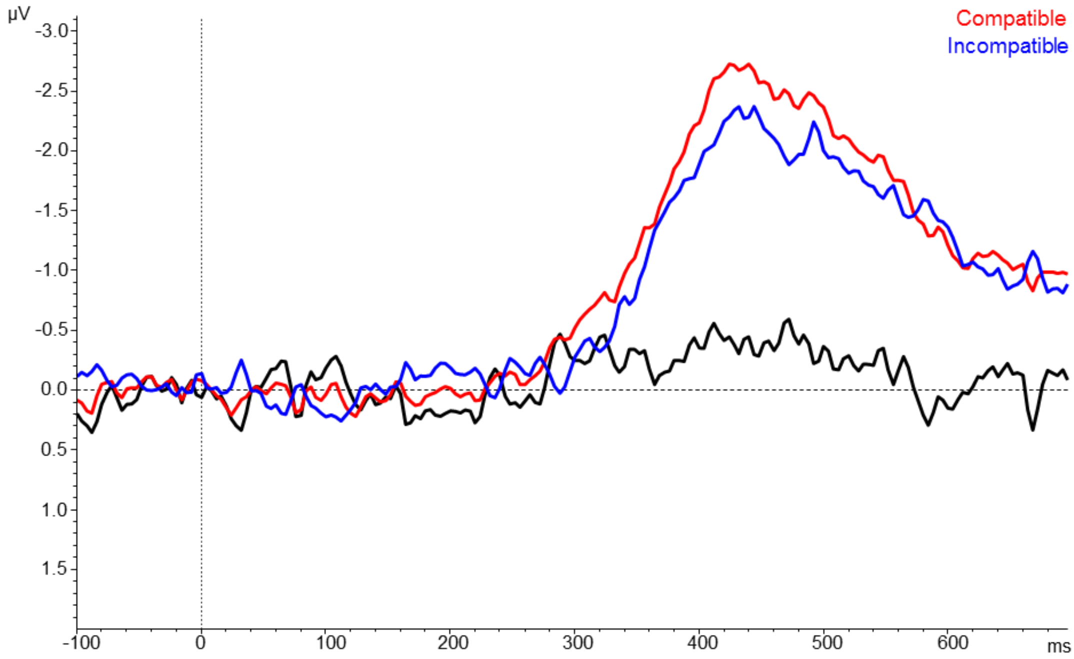



*Figure 14*. Plot depicts LRP for masked, grip-type experiment four in which no significant compatibility effects were detected from 0-600ms. The red trace plots the compatible trials, the blue trace plots the incompatible trials and the black trace plots the difference of the two. Experiment two used the same SR pair without masking and obtained a significant compatibility effect from 200-300ms, however no tendency toward such an effect was observed here.

perception as suggested by authors such as Symes et al. (2008). A main effect of electrode hemisphere ($F$ (1,29) = 7.349, $p$ = 0.011) was also detected, indicating greater right hemisphere activity. A main effect of electrode position ($F$ (1,29) = 51.568, $p$ < .001), indicating greater occipital activity overall. No interactions were detected in P1.

Analysis of N1 revealed no compatibility effects ($p$ < .375), similar to experiment two. ANOVA of N1 did reveal a significant main effect of object size ($F$ (1,29) = 4.926, $p$ = 0.034), similar to the previous experiment. A mean effect of response ($F$ (1,29) = 7.012, $p$ = 0.013) was detected, again showing that prepared actions affect the earliest stages of visual perception. A main effect of electrode hemisphere ($F$ (1,29) = 4.624, $p$ = 0.040) indicated greater activation on right-hemisphere electrodes and a main effect of electrode position

($F$ (1,29) = 56.320, $p < .001$) revealed greater activity on occipital than parietal sensors, similar to previous experiments. Only a single interaction was observed, object size interacted with electrode position ($F$ (1,29) = 7.596, $p = 0.010$) to indicate greater occipital amplitudes for manufactured objects than for organic objects.

### *5.3.4 Discussion*

This masked, grip-type experiment demonstrated the same typical RT compatibility effect as the unmasked grip-type experiment (two), in line with the predictions from Tucker and Ellis (2004). Also, like experiment two no compatibility effects were detected in P1 or N1. However it failed to demonstrate the LRP effect from 200-300ms observed in the previous grip-type experiment. This indicates that the masking procedure was affecting the processing of the motor information contained within the stimulus. As discussed above, Vainio et al. (2011) and Koch (2009) suggested that the use of a backward masking procedure will effectively overwrite the motor information contained within a stimulus in a way that does not occur with brief presentations and here it appears that the masking procedure resulted in no motor effect after the mask was intended to be detectable in ERP around 160-200ms (VanRullen & Thorpe, 2001; others discussed above).

No significant compatibility effects were detected in LRP throughout the experiment, indicating an effect of masking in terms of overwriting the visual action information gathered from the stimuli. When considering the typical RT compatibility effect detected in this experiment the lack of an LRP effect is particularly interesting, suggesting that something else must have enabled the RT effect that in the experiments so far has appeared to be a product of the LRP compatibility effect.

## *5.4 Chapter discussion*

The findings of the experiments in this chapter are remarkable, demonstrating a double dissociation of LRP and RT effects defined by the use of lateralised or grip-type affordances and supporting the differences observed between affordance classes in the previous chapter. The experiments in this chapter used a single sample to determine whether the implication from typical lateralised and grip-type affordance SRC experiments (one and two) in chapter four were due to the different affordances or due to the different samples used. These findings confirm and extend the findings from chapter four that suggested considerable differences in the way different affordances were processed. To reiterate, the masked, lateralised experiment three found a reversed LRP effect at 100ms, the familiar compatibility effects in P1 and N1 but failed to produce an RT effect. The masked, grip-type experiment four found the typical RT effect, but no compatibility effects in LRP, P1 or N1. These findings demonstrate that lateralised and grip-type affordances are handled very differently.

In lateralised experiment one and grip-type experiment two, LRP effects were detected at 100ms and 200ms respectively, so to probe these findings and confirm their veracity the present experiment masked at 94ms based on a variety of evidence suggesting that mask should be detectable in ERP from 160-200ms (e.g. VanRullen & Thorpe, 2001; and others, above), meaning it would be detectable between the peak of the LRP effect from lateralised experiment one and before the onset of the LRP effect in grip-type experiment two. The findings of experiment three and four confirm the differences observed in experiment one and two by showing that the masking procedure elicited different effects with each affordance class; lateralised affordances still showed a significant LRP compatibility effect from 100ms (although this time it was a reversed compatibility effect) but failed to show the subsequent RT effect. In contrast, the LRP effect for grip-type stimuli was not detected due to the masking procedure however the RT effect still emerged. This confirms that the latency difference observed in experiment one and two appears to be a genuine difference between affordance classes with behaviourally equivalent effects. The masked experiments also support the different visual effects observed in experiments one and two, with lateralised stimuli again eliciting compatibility effects in visual P1 and N1 but with neither grip-type experiment eliciting a compatibility effect in these components.

Perhaps the most surprising result was the double dissociation of LRP and RT effects over the two masked experiments.  In the experiments so far the LRP has varied with RT, with compatible trials eliciting a compatibility effect in both RT and LRP.  The co-occurrence of these two effects intuitively implied a direct link between them however the masked results call this into question.  Overall, the results of the masked experiments question automaticity; the lateralised experiments question automaticity because they failed to show the RT compatibility effect suggested to be automatic in the majority of behavioural affordance SRC studies (discussed throughout, *c.f*. McBride et al.'s, 2012 review), despite having demonstrated a significant LRP effect that *did* appear to be automatic because it arose when viewing objects to make a categorical judgement that bore no relation to action-relevant object properties.  However, the automaticity of the generation of an LRP effect was itself questioned by the failure of the masked, grip-type experiment to elicit an LRP effect.  This picture is further muddied by the significant RT effect in that experiment. The findings of the masked experiments question the notion of automaticity in affordance generation, an issue that has received minimal attention in the literature; Tipper, Paul and Hayes (2006) showed participants images of common affording objects (doorhandles) oriented to the left or right, with squared or rounded edges, depicted in either blue or green.  Participants made left or right button presses (compatible or incompatible with handle orientation) to deploy one of two categorical judgments; a colour judgement (blue vs. green) and a shape judgement (square vs. round).  They found no affordance effect when participants made the colour judgement but they did find an affordance SRC effect when participants made the shape judgement.  So despite viewing the same affording objects, participants only demonstrated automatic affordance generation with the shape judgement.  Similarly, Pellicano, Iani, Borghi, Rubichi and Nicoletti, (2010) demonstrated that categorical judgements affected whether they generated an affordance or a Simon effect.  Participants were asked to make a judgement on either the colour or the inversion of a stimulus, and an affordance effect was only detected when participants attended to the inversion of the stimulus and not when attending to the colour of the stimulus. Alongside the masked findings, these studies imply that automaticity may not be as robust as suggested in the behavioural literature.  The masked results question whether the LRP or RT effects could be described as automatic and the dissociation of the two raises an interesting question and one to which the answer may elucidate the differences between these affordance classes: How can the grip-type experiment show a motor effect in RT without detecting a motor effect in motor cortex to support the RT advantage?  This appears to go against previous experiments where the co-occurrence of the effects implied that the behavioural effect was a product of the LRP effect.  This view is intuitive, with the assumption that brain activity directly relates to behavioural output and the finding both RT and LRP varying together in both unmasked studies and there is little in the literature to choose between different sources of affordance or the automaticity of their effects.

One approach to the question of different sources of affordance comes from Derbyshire, Ellis and Tucker (2006), who suggested a distinction between intrinsic and extrinsic affordances.  They defined intrinsic affordances as those that are linked to invariant object properties such as the identity of an object and are an inextricable component of the size and shape of the object.  This means that when the object is imagined or described an agent will generate the affordance automatically because the affording properties are *intrinsic* to the objects form and/or identity.  This would include the grip-type stimuli used in experiments two and four.  Derbyshire et al. (2006) give the examples of peanuts or paperclips, which agents will know are small, lightweight objects that would be picked up with a precision grip.  In contrast, an extrinsic affordance is a variable object property that is not implicitly part of the object but instead comes from the way the object is positioned in relation to the viewer. So extrinsic affordances would not implicitly relate to a particular bodily state in abstraction in the way an implicit affordance would. This definition includes lateralised affordances, where the affordance is based on the non-object property of lateralisation, i.e. the relationship of object orientation with the agent. This distinction could attempt to account for the present data in two ways. Firstly, it might suggest that the grip-type stimuli elicit a later LRP effect because their affordance is intrinsically linked with the object identity. However, the compatibility effect in experiment two occurred at 200ms which is considerably earlier than object identification, which studies from Supp et al. (2005) or Van Elk, Van Schie and Bekkering (2010) have suggested occurs earliest at 280ms and is associated with the semantic N400 ERP component. The intrinsic vs. extrinsic dichotomy offers a second explanation by positing a different timecourse for intrinsic and extrinsic affordances; perhaps intrinsic affordances elicited a later LRP effect because the affordance was an implicit part of its shape and so was detected very rapidly and reflected in the main effects of object category detected in N1 for grip-type stimuli. This would reduce time pressure to extract the object affordance and prepare the afforded action. This would mean that LRP for grip-type stimuli would appear later and the lateralised LRP appeared earlier due to increased imperative to extract the orientation information. That said the lack of a compatibility effect in visual components for the grip-type stimuli undermines the notion that the grip-type affordances are being extracted at this stage, because main effects of response were also detected and these did not interact with object category in a compatibility effect in the way they did for lateralised stimuli. The lack of a compatibility effect in visual components for grip-type stimuli implies that whatever supports the RT effect is occurring further downstream, however the lack of an LRP effect for the masked grip-type experiment suggests that this is not occurring in motor cortex. These possibilities are discussed in greater detail in the general discussion.

Another potential explanation comes from considering the differences between the experiments. The lateralised SR pair is a binary pairing of left and right lateralised objects and left and right lateralised responses, whereas grip-type is continuous with no clear point at which a grip begins or ceases to be a power or precision grip. This offers a potential explanation because that ambiguity could explain the later LRP effects for grip-type affordances. However, in context of the present experiments the stimuli were selected so that there was no ambiguity in terms of what grip would be required to interact with each object, with clear differences between power and precision compatible objects. This means that even for grip-type stimuli the relationship between stimulus and response was still effectively binary. So, this practical concern for real-world object use is less informative in the present laboratory setting.

A key difference between the experiments is what participants were doing with their bodies during the experiments. As discussed in the introduction, embodied cognition holds that bodily states have a profound effect on cognition and relevant evidence for this comes from Symes et al. (2008), who demonstrated a large RT advantage in a visual search task when participants prepared the grip required to interact with the target object compared to when they prepared a different grip. This finding seems particularly pertinent to the present thesis, which used the same response devices that Symes et al. (2008) used to show that the grips participants used to hold the devices affected their perception of the affording object stimuli. This opens up another potential interpretation of the present data; perhaps the differences observed between grip-type and lateralised affordances are a product of the response devices employed and the effects they had on the perception of the stimuli? Indeed other studies such as Van Elk, Van Schie, Neggars and Bekkering (2010) have shown that action intentions affected visual N1 amplitudes, providing physiological evidence to support Symes et al.'s (2008) behavioural study. Supporting evidence for this proposition may be drawn from the main effect of response detected in grip-type stimuli in

N1 for grip-type experiments as well as for lateralised experiments. These main effects of response in early visual component N1 indicate that the responses (action intentions for lateralised experiments, prepared actions for grip-type experiments) were exerting an influence during the early stages of visual perception and support Symes et al.'s (2008) and Van Elk et al.'s (2010) findings. This focus on the response challenges the typical view on SRC affordance, which tends to focus on the stimulus as the critical part of the SR pair (e.g. Derbyshire et al., 2006 focuses on classifying stimuli without reference to responses) because that is what should elicit the affordance, however the current line of argument also suggests that the bodily states of participants may influence the visual interpretation of the stimuli. This fits with discussions such as Hommel et al. (2001) or Ellis (2009) as well as experiments such as Ellis and Tucker (1998) that suggest a two-way relationship between vision and action, where bodily states affect visual processes.

These potential explanations are not mutually exclusive and generate a complicated set of questions and predictions. One key question raised by both approaches is couched in the relationship of response to object; Derbyshire et al. (2006) suggest that extrinsic affordances such as the present lateralised affordances are contingent on a relationship with participants' bodily states (e.g. prepared responses) in order to afford an action. The suggestion that prepared actions affect what affordances are generated is also couched in the relationship in the SR pair. Each of these questions the notion of automaticity; Derbyshire et al.'s (2006) suggestion that extrinsic affordances are generated based on the relationship with the agent suggests that were there no relationship, an affordance may not be generated. Similarly, if the participant is not preparing an action then it will not shape the perception of the stimulus into yielding an affordance, also suggesting that response may affect automaticity. In order to address these differing potential explanations in a straightforward manner the following experiments will attempt to address this question directly, by removing the response from one experiment and manipulating the temporal proximity of the response to the affording stimulus in the other in an effort to address this fundamental question about a core assumption in the affordance literature, automaticity.

6. Chapter six

*Assumptions in the affordance literature*

*6.1 Outline*

The experiments so far have raised questions on the equivalence of different classes of affordance in terms of the visual, motor and behavioural responses that they elicit. The different combinations of effects observed over masked and unmasked affordance SRC experiments question the notion of automatic affordance generation because for some no effect was detected in RT and in others, no motor activity was detected to support a subsequent RT effect. In order to begin to tease apart the unexpected differences between grip-type and lateralised affordances the following experiments will examine the core assumption of automaticity by manipulating response and presentation parameters.

Having established that lateralised affordances consistently elicited an LRP effect from 100-200ms this chapter will use this LRP effect to investigate the assumption of automaticity. It will focus on lateralised affordances over grip-type affordances because the LRP effect for grip-type affordances was not obtained in the masked experiment, implying a greater difference between lateralised and grip-type affordances than may have been previously predicted. Although the difference between lateralised and grip-type affordances is certainly interesting, a full explanation of the differences is beyond the scope of this thesis which nonetheless provides a novel indication of the differences in processing affordance classes. So, this final experimental chapter will use the visual and LRP findings from previous experiments to check two core assumptions in the behavioural literature that have so far gone unaddressed, primarily because behavioural investigations would be unable to offer conclusions on them. The first assumption is automaticity; that viewing objects is sufficient to yield preparation of the actions that they afford, even in the absence of the intention to act on the objects. This assumption may be traced back to Gibson's (1979) early treatments on affordance which state this is part of the core concept of affordance, however little or no direct evidence of this has been demonstrated. Most evidence for this has been indirect, being drawn from speeded RT to matched SR pairs however this does not preclude the possibility that the forced-choice, bimanual responses may affect the way the simple binary SR pairs are perceived. This is not outlandish, because the literature is peppered with examples such as Symes et al. (2008) or Lindemann and Bekkering (2009) (discussed above) who found that not only does viewing objects prepare actions but also preparing actions affects object perception. This chapter will assess this claim by determining whether merely viewing objects in a go, no-go paradigm will yield the same LRP effect as in experiment one. This is of course unavailable to behavioural investigations because if the participants do not make a response, there is no behavioural data to collect but when using LRPs, data may be collected without response allowing us to see whether merely viewing the same stimuli will elicit the same preparation as experiment one.

The second assumption also relates to automaticity. It is universally assumed that the categorical judgement does not exert an influence on the generation of these affordance effects and indeed the choice of categorical judgement is intended to demonstrate automaticity because participants are asked to make their judgements on object characteristics that are not action-relevant, allowing authors to claim for automaticity because the action-relevant object properties were not task relevant. This has been implicit in almost all affordance research to date, however Tipper et al. (2006) and Pellicano et al. (2010) have demonstrated that whilst a category judgement will elicit an affordance effect with affording stimuli, a colour judgement will not. This is attributable to a levels of processing type argument, where colour judgements do not require sufficiently deep processing to elicit the affordance, but this in itself implies that perhaps merely viewing an object is not sufficient to elicit its affordance. In order to assess both assumptions, experiment six will attempt to separate categorical judgement and response in a novel, two object version of the SRC paradigm.

The nature of the experiments in this chapter mean that trial durations will be longer than in previous experiments, so in order to accurately assess the claim, as well as to control for multiple comparisons, the literature and previous experiment will be considered to provide a priori temporal constraints on epochs for analysis. Due to the nature of these assumptions the first 500ms of any trial will be of primary interest, chiefly because these are questions of motor preparation and not of response execution. Chapter three saw a body of evidence presented that showed that motor preparation occurs well before 500ms, which incidentally has been roughly the mean RT for lateralised experiments in this thesis as well as in the literature. For example, Grezes et al. (2003) found mean RTs of approximately 560ms with others clustered around it, such as Ellis and Tucker (2000) who found 380-435ms RTs or Tucker and Ellis (1998) who found mean RT of 600-630ms. The RTs in the present thesis fall within this range too. These RTs make for a sensible upper temporal boundary when assessing the above claims about affordance generation and motor preparation because these processes must occur before response deployment in order to have an effect.

Also supporting this upper boundary are the latencies observed in relevant electrophysiological investigations which indicate that action preparation/ affordance generation actually takes place well before 500ms, with this thesis indicating 100-200ms as the critical epoch. Examples from the literature include Proverbio et al. (2007) who found LRP and visual effects from 100-400ms and Hohlefeld et al. (2010) who found motor effects beginning at 120ms. Looking at older evidence with abstract stimuli, Osman et al. (1992) found effects from 100-300ms on go trials in their spatial compatibility go, no-go experiment and these findings were replicated by Miller and Hackley (1992). Eimer and

Schlaghecken (1998) also found motor effects from 100-400ms using abstract stimuli. Evidence from single cell recordings put motor preparation effects in a similar period, with Requin and Riehle (1995) finding a motor component from 113-173ms and Riehle, Kornblum and Requin (1997) found effects in two distinct populations of motor cortex neurons from 100-400ms. Also, Zhang et al. (1997) found motor effects at 160ms and 260ms. Converging evidence from the studies presented here as well as a variety of studies that used a range of electrophysiological measures have found effects commencing at around 100ms after stimulus onset. For that reason, the experiments in this chapter will not analyse beyond 500ms and seem unlikely to find effects before 100ms in LRP, though this epoch will be assessed.

## *6.2 Experiment five – lateralised affordance in a go, no-go paradigm*

### *6.2.1 Introduction*

This experiment sought to test the assumption of automaticity, which states that viewing an object is sufficient to elicit its affordance regardless of any intention to act on the object. In doing so, it also tested whether or not the affordance effect is contingent on a response being made. Put another way, this experiment sought to show that the SRC affordance effect is not contingent on the kind of forced choice manual response observed almost universally in SRC research and really is a product of the observed action possibilities and that the action preparation by observed action possibilities is not entwined with the preparation of a manual response. In turn, this will confirm that the LRP effect observed in the previous experiments is indeed a marker of the action possibilities contained within the viewed stimuli and is not merely detecting the preparation of the task-based response. Separating afforded and task-based action preparation is a challenge for studies of affordance, which have typically made deep claims about action preparation by seen objects by using paradigms that also entailed participants prepare and execute actions.

In order to assess the assumption of automaticity, this experiment used a novel variation on the SRC affordance paradigm. No behavioural responses were collected and instead a go, no-go format was used where participants made a categorical judgement on the stimuli that was declared verbally, but only for one category. A verbal response ensures no lateralised motor activity may interfere with the LRP. For the other category, no response was made. A go, no-go paradigm was chosen because it allows the monitoring of the LRP effect in the absence of any sort of response, i.e. by removing the motor response, we remove any motor preparation associated with response and so any observed motor activity is attributable to viewing the stimulus. Given the dissociation of LRP and RT effects in the masked studies, the go, no-go experiment will give direct evidence of what (if any) motor activity observed in LRP was due to the stimulus and what was due to the response. If the ERP and LRP findings from experiment one are replicated, it may be concluded that viewing objects gives rise to their affordance and this is not a product of the response. So, because this experiment is seeking to replicate the LRP effect observed in the previous experiments without having participants make a response, all other features must be the same as those used in experiment one to ensure parity between experiments. If the same 100-200ms effect is detected in the absence of the intention to make a motor response then it may be attributed to an effect of the handle affordance cuing motor cortex. If it is not obtained, then it may be concluded that the LRP effects observed in previous experiments represent an effect of overlap between visual input and motor preparation. This is a key point in understanding the nature of the LRP effects observed so far.

### *6.2.2 Method*

*Participants*

40 (25 male) students from the University of Plymouth were recruited. All were right handed, aged 18-28 (mean = 22, *SD* = 2.74), with normal or corrected vision and no known history of neurological problems. Ten participants were removed from the analysis due to problems with the recording or excessive artefact, defined as greater than one third of segments rejected due to ocular, muscular or other artefact. The verbal response was responsible for the high rejection rate due to muscular artefact, showing great individual variation in amplitude and causing most rejections.

*Stimuli*

Participants were shown the same colour images as in experiment one.

*Procedure*

The procedure from experiment one was replicated here, with two critical changes. Participants responded only to kitchen items by making the verbal response “kitchen” and tool objects required no response. As per experiment one, half of the trials consisted of tools and the other half of kitchen items. This format was chosen because tool stimuli elicited a stronger effect in experiment one. The other change was the use of a microphone connected to the response box used in experiment one. Participants completed a practice period of 15 trials up to three times in order that their responses were of sufficient volume to be detected throughout the experiment.

*EEG Acquisition*

EEG was recorded using the same amplifiers and references as previous experiments, but with a new montage consisting of 29 actively amplified electrodes (ActiCap, Brain Products) arranged in a montage conforming to the 10/10 system, consisting of FP1, FP2, AFz, F7, F3, F4, F8, FC5, FC1, FCz, FC2, FC6, T7, C3, Cz, C4, T9, CP5, CP1, CP2, CP6, P7, P8, O1, Oz and O2 electrode sites. A higher sampling rate of 5kHzwas used, downsampled offline to 500Hz.

*ERP Analysis*

The same analysis procedures were applied as in experiment one. The only exception being a wider artefact rejection amplitude criterion range of 100µV to -100µV was employed here due to greater amplitudes in muscular artefacts caused by the verbal response. The automatic artefact rejection was again manually checked as in the previous experiments and so does not represent a significant deviation from experiment one.

### *6.2.3 Results*

*Behavioural Data*

The mean error rate for left oriented kitchen items was 13.38%, for right oriented kitchen items was 13.91%, for left oriented tools was 0.58% and for right oriented tools was 0.43%. ANOVAs revealed no significant differences between left or right oriented kitchen items. For the tool items, the error rate was extremely low with a total of 19 false positive responses (verbally declaring a tool item as a kitchen) throughout the experiment, out of a total of 3780 tool trials.

*LRP data*

*Replicating LRP analysis from experiment one*

The lack of a manual response in this experiment requires reconsideration of the structure of LRP analyses in order to make them comparable to previous lateralised experiments. In previous lateralised experiments (one and three), compatible LRPs were calculated as:

$$\frac{[\mathrm{Mean(C4-C3)}\mathit{left\ response\ to\ left}\ \mathrm{han}\mathit{dle} + \mathrm{Mean(C3-C4)}\mathit{right\ response\ to\ right\ handle}]}{2}$$

And incompatible LRPs were calculated as:

$$\frac{[\mathrm{Mean(C4-C3)l}\mathit{eft\ response\ to\ right}\ \mathrm{han}\mathit{dle} + \mathrm{Mean(C3-C4)}\mathit{right\ response\ to\ left\ handle}]}{2}$$

With these calculations the LRPs had opposite polarities during the critical 100-200ms epoch, when compatible trials were negative-going and incompatible trials were positive-going. As can be seen from these LRP calculations, one interpretation of this effect is that it is contingent upon the relationship between the SR pair, that is, the handle of the object and the hand used to respond in the task. However as discussed above, it is also possible that the differences in LRP were born purely by an affordance generated by the stimulus, not by the relationship between stimulus and response. In this experiment these two explanations are disambiguated by removing the manual response from the experiment, and from the LRP calculations. Thus, in the LRP calculations used in this experiment the response factor is simply removed, resulting in:

$$\frac{[\mathrm{Mean(C4-C3)}\mathit{left\ handle} + \mathrm{Mean(C3-C4)}\mathit{right\ handle}]}{2}$$

and:

$$\frac{[\mathrm{Mean(C4-C3)}\mathit{right\ handle} + \mathrm{Mean(C3-C4)}\mathit{left\ handle}]}{2}$$

Note that the order of operations from experiment one is preserved with respect to the salient object feature, the handle. If the same 100-200ms effect is found in this experiment using these LRP calculations, then we can attribute the effect to the orientation of the handle, suggesting that the lateralised handle affordance is cuing ipsilateral motor cortex. Another way to view this in the context of a normal LRP calculation is that the handle orientation of the object is being used as a proxy to the response hand to determine whether the handle alone is sufficient to elicit the effects.

It is important to note that these calculations do not represent arbitrary assignment of conditions to LRPs, instead they preserve the order of operations applied to the LRP in experiments one and three (lateralised and masked lateralised). In each lateralised experiment, right handle is subtracted from left handle to create one LRP, and left handle is subtracted from right handle to create the other LRP. As in previous experiments, subtracting the right from left handle will yield a negative potential from 100-200ms and subtracting the left handle from the right handle will yield a positive potential during that epoch.

Following the findings of previous experiments analyses were conducted over four 100ms epochs from 100-500ms, including a fifth epoch from 150-200ms based on visual inspection of the data. Five epochs were analysed so the Bonferroni corrected alpha is set at $\alpha = 0.01$.

The main LRP effect from experiment one was replicated from 100-200ms ($F$ (1,29) = 7.185, $p$= .012) with waves adopting the same polarity as experiment one during this epoch. However, when interpreted using the Bonferroni corrected alpha (0.01) this 100-200ms effect is only borderline significant. Based on visual inspection of the data another epoch was analysed from 150-200ms (F (1,29)=9.936, $p$= 0.004) which yielded a significant result, in line with the findings from the unmasked affordance SRC experiment (one). The 100-200ms tendency and the 150-200ms significant effect indicates that viewing the objects was sufficient to give rise to this early activity and confirms the suggestion that this 100-200ms activity reflects motor preparation cued by object orientation (i.e. affordance) and is free from influence by the motor response.

Subsequently, a second phase of effects occurred, with a reversal of the polarity of the earlier effects occurring at around 250ms (figure 15). Following this reversal, from 300-400ms the compatibility effect was nonsignificant (1,29) = 5.234, $p$= 0.030) when interpreted with the Bonferroni correction, however it still represents an interesting tendency that fits with Zhang et al.'s (1997) and Miller and Hackley's (1992) finding that as

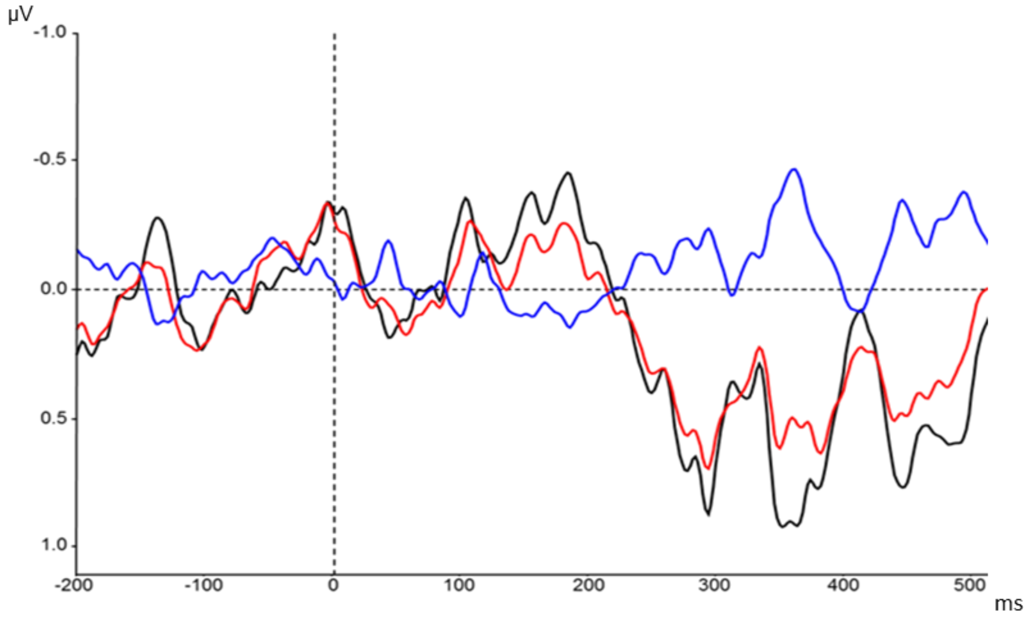



*Figure 15.* Grand average LRP for go, no-go experiment five. The red trace plots the data for left handled kitchen objects minus right handled tools and the blue trace plots the data for right handled kitchen objects minus left handled tools. The black trace plots the difference between red and blue. Significant effects were detected from 100-200ms and later from 250-450ms. Most notable is the reversal of the effect around 250ms that appears to reflect a suppression of the earlier effects.

long as an object is visible it will continue to elicit motor preparation. The polarity change entailed in this continued preparation suggests that this represents a suppression of the earlier effect that may be attributed to the generated affordance not being deployed. This was not observed in previous experiments where response-related activity dominated the LRP after around 250ms, offering a novel insight into what happens when afforded motor activity is not deployed. Given that this is the first demonstration of this, further investigation would be required to ascertain whether the 300-400ms tendency toward a reversal of the afforded motor preparation is a genuine effect, but it still provides an interesting first indication of what becomes of undeployed afforded motor preparation.

Finally, a third phase of activation saw another change in polarity, this time a negative inflection in both waves commencing at around 500ms and persisting until the end of the segment. During this time RM ANOVA did not reveal any significant differences between the waves ($p > .235$). Single sample *t*-tests also failed to yield a significant effect (*p*'s <0.058) but did reveal a tendency. This implies that sub-threshold tendency towards activation of the hand cued by the object was occurring late in these trials, long after the response is usually deployed. The nonsignificant tendency does not allow great concluding power but both these and the 300-400ms effect appears to be analogous to Zhang et al.'s (1997) observation that as long as action relevant stimuli persist on screen, motor preparations will continue. Zhang et al. (1997) used primates in their study however Miller and Hackley (1992) showed found a similar effect in human participants.

One consideration here is that LRPs are calculated using both go and no-go trials, so a comparison of go and no-go activity is required to understand whether this affected the results.

*Comparing go LRP and No-go LRP*

As discussed above, the reversed effects around response time require further analysis to understand whether the polarity of the LRPs was influenced by the verbal response. The above analysis mimicked experiment one, however it required that both go and no-go trials were used to generate each LRP. This introduces a possible confound because the go trials contained a verbal response and this may have exerted an influence, particularly on the later effects. In order to rule out this possibility another set of LRPs were calculated.

This time C3 was subtracted from C4 for left oriented kitchen items and C4 subtracted from C3 for right oriented kitchen items, yielding the go LRP:

$$\frac{[\text{Mean}(\text{C4} - \text{C3})\textit{left oriented kitchen item} + \text{Mean}(\text{C3} - \text{C4})\textit{right oriented kitchen item}]}{2}$$

And C3 was subtracted from C4 for left tool items and C4 from C3 for right tool items, forming the no-go LRP:

$$\frac{[\text{Mean}(\text{C4} - \text{C3})\textit{right oriented tool item} + \text{Mean}(\text{C3} - \text{C4})\textit{left oriented tool item}]}{2}$$

With these calculations, each LRP will index asymmetry within a stimulus type and so comparing them will look for differences between go trials and no-go trials. In this way it tests whether there was an effect of the verbal response or whether go and no-go trials were equal. Any significant differences here would indicate that the verbal response had an effect. As above, five epochs were analysed so the Bonferroni corrected alpha is set at $\alpha = 0.01$. RM ANOVA was conducted with a factor of trial type (go vs. no-go) on all epochs. No significant effects were found during any epoch (all *p*'s > 0.517) demonstrating that there was no influence of trial type on the LRP effects. This is as expected with the present calculations, where all symmetrical activity is subtracted out (detailed above).

*ERP data*

Figure 16 shows averaged ERPs across parietal electrodes P7, P8 and occipital electrodes O1 and O2. Averaged ERP amplitudes were calculated for the visual P1 from 80-120ms and for N1 from 120-180ms. In the absence of response the factor of 'proxy mapping' was determined based on experiment one; this is effectively a dummy variable that acted as substitute to the response hand factor from previous experiments in order to ensure the data were subject to identical transformations and statistical procedures, similar to the LRP analyses. This acted as a proxy to response hand and again, tested whether the effects observed in the previous lateralised experiments were products of the visual affordance alone generating visuomotor activity, or whether the observed visuomotor activity is borne of an interaction of the SR pair. Again the goal was to determine whether the P1 and N1 effects were contingent on a relationship between stimulus and response or elicited by merely viewing the affording stimulus. The transformations were based on the response mapping from the masked lateralised experiment (three), where participants responded to tool objects with a right handed button press. This mapping also obtained a slightly stronger effect in experiment one. This was chosen in order to ensure comparability. So, the factor of response mapping is effectively a dummy variable with a binary value designed to ensure that the data were subject to the same transformations as in previous experiments. In practice, this was accomplished by simply coding trials based on whether they required a left or right response in the equivalent mapping in experiments one or three and using this to construct the conditions in the analysis so they were comparable to previous experiments. With this factor, an interaction of proxy mapping and handle orientation would indicate the same effect observed in the interaction of response hand and handle orientation observed in experiment one. However, since there is no response to define compatibility such an interaction will be referred to as a 'visual affordance' effect. Repeated measures ANOVA was employed with factors of proxy mapping (left vs. right), handle orientation (left vs. right), electrode hemisphere (left vs. right) and electrode position (parietal vs. occipital).

For P1, a main effect of category ($F$ (1,29) = 8.521, $p$ = 0.007) demonstrated kitchen items elicited greater positive amplitudes. A main effect of hemisphere ($F$ (1,29) = 13.425, $p$ = 0.001) indicated greater amplitudes on left-hemisphere sensors. A main effect of electrode position ($F$ (1,29) = 62.438, $p$ < .001) indicated significantly greater activity on occipital sensors than parietal. Visual affordance effects were observed in P1 in an interaction of handle orientation, proxy mapping and electrode hemisphere ($F$ (1,29) = 5.107, $p$ = 0.032) indicating a left-hemisphere locus for the visual affordance effect, and an interaction of handle orientation, proxy mapping and electrode position (*F* (1,29) = 7.784, *p* = 0.009) that indicated greater amplitude on occipital sensors than parietal, similar to previous experiments such as masked, lateralised experiment three.  An interaction of handle, electrode hemisphere and electrode position (*F* (1,29) = 7.566, *p* = 0.010) showed that handle orientation elicited greater activation in left occipital cortex, similar to the visual affordance effect.  This interaction likely reflects much of the same variance as the interactions of visual affordance with electrode hemisphere and position, with the handle orientation offering the affordance which –in the absence of a response to shape perception (e.g. Symes et al., 2008) – appears to be handled by left occipital cortex.

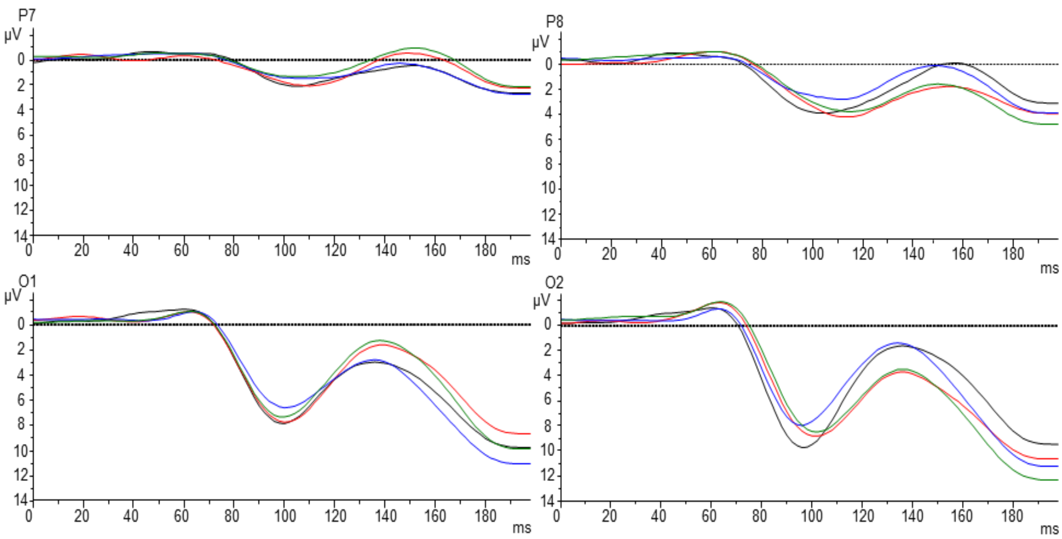



*Figure 16.* Plot of averaged ERP activity for P1 and N1 components across sensors O1, O2, P7 and P8, which were used for the visual component analysis.  Separate waveforms are displayed for each handle orientation.  The black trace plots the activity for left orientated kitchen items.  The red trace plots activity for right orientated kitchen items.  The blue trace plots activity for left orientated tool items and the green trace plots activity for right orientated tool items.

No visual affordance effects were observed in N1.  However N1 demonstrated a significant main effect of electrode position (*F* (1,29) = 7.415, *p* = 0.011), indicating greater activity on occipital sensors than parietal.  An interaction of handle orientation and electrode hemisphere (*F* (1,29) = 43.247, *p* < .001) revealed greater activation in left hemisphere, as per P1 analyses and previous experiments. A significant interaction of electrode hemisphere and position (*F* (1,29) = 5.582, *p* = 0.025) demonstrated a tendency to greater amplitudes on left occipital sensors. A significant interaction of handle, electrode hemisphere and electrode position (*F* (1,29) = 8.953, *p* = 0.006) was also detected in N1, however no visual affordance effect was detected in N1, only an effect of handle. This suggests that N1 is sensitive to the action intentions of the agent because when the participants had no action intentions, no visual affordance effect was detected.

### *6.2.4 Discussion*

*Motor effects*

This experiment confirms the assumption that viewing an object potentiates the actions that may be performed on it by demonstrating preferential activation of motor cortex by the affordances of common object stimuli. Even in the absence of a response the LRP effect from previous experiments was still observed from 100ms. These findings confirm assertions from across the behavioural literature (e.g. Tucker & Ellis, 1998; Craighero, Fadiga, Rizzolatti & Umiltà, 1998, 1999; Rumiati & Humphreys, 1998) and theoretical literature (e.g. Gibson, 1979; Hommel & Prinz, 1997) that viewing objects is sufficient to elicit a motor preparation consistent with their afforded actions. This suggests that this early activation is elicited by merely viewing the stimulus, regardless of the intention to act on or toward it. This supports the notion of automaticity and suggests that this early LRP activity actually reflects the preparation of the afforded action and confirms that the LRP does not reflect motor preparation related to manual responses. Put differently, this experiment confirms that a response is not a necessary component for seen objects to generate motor activity. Previous experiments have shown that it is unreliable to generalise across different affordance classes, so these conclusions are limited to lateralised handle affordances but nonetheless represent some of the first *direct* evidence for automatic activation of object affordance with lateralised affordances.

An experiment by Proverbio et al. (2011) obtained similar findings with manipulable tool and non-tool stimuli in a passive viewing experiment. They found a greater anterior negativity (including sensors C3 and C4) around 250ms and 550ms for tools than non-tools without a manual response to those stimuli. One obvious difference emerges however; their motor effects were detected considerably later than the present experiment however this may be explained by their stimuli. The stimulus set consisted of manipulable tools of many more types than seen here and was not simply limited to objects with lateralised handles. Instead, objects such as typewriters and puzzle cubes were presented that do not necessarily yield affordances in the same way as each other or as the stimuli here. In some cases stimuli were more comparable to those seen in experiments two and four, which also found later effects. They also did not necessarily cue a particular hemisphere similar to the stimuli used in experiment two, which also saw effects emerging during a similar epoch.

A novel finding in the present experiment is the later reversal of the effect from 300-400ms which has not been shown so far. Zhang et al. (1997) and Miller and Hackley (1992) found that as long as action relevant stimuli remain on screen then effects remain detectable in motor cortex. Proverbio et al. (2011) also detected late effects, although they were not detected in LRP or over motor cortex but rather represented a centro-parietal P300 component. Nevertheless, this combined with other studies such as Adamo and Ferber (2009) who found similar later effects indicate that the additional attention-capturing properties of affording stimuli may be responsible for these later effects. Later effects in Proverbio et al. (2007) are attributed to semantic integration and cognitive updating processes and this may explain why later effects are observed here in the absence of response. Considering the reversed polarities during this epoch and the kind of task and stimuli used, semantic integration seems poorly supported and would not explain the polarity reversal. That said, given the obvious and consistent left/right affordances throughout the stimulus set, this reversal may be attributable to the lack of response causing a suppression of the previously generated affordance after it was determined that the affordance developed from 100-200ms will not be deployed. This explanation is consistent with Proverbio et al.'s (2007) suggestion of cognitive updating processes being used to rapidly generate and suppress affordances in order to aid real-time action. It is also consistent with the real-world usefulness of affordance as a rapid but disposable means of dynamic preparation for motor actions in real-time however this is a novel result and so further research is required to draw firm conclusions on this.

Overall, the motor effects elicited by this simple experiment replicate the core LRP finding from experiment one in the absence of the intention to act. This confirms a claim core to the concept of affordance; that viewing objects alone is sufficient to prepare the actions that may be performed on them. It also validates the assumption that making a motor response does not influence affordance preparation in the same way that prepared actions affect the detection of affordances; this is a critical consideration given the vast majority of the affordance literature has made deep claims about affordances eliciting particular patterns of motor preparation, and have done so whilst having participants prepare motor responses. This introduced a potential confound wherein it is difficult to separate the afforded motor preparation from the motor preparation required by the rule-cued response, however the presence of motor preparation in the absence of response seen in this go, no-go experiment allays any such concern. In turn, motor preparation in the absence of an intention to act shows that a response is not required to elicit affordance preparation despite considerable evidence that prepared actions can affect affordance generation/ object detection (*cf*. Fagioli, Ferlazzo, & Hommel, 2007; Fagioli, Hommel, &

Schubotz, 2007; Symes et al., 2008; Lindemann & Bekkering, 2009; Van Elk et al., 2010). Additionally, it demonstrates a novel reversal of the effect after 200ms in line with Miller and Hackley's (1992) go, no-go experiment and Zhang et al.'s (1997) comparative study, which also found that while an action-relevant stimulus persists on screen it will continue to elicit action-preparations. The polarity reversal observed after 200ms suggests that this continued action preparation in LRP appears to represent suppression of the afforded action, likely because participants had no intention to make a motor response, rendering the afforded action as surplus to the task requirements. Or put differently, the absence of intention to make any motor response *may* be the cause of the reversed polarity because participants had no intention to deploy the afforded action. However, given that this is a novel demonstration of the later affordance reversal/ suppression effect this discussion must exercise caution in interpreting these novel results and additional evidence is required before strong conclusions may be reached on these later effects (discussed further in delayed response experiment six). Nonetheless, the afforded action (and its subsequent reversal/suppression) is still detectable in LRP and VEPs in the absence of the intention to act, supporting the notion of automaticity by directly demonstrating that affording objects elicit motor activation regardless of participants' intentions.

*Visual P1 and N1*

A 'visual affordance' (defined above) interaction was again elicited in P1, mirroring the compatibility effect from experiments one and three, only this time in the absence of a response. This essentially means that when subjected to the same transformations, the visual P1 associated with viewing affording objects without response is similar to visual P1 when viewing affording objects with the intention to make a manual response to them. Although it is more difficult to interpret the visual effects than motor effects in the absence of response, detecting a visual affordance effect in visual P1 in the absence of a response does imply that the P1 compatibility effects are not full compatibility effects in the sense of processing being facilitated by SR match. This is simply because without a manual response, there are no grounds for an SR match. Also, these effects occur too early (80-120ms) to reasonably be expected to reflect a compatibility effect that comes from relating SR pairs in full. Instead, the detection of a compatibility effect in P1 both with and without response suggests that this component is not sensitive to response parameters and instead seems to be only concerned with the visual input. This interpretation is supported by the lack of a compatibility effect in N1, which suggests that N1 may be sensitive to response parameters or planned actions. This begins to offer a differentiation of the role of P1 and N1 in processing affordance SRC paradigms; P1 appears to be insensitive to response parameters and N1 appears to be sensitive to response parameters, offering a potential subject for investigation related to Symes et al.'s (2008) findings that prepared actions affected visual search times, although this is conjecture and requires further investigation to confirm.

It is important to note that the visual affordance effect did not emerge in P1 as a two-way interaction as in experiment one but rather a three-way interaction with electrode hemisphere as in the masked lateralised experiment three. There was also a three-way interaction of visual affordance and electrode position, revealing greater activation on occipital sensors than parietal. The detection of a compatibility effect in P1 in the absence of a response could be seen to suggest an automatic component to early compatibility effects in visual P1, however it is unclear what automaticity might mean in terms of visual effects where viewing any stimulus should elicit this component (e.g. Luck, 2005; Van Voorhis & Hillyard, 1977). The idea of automaticity in relation to visual activity is also complicated by the lack of compatibility effects in P1 in the grip-type studies and more research is required to explore these early indications of previously unconsidered differences between affordance classes. The notion of automaticity does not appear to be appropriate to visual N1 either because no visual affordance effects were elicited in N1 in the absence of response, suggesting that N1 compatibility effects *are* contingent on a response and that N1 indexes a relation of body to environment that makes N1 an excellent candidate for exploring the findings of Fagioli et al. (2007a, 2007b), Symes et al. (2008), Van Elk et al., (2010) and others (discussed variously) that have shown bodily states affect object perception.

*Conclusion*

The go, no-go experiment demonstrates that responses are not essential to the motor effects observed with lateralised affordances in this thesis and suggests that the LRP effects may indeed reflect the afforded motor preparation from 100-200ms and that influences of task or response do not appear to occur until after 200-300ms. This is supported by examining the figures from previous experiments where response-related activity did not become apparent in LRP until around 250-300ms, and was roughly equal for both compatible and incompatible waveforms. The go, no-go data also offer a novel, functional differentiation of P1 and N1 effects; P1 and N1 compatibility effects have been detected in all lateralised experiments so far and all of these had manual responses, however the lack of an N1 effect in the go, no-go experiment (where there was no manual response) suggests that N1 effects may have a relationship with manual responses, in line with data from Van Elk et al. (2010). Overall, this experiment provides direct evidence for automaticity and supports the notion that the prepared motor response has not influenced the early LRP effects observed in this thesis.

*6.3 Experiment six – effects of delayed response on lateralised affordance generation*

*6.3.1 Introduction*

Following from the examination of the assumption of automaticity in go, no-go experiment five, experiment six sought to provide additional confirmation for this by approaching the question of automaticity from a different angle. As described above, this experiment sought to test the assumption that categorical judgements do not have a specific role in the generation of an affordance effect. Typically, every SRC paradigm from Fitts and Seegar (1953) to modern affordance SRC paradigms has used a categorical judgement of some kind, the deployment of which usually constitutes the grounds for compatibility with the stimulus. However, Tipper et al. (2006) and Pellicano et al. (2010) provide evidence that different categorical judgements will elicit different effects with the same affording stimuli. This questions the notion of automaticity and introduces the idea that categorical judgements could be affecting the way the stimulus is parsed and in turn, what effects are generated. This is another critical question hanging over the affordance literature; if participants are required to attend an object by a task such as a categorical judgement, then this clouds assertions of automaticity because, as discussed by Vainio, Symes, Ellis, Tucker and Ottoboni (2008), identifying a graspable object will entail visually processing various aspects of the object in order to identify it, and in the process will necessarily include processing of any action cues contained in the stimulus. This makes it difficult to assert automaticity (i.e. that it is the mere presence of the object that gives rise to its affordance) because completing the categorical judgement task entails a particular means of considering the object.

Tucker and Ellis (2004) used masking to show that it is not necessary for the affording stimulus to be visible during response deployment in order to yield a compatibility effect. The present experiment will work along similar, but inverted logic by attempting to separate the categorical judgement from the affording stimulus, which will be presented only at the point of response. No lateralised affordance will be present when participants make their categorical judgement. This will be accomplished by presenting the first stimulus in a neutral rotation with its handle following the midline of the image in order to avoid cuing a particular hand. While this stimulus does not provide a lateralised affordance, it does provide all the information required for the participant to select and prepare the rule-cued response hand as dictated by the task (the standard categorical judgement from previous lateralised experiments; identify whether the stimulus is a kitchen implement or a tool). After this the same object will be displayed in a second image, but will then be oriented to the left or right to provide lateralised affordance. Participants are instructed to respond with their categorical judgement by deploying their rule-cued lateralised response only at the onset of this second image. This separates any influence of the categorical judgement from the response and tests the notion of automaticity in a novel way by removing any impetus to consider the content of the image of the affording stimulus at the point of response. This represents a change from typical affordance SRC experiments (e.g. Tucker & Ellis, 1998, 2001; Ellis &Tucker, 2000, 2004; etc.) which normally use the categorical judgement as a means to have participants examine the object and thus observe the affordance (as discussed in Vainio et al., 2008); instead, participants will have no impetus to examine the contents of the affording stimulus because they will have already made their categorical judgement. This allows a different approach to examining automaticity, because if any affordance/ compatibility effect is found, it can only be attributed to the mere visual presence of the stimulus and not to any feature of the categorical judgement (e.g. Pellicano et al., 2010; Tipper et al., 2006). This is unlike Tucker and Ellis (2004), as the affording stimulus will be on screen whilst the response is deployed but has similarities in temporally separating components of the task. Tucker and Ellis (2004) used masking to separate stimulus and response however the present experiment will deliberately avoid masking or rapid stimulus array changes due to their association with negative compatibility effects (see also masked, lateralised experiment three and Klapp and Hinkley, 2002). In order to control any effects of apparent motion and to control for rapid display changes, there will be an 800ms interval between the first and second stimulus on each trial.

By presenting the first stimulus in a neutral rotation we can examine the possibility of an interaction between making the categorical judgement and lateralised information contained within the stimulus, free from potential interference by laterality information in the first object. Participants will prepare their response well ahead of time and without interference by visual action information, meaning that any affordance effects detected during the presentation of the second stimulus should be free from influence by the categorical judgement, which itself should also not be influenced by visual affordances interacting with the response rule. This allows the examination of the assumption outlined above. This also means that we can predict shorter RT's in this experiment than in the single object experiments because the participants will simply be waiting for the second object to appear in order to deploy their response. This effectively renders the second stimulus as merely a go cue to deploy a rule-cued response that is generated when viewing a neutrally rotated stimulus, giving this experiment the ability to unpick the relationship between automaticity and task-judgements.

### *6.3.2 Method*

#### *Participants*

29 participants (16 female) formed the sample. All were right handed, aged 18-28 (mean = 21.06, SD = 2.01), with normal or corrected vision and no known history of neurological problems. No participants were removed from the analysis due to excessive artefact, with

the largest proportion of artefacts rejected at 30% and the mean artefacts rejected at 9%. However two participants were removed due to equipment failure.

*Stimuli*

A new stimulus set was generated because the previous one did not contain neutrally rotated objects however it was deliberately designed to be as similar as possible to the previous lateralised stimulus set. The new stimulus set consisted of 100 colour photographs of common household objects classifiable as kitchen or tool items. There were 25 objects in each category, each photographed with the handle rotated left or right, similar to the stimuli from experiment one (see appendix for a complete stimulus list). Each object was also photographed in a neutral rotation, with the handle pointing vertically down. Objects were carefully selected for the neutral images in order to ensure that implicit laterality could not have introduced a confounding variable. For example, the orientation of the blade of a knife indicates a usage preference and a hammer has a clearly defined flat head used for striking on only one side of the object. Therefore only stimuli that were vertically symmetrical, such as serving spoons and paintbrushes were included. Note that whilst there were different examples of the same kind of object (e.g. small and Large frying pans) no single image appeared any more than another.

*Procedure*

Data were gathered in the same location and using the same equipment as previous experiments. Participants were asked to respond to the second stimulus only, with the first stimulus acting as a kind of explicit prime. Participants viewed a fixation point for 1000-1200ms before the first stimulus, an object in a neutral rotation, was presented for 1000ms. This was followed by a blank screen for 800ms, intended to control any apparent motion or masking-type effects, before the onset of the target stimulus, a lateralised image of the first neutrally rotated object that remained onscreen for 1000ms. After this target stimulus offset participants viewed a blank screen for 400-600ms before the blink symbol appeared on screen for up to 1400ms after which the trials commenced again with a fixation point. This procedure is visualised in figure 17.

*EEG Acquisition*

Continuous EEG was digitised at a sampling rate of 500Hz by Brain Products MR Plus amplifiers connected to Brain Visions Recorder software (Brain Product GmbH). The same 64 electrode montage was used here as in experiment two.

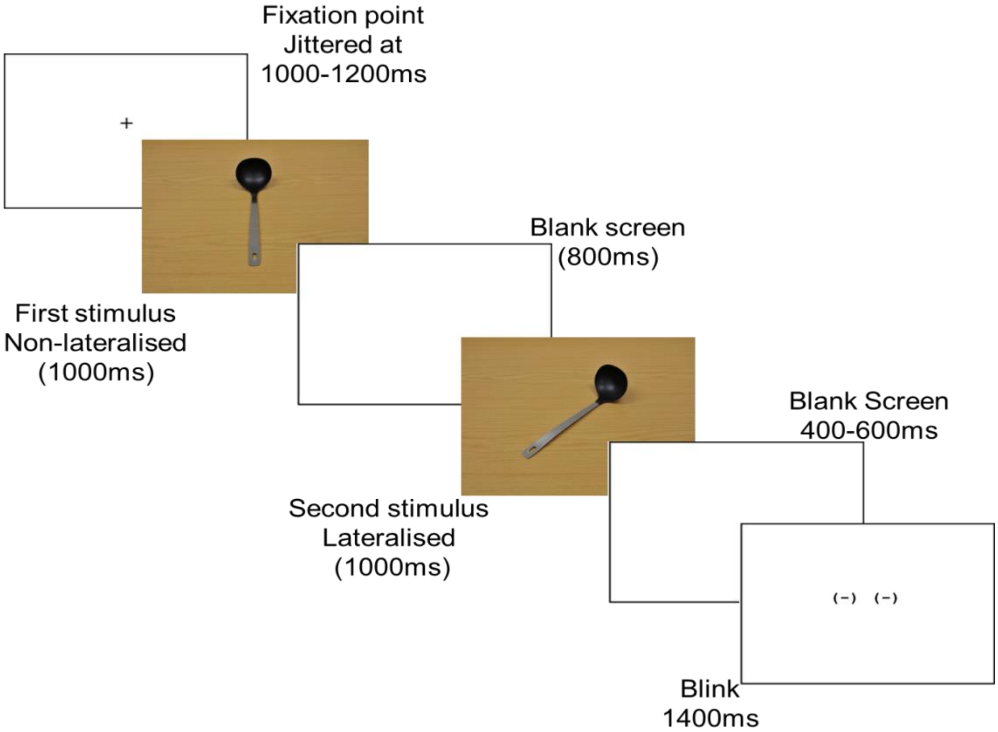



*Figure 17.* Visualisation of the timecourse of the trials in experiment six. Each pane represents a change in the display, with six such changes occurring per trial. Participants knew that the second stimulus would always be the same object as the first. Participants made their categorical judgement whilst viewing the first, non-lateralised stimulus and selected and maintained their rule-cued response until the onset of the second stimulus, which did contain a lateralised affordance and acted as a cue to respond.

*ERP Analysis*

Using Brain Vision Analyser 2 (Brain Products GmbH) a 0.5-40Hz Butterworth filter was applied and a notch filter was applied at 50Hz. The data were then re-referenced offline to a reference consisting of an average of the two mastoids and a 200ms baseline correction was applied in the 200ms before the onset of the first (neutral) stimulus. An automatic artefact rejection procedure was conducted on all of the segmented data from scalp and EOG electrodes using the inbuilt module in Brain Vision Analyser 2 with an amplitude criterion range of -150µV to 150µV and a gradient criterion of 50µV/ms in order that the procedure only marked artefacts. The automatic rejection procedure was manually checked for all participants to ensure that no good segments were removed and that no bad segments were allowed into the averaged data. LRPs were calculated as per previous experiments. The LRP data were time locked to the onset of the first image. For each analysis RM ANOVA with a two-level factor of compatibility (compatible vs. incompatible) was used to compare findings for both waveforms. To understand the direction of the effects during the presentation of the second, affording stimulus *t*-tests were conducted on each waveform against a hypothetical baseline of zero.

### *6.3.3 Results*

*Behavioural data*

Participants responded only to the second image, having made the categorical judgement during the presentation of the first, non-lateralised image and maintained this decision until the presentation of the second, lateralised image. This led to greatly reduced RTs than in previous experiments on both compatible (mean = 298ms) and incompatible (mean = 306ms) trials. Behavioural responses were analysed using repeated measures ANOVA with a factor of compatibility (compatible vs incompatible) obtaining a significant effect of compatibility ($F$ (1,26) = 5.878, $p$ < .023). The same analysis was conducted on the proportion of errors (overall 95.3%), but no significant effect of compatibility was found ($p > 0.3$).

*LRP analysis*

*Parameters*

The LRP for this experiment is roughly three times the length of previous experiments and has three distinct stages; the first, neutral stimulus presentation, the blank screen period and the second, affording stimulus presentation. Based on the previous experiments, it is possible to predict that the experimental effect should only be detected during the presentation of the second, affording stimulus. It is difficult to predict an effect during the presentation of the first, neutrally rotated stimulus and there is no reason to predict any action effects during the blank screen period. The inclusion of a neutrally rotated stimulus offers an opportunity to determine whether a stimulus that fails to cue a particular hand will yield any motor activity. Analysing the first, neutral stimulus presentation will also ensure no earlier effects exist that may affect the presentation of the second, affording stimulus.

It is possible to make predictions on the presentation of the second, affording stimulus based on previous experiments, specifically that there will be a compatibility effect in LRP 100-200ms after the presentation of the affording stimulus that will adopt polarity changes consistent with previous experiments (greater positivity for incompatible trials during this epoch, greater negativity for compatible trials during same epoch). Based on the go, no-go data one may also predict that later effects will be detected too because stimuli again persist on screen after response, and that a reversal of the polarity of each waveform will be observed after the initial compatibility effect (i.e. around 200-300ms).

*Neutral stimulus presentation stage*

The LRP is pictured in figure 18. From 0ms to 1000ms no significant effects were detected (*p* > 0.103), in line with the expectation that a neutrally rotated stimulus should not produce a compatibility effect. No preparation of the rule-cued response was detected. Although not the subject of this investigation this is interesting in its own right, demonstrating no particular hand preparation by neutrally rotated stimuli and so indirectly confirming the suggestion that it is the object orientation that produces lateralised compatibility effects, free from predispositions to use a particular effector with a particular object. The lack of effects during this stage of the trial confirms that there was no motor preparation that may have affected the later stages of the trials.

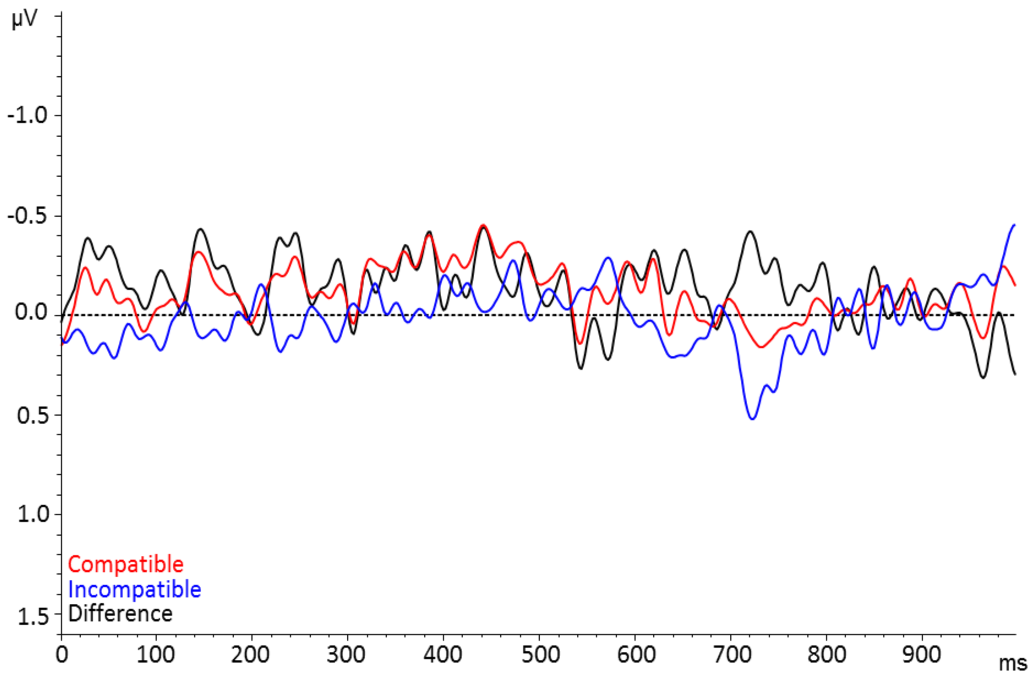



*Figure 18.* LRP for the neutral stimulus presentation stage. LRPs were calculated separately for compatible (red trace) and incompatible (blue trace) waves. Participants viewed an image of a common household object in a neutral rotation, with the handle pointing directly toward the participant's midline. This meant that the handle did not afford a particular action at this stage. No effects were observed during this period (p > 0.103).

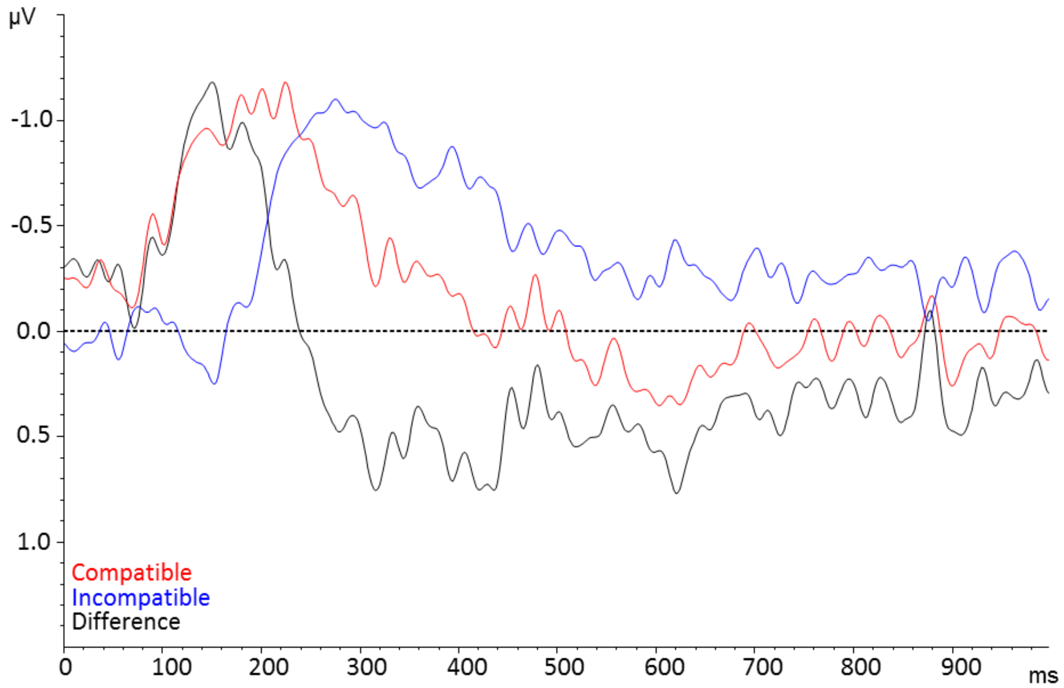



*Figure 19.* LRP for the second, affording stimulus presentation, time locked to onset of first, neutrally rotated stimulus. LRPs were calculated separately for compatible (red trace) and incompatible (blue trace) waves. The black trace plots the difference between compatible and incompatible waves. From 100-200ms the typical LRP compatibility effect was observed. Following this, LRP polarity reversed and the compatible wave returned to baseline for the remainder of the trial. The incompatible wave demonstrated negative activity for the remaining duration of the trial, consistent with the preparation of the rule-cued response.

*Analysis of second, affording stimulus stage*

The second, affording stimulus onset 1800ms after the first, neutral stimulus, so the critical 100-200ms epoch occurred from 1900-2000ms when timelocked to the first, neutral stimulus onset. The stimulus was visible for one second, generating ten 100ms epochs for analysis, generating a Bonferroni corrected alpha of (0.05/10) α = .005.

Consistent with the short RTs, the most rapid LRP activity was observed in this experiment; a tendency was observed in the first 100ms after the onset of the second stimulus from 1800-1900ms ($F$ (1,26) = 3.255, $p$ =0.083) that failed to reach significance. One-sample *t*-

tests reveal that during this epoch, only the compatible wave was significantly different from zero ($t(26) = -2.763$, $p = 0.01$) with no effect in the incompatible wave ($p = .987$).

The typical SRC affordance effect is obtained from 100-200ms after the onset of the second image ($F$ (1,26) = 28.335, $p < .001$) at 1900-2000ms in this analysis (timelocked to the onset of the first stimulus). However, figure 19 shows that both compatible and incompatible trials elicited a negative wave during this critical epoch, which using the current LRP calculations signals the preparation of the hand cued by the response rule. For incompatible trials, despite the typical positive inflection associated with the incompatible affordance, the activation in this period was overall negative-going, which typically indicates a preparation of the rule cued response. However, the typical 100-200ms effect may still be observed in the positive inflection in the [overall negative] incompatible waveform between 100-200ms and it was this positive inflection for incompatible trials that was sufficiently different from the negative inflection in the compatible trials to generate the significant ANOVA result for this epoch, just as in previous experiments. The positive inflection in the incompatible LRP and the negative inflection in the compatible LRP appear to reflect the typical compatibility effect, which in previous experiments has occurred during this epoch. However the peak value for this positive inflection remained below zero, where in previous experiments (one & three) the peak value for the incompatible LRP was significantly greater than zero during this epoch. Nonetheless, the typical dipolar formation across LRPS from 100-200ms observed in previous experiments was significant during this critical epoch, demonstrating a compatibility effect in LRP. Overall it appears that greater activity was elicited by the compatible wave during this epoch, consistent with the idea that SRC affordance effects are facilitatory by nature (e.g. Galpin et al., 2011). No differences between conditions were observed from 2000-2100ms ($F$ (1,26) = .120, $p$ =0.732) (200-300ms after affording stimulus onset), however both compatible ($t(26) = -6.154$, $p < .001$) and incompatible ($t(26) = -6.631$, $p < .001$) were significantly different from zero during this epoch. Examining the figure, these waves were both significantly and approximately equally negative-going during this epoch, probably signalling activity related to deploying the response (mean RT 302ms).

Following this, a second phase of effects developed after response (mean RT 302ms), as predicted by the go, no-go experiment, persisting until stimulus offset (2800ms). During this second phase each of the compatible and incompatible LRPs were still negative, but now the difference in voltage between these conditions was the opposite to that of the earlier phase (100-200ms). That is, the waveform for compatible stimuli was more positive than that of the incompatible stimuli. The second phase of effects commenced with a significant effect from 2100-2200ms ($F$ (1,26) = 15.165, $p$ =0.001) (300-400ms after second stimulus onset) with a significant deviation from baseline for both conditions, compatible ($t(26) = -2.486$, $p = 0.020$) and incompatible ($t(26) = -5.177$, $p < .001$). This effect is the opposite of the typical 100-200ms LRP compatibility effect, with the incompatible LRP being more negative-going than the compatible LRP. This marked the return of the compatible LRP to baseline for the remainder of the trials (see below). Following this 2100-2200ms effect the RM ANOVA results did not pass the Bonferroni corrected alpha (0.005), but represent interesting tendencies toward preparation of the rule-cued response until the stimulus offset at 2800ms. The $t$-tests show that these effects were located only in the incompatible wave, with no further differences between the compatible wave and baseline ($p$'s > .146). They were as follows; 2200-2300ms ($F$ (1,26) = 7.433, $p$ =0.011) driven by the incompatible wave only ($t(26) = -4.467$, $p < .001$), 2300-2400 ($F$ (1,26) = 7.477, $p$ =0.011) with an effect detected in the incompatible wave only ($t(26) = -2.706$, $p$ =0.012), 2400-2500ms ($F$ (1,26) = 6.894, $p$ =0.014) detected in the incompatible wave only ($t(26) = -2.034$, $p = 0.052$), 2500-2600ms ($F$ (1,26) = 3.532, $p$ =0.071) in the incompatible wave only ($t(26) = -7.973$, $p = 0.059$), 2600-2700ms ($F$ (1,26) = 3.264, $p$ =0.082) in the incompatible wave only ($t(26) = -2.135$, $p = 0.042$), and 2700-2800ms ($F(1,26) = 4.248$, $p = 0.049$) in the incompatible wave only ($t(26) = -2.252$, $p = 0.033$).

*LRP Summary*

There were significant differences between LRPs in two distinct phases; the typical effect was detected from 100-200ms. Following this a second phase of LRP effects commenced after responses had been deployed (mean RT 302ms) from 2100-2800ms (300-1000ms after the onset of the affording stimulus). Occurring after response, these were not the typical LRP compatibility effects seen elsewhere in the thesis and they adopted the opposite polarities to the earlier LRP compatibility effects (demonstrating greater negativity in the incompatible LRP, rather than the compatible LRP). This was in line with predictions from the go, no-go experiment (five) that saw a polarity reversal after 250ms whilst stimuli remained visible. The second phase of effects also differ from the earlier (100-200ms after affording stimulus onset) compatibility effects because there were no effects in the compatible LRP; *t*-tests showed that after the compatible response was deployed, from 400ms no further effects were detected in the compatible LRP. After 400ms, only the incompatible wave was significantly different from zero, with a negative amplitude consistent with the preparation of the rule-cued response. The *t*-test results for epochs from 2200-2800ms show that these were not compatibility effects in the sense of compatibility facilitating responses because there were no effects in the compatible LRP; rather the second phase of effects was a product of the incompatible LRP being significantly different from the compatible LRP, which did not differ from zero during these later epochs. So, the later ANOVA and *t*-test results were not compatibility effects in the typical sense but instead demonstrated continued preparation of the rule-cued response only for the incompatible LRP. As discussed above, these persistent effects are explained by the finding from Zhang et al. (1997) and Miller and Hackley (1992) that when action relevant stimuli remain visible, action preparation will continue to be detectable in motor cortex. A novel finding is that this appears to be unique to incompatible trials, where the rule-based preparation and the object-based preparation conflict. After the afforded action was deployed on compatible trials activity returned to baseline however this was not true for incompatible trials, where the overall negativity indicates a continued preparation of the rule-cued response.

In summary, the typical LRP compatibility effect was observed 100-200ms after onset of the affording stimulus. Subsequently, LRP polarities reversed; after the compatible response was deployed (mean compatible RT 298ms) the compatible LRP returned to baseline, but after the incompatible response was deployed (mean incompatible RT 306ms) a second phase of effects developed wherein the incompatible LRP continued to be significantly negative going consistent with the preparation of the rule-cued response.

*ERP data*

As in previous experiments RM ANOVAs with factors of response hand (left vs. right), handle orientation (left vs. right), electrode hemisphere (left vs. right) and electrode position (parietal vs. occipital) were conducted over data from parietal electrodes P7, P8 and occipital electrodes O1 and O2. P1 was measured from 100-140ms and N1 was measured from 140-190ms, both were measured from second stimulus onset.

P1 revealed a significant main effect of electrode position ($F$ (1,26) = 119.981, $p$ < .0001), revealing greater activity on occipital sensors than parietal sensors, consistent with previous experiments. A significant compatibility effect was observed in a three-way interaction of handle orientation, response hand and electrode hemisphere ($F$ (1,26) = 12.356, $p$ = 0.002) again indicating a left-hemisphere locus for the compatibility effect, consistent with previous experiments and literature discussed above (e.g. Cisek, 2007). A tendency toward an interaction of response hand and electrode position ($F$ (1,26) = 4.189, $p$ = 0.051) indicated tendency toward greater activation on occipital sensors overall, as in previous experiments. A significant three-way interaction of handle orientation, electrode hemisphere and electrode position (F (1,26) = 22.664, p < .0001) reflected the same left occipital preference seen in the previous experiment. An interaction between electrode hemisphere and electrode position ($F$ (1,26) = 4.911, $p$ = 0.036) indicated overall imbalance of activity across the sensors, indicating greater activation on left occipital sensors, consistent with previous experiments. A weak, four-way interaction of handle orientation, response hand, electrode hemisphere and electrode position ($F$ (1,26) = 4.379, $p$ = 0.046) was observed. Additional tests revealed a significant interaction of handle orientation, response hand and hemisphere on occipital sensors ($F$ (1,26) = 14.438, $p$ = 0.001, $\eta_p^2$ =0.357), and a weaker interaction on parietal sensors ($F$ (1,26) = 8.180, $p$ = 0.008, $\eta_p^2$ =0.239), indicating that the effect was stronger on occipital sensors. An interaction of handle orientation, response hand and electrode position ($F$ (1,26) = 11.968, $p$ = 0.002, $\eta_p^2$ =0.315) was significant in left hemisphere, but not in right hemisphere ($p$ = .168). This supports the idea that the P1 compatibility effect had a left occipital locus, with a weaker interaction on parietal sensors, fitting with Cisek (2007) and others asserting a left-hemisphere network for handling object properties.

N1 revealed a significant main effect of electrode position ($F$ (1,26) = 4.941, $p$ = 0.035) showing greater activity on occipital than parietal sensors. A significant interaction of handle orientation and electrode hemisphere ($F$ (1,26) = 27.90, $p$ < .001) indicated a tendency toward preferential activation on ipsilateral sensors by object handles, but with overall bi-hemispheric activation as in previous experiments. A significant compatibility effect was again observed in a three-way interaction of handle orientation, response hand and electrode hemisphere ($F$ (1,26) = 11.150, $p$ = 0.008). As in P1, an interaction of handle orientation, electrode hemisphere and electrode position (*F* (1,26) = 4.960, *p* = 0.035) in N1 reflected the same left occipital locus seen in previous experiments three and five. Also as in P1 significant interaction of response hand and electrode position (*F* (1,26) = 10.472, *p* = 0.003) indicated greater activation on occipital sensors overall. This left occipital locus was also conspicuous in the masked experiments, suggesting that the left-hemisphere network for object representation is enlisted in experiments where stimuli disappear from the screen during the trial as the first, neutrally rotated object did here. This fits with the functions of the left-hemisphere object network as proposed by Cisek (2007) or Johnson-Frey et al. (2005).

### *6.3.4 Discussion*

The delayed-response experiment (six) showed that the categorical judgement does not appear to be a necessary factor in generating an affordance effect in LRP or RT, and shows that merely viewing an affording stimulus is sufficient to elicit preparation of the actions associated with that stimulus. This experiment was intended to confirm the findings of the go, no-go experiment five which found action effects in the absence of response, but included a categorical judgement that experiments such as Tipper et al. (2006) and Pellicano et al. (2010) have suggested are related to the generation of affordance effects. This section will discuss the results of this novel variation on the SRC affordance paradigm before considering their relationship with the findings of Tipper et al. (2006) and Pellicano et al. (2010):

This experiment showed two distinct phases of effects similar to the previous experiment, offering a novel view on what occurs after response but when an object is still visible. The first phase of LRP effects from 100-200ms confirms the assumption that a categorical judgement is not required to elicit the familiar affordance effects by showing a significant behavioural and LRP effect even when categorical judgement is separated from response.

However the LRPs for both compatible and incompatible trials were negative going, indicating a preparation of the rule-cued response hand for both trial types. This overall negativity is attributable to participants having almost two seconds to prepare the rule-cued response having made the categorical judgement on a neutrally rotated stimulus long before the target appeared. This is supported by the reduced RT (mean RT 302ms) and the 1800-1900ms (0-100ms after affording stimulus onset) tendency in LRP, both of which suggest that participants were prepared to respond more rapidly than in previous experiments. Of course, it is possible that the shorter RT is merely a product of participants having made their categorical judgements in advance, but that does not explain the greater motor activity from 0-100ms here compared with previous experiments. The overall negativity shows a dissociation of the effect of response rule and of object affordance because, despite the preparation of the rule-cued response eliciting overall negativity, the typical affordance effect was still obtained; a sub-threshold positive inflection in the [overall negative] incompatible waveform signalled a brief (100-200ms) preparation of the visible affordance for incompatible trials. The 100-200ms (1900-2000ms) LRP effect adopted the same polarity changes as previous experiments during the same epoch, but did not reach the same overall polarity. Even at its peak the positive inflection in the incompatible wave still had a negative value, however the positive inflection was sufficiently different from the negative inflection in the compatible wave to yield a significant difference between the trial types during the critical 100-200ms LRP epoch, as seen during this epoch in previous experiments. This similarity to previous experiments suggests that this was the typical LRP affordance effect observed previously and the overall negative polarity was merely a factor of the prolonged preparation of the response rule (discussed in greater detail below).

This variation on the SRC affordance paradigm also demonstrates the affordance effect in a novel way because the affording stimulus was not relevant to the task, whereas most experiments have participants examine the affording stimulus when making a categorical judgement. Here, participants were able to make their categorical judgement well in advance of the second [affording] stimulus and as the extremely short RT (approximately 300ms) shows, were prepared to deploy their response extremely rapidly at the onset of the target image, certain that the category of the first stimulus predicted the category of the second stimulus. This means that an effect based on the affordance of the second object still developed despite participants knowing that they did not have to examine the second stimulus at all in order to deploy a correct response. This shows not only that the effect is not contingent on a categorical judgement, but this format also provides novel support for automaticity because not only was the affordance a non-task property (e.g. Tucker and Ellis, 1998 and the majority of SRC affordance research, handle laterality was not relevant to task), but in this experiment only the onset of the second stimulus was task-relevant (acting as a cue to respond) and the affordance contained in the second stimulus was not relevant to the task. Importantly, the task placed no impetus on participants to consider the content of the stimulus as exists in typical affordance SRC experiments where participants must attend the stimulus (and therefore its affordance) to make their categorical judgement. This was discussed by Vainio et al. (2008), who argue that identifying a graspable object necessarily includes processing the action possibilities contained in the object and here, there was no imperative to identify that object to elicit that mode of processing in the way seen in other affordance SRC experiments. Put differently, participants made their categorical judgement on the first, neutrally rotated stimulus and simply waited to deploy it, meaning that the second (affording) image had no bearing on their selected response hand. Despite this the action-relevant information in the non-task relevant second (affording) stimulus still exerted an effect. Finding an effect of an irrelevant affordance has provided the basis for claims of automaticity so the finding is not novel. However this delayed-response SRC paradigm is a novel means of showing this without contamination by the categorical judgement and so compliments the existing literature by showing an effect not only of an irrelevant affordance, but of an irrelevant object with no impetus to attend it. In this experiment it was not necessary to attend the second image that contained the irrelevant affordance yet the affordance effect still emerged, speaking to the surreptitious nature of affordance generation, often treated as occurring in a vacuum, free from interference from intention, necessity or planned actions. Although these factors have been shown to affect affordance generation (e.g. Tipper et al, 2006; Pellicano et al. 2010), experiments five and six from this thesis provide evidence that these are supplementary concerns for affordance generation, which will occur without these influences. This provides a stronger case for automaticity because it suggests that the mere visual presence of the affordance is sufficient to elicit an effect, without the need for a task-device such as a categorical judgement to encourage participants to attend the features of the stimulus, as has been commonplace in the literature.

This conclusion is supported by the findings in visual P1 and N1 components, which showed the same overall effects as previous experiments. This shows that the rapid visual computation of action possibilities indexed by compatibility effects in P1 and N1 still functions without an explicit task-goal to examine the affording object to determine its category. As in the go, no-go experiment this finding supports the notion that these early visual compatibility effects occur regardless of action intentions or prepared actions (which were already determined by the time the second, affording stimulus was displayed) and the presence of an N1 compatibility effect also supports the assertion from the go, no-go experiment that N1 bares a relationship with response, potentially indexing the effect of response on visual perception (e.g. Van Elk et al., 2010; others discussed above). As in the masked and go, no-go experiments the compatibility effect occurred in an interaction with left-occipital sensors, supporting previous recommendations to reconsider the role of occipital cortex in the visuomotor processes elicited by viewing action-relevant stimuli.

The left-hemisphere locus of these effects was again consistent with the notion of a left-hemisphere network for representing object characteristics as suggested by Cisek (2007), Johnson-Frey et al. (2005) and others (discussed in introductory chapter three) however the occipital preference in these effects recommends some revision to these proposed networks to include early occipital areas directly. Overall, these visual data appear to reflect the same processes as in previous experiments, extracting action possibilities from the earliest stages of stimulus perception.

*Later effects*

A second phase of effects occurred in LRP from 200-500ms which saw the compatible wave return to baseline whilst the incompatible wave developed greater negativity after response (mean incompatible RT 306ms), leading to significant effects in ANOVA from 300-500ms that were solely attributable to the incompatible LRP because the compatible LRP no longer differed from baseline. As discussed above, Zhang et al. (1997) have shown that while action-relevant stimuli remain on screen motor preparation will continue. However, this does not explain why t-tests showed that the effects were restricted to the incompatible waveform. One possibility may be drawn from Zhang et al. (1997) being a comparative study where the abstract stimuli did not have the same valence to their primate participants as affording objects do to human participants so perhaps the restriction of these effects to incompatible cases may be a feature of affordance. Perhaps this can be attributed to whether the afforded response is actually deployed in the task. On a compatible trial the afforded response is also the rule-cued response and so the affordance is always deployed. But on an incompatible trial the afforded response is never deployed. So perhaps, because the affording stimulus persists after response the later effects in the incompatible wave represent a suppression of the undeployed affordance according to the response rule. This was not visible in previous experiments because there, afforded LRP activity and LRP activity related to deploying the response occurred in distinct phases, with the response-related LRP activity occurring during the same epoch as these later effects. This leaves two possible explanations for why these later effects were not detected; either the response-related LRP activity was of sufficient amplitude to obscure any later effects, or they merely did not occur because the stimulus offset with response, meaning there was no stimulus visible to elicit a later effect. It is not possible to separate these possibilities without further investigation however based on the present data alone, it seems likely that this is attributable to the stimulus remaining on screen after response, given the occurrence of these effects in two experiments where the stimulus remained on screen and their absence in two experiments where stimuli offset with response.

The negative polarity precludes a preparation of the afforded response which would have a positive polarity with these LRP calculations. However it is impossible to separate the suppression of the affordance from a protracted preparation of the rule-cued response based on these data alone. Galpin et al. (2011) may offer some insight on this point; they found a significant facilitation effect on compatible trials compared with neutral and incompatible trials, which were not significantly different from each other. They used this to suggest that affordance effects are driven by facilitation by action-relevant stimulus properties and not by inhibition. This could be seen to provide an indication that the 300-500ms effects represent suppression (according to the response rule) of the undeployed afforded response that was being constantly primed by the stimulus remaining visible after response, unlike previous experiments. However this is not clear cut and because typical SRC affordance paradigms see stimuli offset with response, other relevant experiments are scarce. As such, further investigation is required to disentangle these two potential explanations of these novel late effects.

Another possibility exists in considering the structure of the task; because participants had already made their categorical judgement and prepared their responses, response deployment is not delayed by the categorical judgement as it was in the previous experiments, as shown by the reduced reaction times (approximately 200ms faster than previous experiments). This means that the afforded LRP activity is overlaid on the rule-cued motor activity. This is unlike previous experiments (one and three) where the afforded preparation and response deployment were visible in the LRP in distinct phases, with afforded activity visible from 100-200ms and being overtaken by response activity after approximately 250ms. These phases were demonstrated in the go, no-go experiment too, where an inversion of the 100-200ms effect occurred during the same epoch as response in previous experiments (commencing around 250ms). This leads to the suggestion that the task-related and afforded LRP activity were no longer presenting serially in the LRP, but instead were overlaid on each other and visible in parallel. This interpretation then characterises the overall negative polarity not as a product of participants maintaining their responses, but of the rapid preparation of the prepared, rule-cued response in the epochs immediately preceding the onset of the second image, without being delayed by making the categorical judgement in order to determine the rule-cued response. Again, this requires further investigation to disentangle from the previous possibilities but receives some support from the findings of the masked, lateralised experiment three, which showed that afforded LRP activity can be dissociated from the LRP effect.

Common among these differing suggestions is the idea that these later effects are due to the stimulus persisting on the screen after response and this is the fundamental difference between experiments five and six (go, no-go and delayed response lateralised affordance experiments) when compared to experiments one and three (typical lateralised SRC affordance and masked, lateralised experiment, respectively). In experiments one and three, objects offset with response and found the same 100-200ms effect without any later effects; only when objects persisted after response were later effects detected. This is a crucial detail because after response, the participant's goal states change and this recalls other evidence on the automatic suppression of affordance when goal states change. For example Vainio (2009) has suggested that the negative compatibility effects observed when an affording stimulus offsets are consistent with the automatic inhibition of affordance according to goal states. Vainio (2009) had participants complete two versions of an affordance SRC paradigm in which they reached toward the location of a stimulus; when the stimulus remained onscreen they found a typical affordance SRC facilitation effect however when the stimulus offset after 300ms the compatibility effect reversed. They suggest that constant online updating of action possibilities in accordance with goal states means that when an affording stimulus (that typically facilitates compatible actions) offsets (or is masked), the typical facilitation effect becomes inhibition and produces the negative compatibility effect. This was observed in LRP in masked, lateralised experiment three. As discussed above, Vainio et al. (2011) also demonstrated similar effects with brief object presentations and reached a similar conclusion. This idea of automatic inhibition of afforded motor responses has been extended by McBride et al. (2013) to explain the involuntary motor actions associated with Alien Hand Syndrome, where McBride suggests that these involuntary motor actions are products of faulty automatic inhibition processes, which fail to sufficiently inhibit afforded actions and ultimately produce the involuntary actions. Sumner and Hussain (2008) have suggested that when goal states change the automatic suppression of afforded responses is beneficial because it allows an agent to act without interference from low-level object properties and in their words, maintains a level playing field for alternative actions. Taken with the present data, these arguments suggest that the later effects observed in experiments five and six may be explained in terms of the automatic suppression of the action afforded by the object when it persists on screen but is no longer relevant to the task (i.e. after participants' goals have changed) and the present use of LRP data extends these behavioural findings to show that the observed RT differences appear to be driven by inhibition of the incompatible affordance, in-line with the response rule. Further research will aid in disentangling the mechanisms and parameters underlying this suppression, however these findings offer a framework in which to explore this element of object perception. In particular, further research could examine whether the reversal of the effects is still observed when stimuli persist on screen but remain task relevant. This could be achieved either by a pure passive viewing task or alternatively, by displaying an affording stimulus for a full second whilst participants complete an unrelated task with no relationship to lateralised affordance.

*Categorical judgements*

The introduction to this experiment described experiments from Tipper et al. (2006) and Pellicano et al. (2010) that showed different judgements on the same stimuli elicited different effects, with a categorical judgement eliciting an affordance effect but no such effect found for colour judgements. The present data indicate that a categorical judgement is not required at the point of response in order to generate an affordance effect and suggests that Pellicano et al.'s (2010) effects are due to features of the colour judgement. Iani, Baroni, Pellicano and Nicoletti (2011) developed Pellicano et al. (2010) using upright and inverted stimuli with handles orientated left or right, similar to Tucker and Ellis (1998) except that they were pictured to the left or right of fixation. They dissociated Simon and affordance effects by having participants make button presses or reaching movements to the stimuli and found that both Simon and affordance effects emerged in RT. They attributed their observations to stimuli generating different codes for object location and object affordance. The present experiment extends the findings of both of these experiments by showing converging evidence that the categorical judgement is sufficient but not necessary to elicit an affordance effect and so shows that (if one accepts their code-based explanation) these codes appear to be generated regardless of categorical judgements or intention to act on the objects, fitting with the assumption of automaticity; that viewing an object is sufficient to yield its affordances.

Overall this experiment confirms the assumption that the categorical judgement is not a crucial part of the generation of an affordance effect and moreover, supports the assumption that viewing objects is sufficient to yield their affordances, regardless of intention or task factors. It supports the dissociation of RT and LRP effects proposed in masked lateralised experiment three. It also offers some interesting insight into the automatic suppression of an affordance that is not deployed but remains visible, something unavailable to previous behavioural investigations.

### *6.4 Chapter discussion*

The experiments in this chapter confirm two implicit assumptions that pervade the literature on affordances; that viewing objects is sufficient to yield their affordances and that the categorical judgement is not critical to affordance generation. This was achieved by developing two novel variations on the SRC affordance paradigm. Experiment five showed that viewing objects is sufficient to yield their affordance by removing the manual response and replacing it with a verbal response in a go, no-go version of the paradigm. This serves a dual purpose in context of this thesis by also showing the affordance effects observed in LRP really are due to the lateralised affordances within the stimuli and clearly separating them from the motor preparations necessarily entailed by the bimanual responses seen in the previous experiments. Experiment six showed that the categorical judgement that is prevalent in the literature and that was shown to affect processing by Tipper et al. (2006), Pellicano et al. (2010) and Iani et al. (2011) is not critical to affordance generation. This experiment also served a dual purpose by showing the typical SRC affordance effect not only when the handle rotation was not task-relevant, but also when the entire stimulus was not task-relevant and merely served as a cue to deploy their prepared, rule-cued response. This shows that whilst categorical judgements do entail the processing of affording object properties (e.g. Vainio et al., 2008) they are not necessary to elicit the effects. Taken together, these demonstrations of the 100-200ms LRP affordance effect provide convincing evidence that supports the findings from experiment one that indicate that affordance has a rapid effect on motor cortex around 100ms after viewing an object and that this effect is borne simply by viewing the action possibilities contained within the objects.

Given the volume of converging evidence, confirming the assumption that the categorical judgement does not affect affordance generation is perhaps unsurprising. However this possibility had not previously been addressed directly and has been assumed implicitly in a great deal of evidence for the affordance account. By showing this by investigating the effects in motor cortex, experiment six serves to underline and expand upon the findings of the wealth of experiments that have come before it (e.g. Tucker & Ellis, 1998; Craighero, Fadiga, Rizzolatti & Umiltà, 1998, 1999; Rumiati & Humphreys, 1998). Moreover, in the later LRP effects it has demonstrated for the first time a differential effect of response rule and object affordance on the motor activity derived by an SRC experiment, another element of the SRC paradigm that has generally gone unconsidered. Similar later activation was observed in the go, no-go experiment too, supporting the idea that as long as an undeployed affordance is visible, action preparation will continue to be detectable in motor cortex. In addition, the present data suggest that if participants' goals change during this time (i.e. they complete the task and await commencement of the next trial), the action possibilities contained within the incompatible stimulus seem to be suppressed.

The confirmation of the assumption that merely viewing objects is sufficient to yield their affordances is another result that whilst unsurprising on its own serves to confirm and expand a long-held and under-investigated belief about the nature of affordance. By providing direct evidence of motor activation in the absence of the intention to act on a seen object the experiment demonstrates that it is possible to dissociate motor preparation caused by affordance and motor preparation caused by the task or rule-based response. The experiment also shows that even when the affording stimulus merely serves as a go signal, the affordance still exerts a measurable effect on motor cortex. These findings are extended by the go, no-go results which show that the effects in experiment six would still be predicted even in the absence of an intention to act, or indeed make any response at all. Together, the novel LRP effects from these experiments provide clear support for the fundamental assumptions and assertions in the affordance literature (*cf.* Ch. 1-3).

Unique to this chapter are the extended stimulus durations of up to a full second. This measure was taken to avoid confounding results with rapid display changes or mask-like effects (seen in experiments three and four), however it also demonstrated some previously unseen effects that affording stimuli have on motor cortex after the initial phase of affordance generation. For instance experiment six shows that having already made their categorical judgements, participants began to prepare their rule-cued responses ahead of the onset of the second stimulus, speeding response deployment. Although this is difficult to separate from the temporal advantage gained by simply having made the categorical judgement in advance, the trial structure (first object predicts category, response maintained until second stimulus onset), the LRP effects from 1800-1900ms (0-100ms after affordance onset) and the reduced RT all support the idea that participants were preparing responses ahead of time. Another previously unobserved effect was detected in both experiment five and six, a reversal of the effects in motor cortex after the initial 100-200ms affordance effect that appear to be due to the suppression of an afforded action that has not been deployed as a response. This is most clear in the go, no-go data where both compatible and incompatible waves reversed at approximately 200ms immediately after the generation of the LRP affordance effect. It seems that once the affordances –which participants knew they would not deploy in a manual response– were generated they were immediately suppressed, as shown by a reversal of the polarity for both waveforms around 200ms. A similar effect occurred in experiment six however it was restricted to the incompatible wave, leading to the suggestion that the reversal constitutes a suppression of the undeployed afforded response because when the compatible response was deployed, the wave returned to baseline but when the affordance was not deployed, preparation continued as in the incompatible wave in experiment six and both waves in the go, no-go experiment (five). As discussed above, behavioural studies have shown the automatic inhibition of affordances when goal-states changed (such as after response deployment in an SRC experiment) by using RT methods (e.g. Sumner & Hussain, 2008; Vainio, 2009; Vainio et al., 2011; McBride et al., 2013) and although several potential explanations are offered above, minimally the LRP data in this thesis suggests that where participants *do* make a manual response (in the context of SRC paradigms) this suppression is primarily associated with undeployed affordances on incompatible trials, with the deployed (i.e. compatible) affordances yielding no further effects after response. When there is no manual response, as in the go, no-go experiment, both affordances would go undeployed and both compatible and incompatible LRPs reversed, as seen over the experiments in this chapter. Although these experiments offer some of the first evidence on this, the pattern of reversed LRP effects over experiment five and six seem to indicate that this suppression is not dependent on the experimental condition, but rather the relationship between visual input and goal states. These effects are unavailable to behavioural RT investigations because these effects come after a response is deployed in experiment six and after the initial phase of affordance generation in experiment five, where no typical manual responses were used at all. This means that without using a technique for recording neurophysiological data, it is impossible to obtain data on these processes with behavioural paradigms alone. As mentioned above, it is not possible to separate the effect in the incompatible wave in experiment six from an extended preparation of the rule-cued response without further investigations however the effects in experiment five do lend a degree of support for this interpretation. It is conceivable that the later (200-500ms) effects observed in both experiments represent different processes, however it seems unlikely and is difficult to explain based on the present data. One barrier to this interpretation of the later effects comes from their absence in experiment one, however as mentioned above these later effects were detected unexpectedly and appear to be by-products of leaving the stimulus on screen for longer than usual in these irregular versions of the experiment that also employed quite different response parameters. Also, in the earlier experiments the large, response-based inflections in the waveform could easily have muted the effects that are only visible here due to differences in the paradigms generating more rapid responses or no responses at all. Three possibilities were discussed in relation to the delayed-response experiment (six) that were all contingent on the notion of automatic inhibition of object affordance following goal-state changes (e.g. Sumner & Hussain, 2008; Vainio, 2009; Vainio et al., 2011) and based on the present data alone, this automatic inhibition of undeployed affordances that conflict with task parameters appears to be a likely candidate. However, this thesis provides some of the only evidence of these effects when the goal-state change is comprised of actually deploying a response so ultimately, these possibilities must be the subjected to further investigation.

Overall this chapter provides novel insight into both the early stages of affordance generation and the later stages of motor activity when viewing affording stimuli for extended periods. In providing these insights the experiments also confirm two implicit assumptions found throughout the literature, providing direct evidence for them by directly examining the associated motor activity.

7. Chapter seven

*General Discussion*

This thesis used event-related potentials (ERPs) to investigate the timecourse of object based affordance by employing and adapting the methods from some of the key behavioural studies in the SRC affordance literature. The temporal acuity offered by the ERP technique was ideal to examine the rapid and transient visuomotor activation indicated in those key behavioural studies and so to investigate the assumptions of rapidity and automaticity commonly asserted in the literature (*cf.* Ch.1-3). This was done initially by employing analogues of the affordance SRC methods seen in key behavioural studies in order to expand on their findings. Experiments one to four were based around the methods and findings of Tucker and Ellis (1998), Ellis and Tucker (2000), Tucker and Ellis (2004) and Vainio et al. (2011) before later experiments used novel variations on the SRC paradigm by varying the response parameters. This chapter will draw these experiments together and consider their implications for understanding neural aspects of affordance, how they compare to the literature and what the consequences are for future treatments. This will commence by restating the key points, studies and issues identified in the introduction, followed by a discussion of the motor effects before visual effects are handled separately in section 7.5.1. Finally, some new avenues of research will be considered.

*7.1 Neural correlates of affordance*

As detailed in chapters one to three, the idea of affordance is fundamentally about supporting real-time actions in a complex world of action possibilities both familiar and novel (Gibson & Gibson, 1955; Gibson, 1977). The concept of affordance rests on two key points; firstly, that merely viewing objects is sufficient to potentiate the actions that they afford, regardless of any intention to act on them. This has also become known as automaticity, which means only that there is no requirement for explicit action intentions to be formed in order for an affordance to be generated; hence they are generated automatically. Secondly, generating these affordances, also described as potentiating actions, has a measurable effect on executing actions. This measurement has typically been done in SRC affordance paradigms, such as Tucker and Ellis (1998), who demonstrated a measurable influence of visual affordance on lateralised manual responses. However others such as Symes et al. (2008) have shown improved RTs in a visual search task when participants prepare a response that is compatible with the target object, demonstrating a two-way relationship between action and perception.

These core points underpin the entire affordance literature. However, as seen in chapter two, some researchers have gone further, using behavioural studies to make deeper inferences about the brain activity underpinning these points. Many of these have been pinned on ideas such as the ventral/ dorsal distinction advanced by Ungerleider and Mishkin (1982) and developed by others such as Milner and Goodale (1995) and Goodale and Milner (1992). In context of affordance, dorsal representation of objects has been described by Gallese, Craighero, Fadiga and Fogassi (1999) as ‘pragmatic,’ meaning dealing with aspects of objects that are relevant to action, as opposed to other aspects such as their semantic features. Examples of affordance effects and explanations couched in these terms may be drawn from some of the references that are most important to this thesis, such as Tucker and Ellis (1998) or Ellis and Tucker (2000) who assert that the salient object features for affordance generation –those that produced their effects– are represented in the dorsal stream, such as size, shape and orientation. Others have taken it further, such as Norman (2002) who has suggested that all affordance effects are dorsal in nature and proposed revising the ventral/ dorsal dichotomy into a constructivist/ ecological dichotomy to account for the different approaches to vision and their similarities to the ventral/dorsal distinction, effectively subsuming all behavioural affordance effects into the dorsal stream in one fell swoop.

Others have made similar claims without the ventral/ dorsal distinction; Edwards, Humphreys and Castiello (2003) also claim that viewing objects directly generates motor activity based only on behavioural evidence and secondary evidence from other publications. Witt, Proffitt and Epstein (2005) argue from behavioural evidence that whether an object is in reach or not has a distinct neurological effect, although they do not specify this effect clearly. Fischer and Dahl (2007) examined bimanual button press RTs to an animation of a rotating cup and found that RT changed continuously with the stimulus rotation. Beyond these summary references, a great deal of behavioural research studies(*cf*. Ch. 1-3) make the fairly general claims that the motor effects associated with viewing objects (or even object names) must be detectable rapidly (e.g. Fischer, Prinz, & Lotz, 2008; Sumner & Husain, 2008; Pavese & Buxbaum, 2002) and automatically (e.g. Tucker & Ellis, 1998; Grezes & Decety, 2002; McBride et al., 2012) as products of visuomotor processes (e.g. Tucker & Ellis, 2004; Vingerhoets et al., 2009; Buxbaum & Kalénine, 2010). Conversely, despite the volume of behavioural studies with brain claims there are limited models around them. Cisek (2007) offers one of the few however his fMRI-centred approach offers a poor fit with the electrophysiological data, with no provision for the occipital or early visual effects observed in ERP studies and in this thesis and a focus on frontal and parietal cortices that is not borne out in ERP.

The existing evidence on this is limited and was summarised in chapter three. The evidence overwhelmingly indicated fairly rapid motor activation by object affordance, however the variety of stimuli employed across the different studies did not yield a consistent timecourse, with different affordance classes and indeed paradigms yielding a range of motor effects from 100ms up to 400ms. For example, Proverbio et al. (2011) found effects at around 250ms in a passive viewing paradigm with a stimulus set consisting of a wide variety of manipulable tools (e.g. typewriter, paintbrush, puzzle cube) that afforded a wide variety of actions involving one or both hands. This means that the results may have better ecological validity than studies which use only a single affordance (e.g. lateralised teacup handle affordances in Tucker and Ellis, 1998), however it highlights another issue with the existing literature on neural processes in affordance; it can be very difficult to attribute particular effects to particular characteristics of the SR set because many of the experiments had stimulus sets containing a mixture of affordances. This difficulty is compounded when other studies using similarly mixed stimulus sets find quite different timecourses, such as Proverbio et al. (2007) who found a motor effect with similarly diverse stimuli from 130-160ms. To alleviate this and to get closer to the behavioural results that underpin this literature, the experimental work here focussed on a particular affordance for each experiment and included a within subjects experiment using both lateralised and grip-type affordances. Although a number of localisation experiments such as Grezes et al. (2003) have found effects elsewhere (particularly parietal cortex) that appear to relate to affordance processes, most electrophysiology on the subject has only considered motor and visual cortices (as detailed in Ch.3) and that was adopted as the approach here too because the claims from the behavioural literature tend to describe "motor activity" or refer to processes as "visuomotor". So restricting the analysis in this way allowed for more clear assessment of the behavioural claims of visuomotor processing and motor activation by visual objects described in the SRC affordance literature.

### *7.2 Experimental summary*

This summary and discussion of the experimental work will follow the order of experiments as presented in chapters four to seven. Sections 7.2 to 7.4 will focus on the motor effects, with a separate section (7.5) to discuss the visual effects across all experiments. These will finally be brought together in section 7.6.

### *7.2.1 Chapter four; the core effects*

Chapter four featured two experiments designed to replicate the behavioural SRC affordance effects observed in Tucker and Ellis (1998) and Ellis and Tucker (2000) with ERPs to better understand the visual and motor processes underlying them. As discussed above, these studies found reduced RT and errors when SR pairs were similar compared to when they were dissimilar, regardless of whether they shared a spatial relationship (Tucker & Ellis, 1998) or physical characteristics (Ellis & Tucker, 2000), even though similarity was not task relevant. They concluded that viewing the stimuli automatically activated representations of the afforded actions in the dorsal stream, which led to the effects due to the role of the dorsal stream in the online control of actions. Experiment one used lateralised affordances similar to Tucker and Ellis (1998) and experiment two used the grip-type affordances from Ellis and Tucker (2000). Both experiments observed the typical SRC affordance effect in RT however quite different results were observed in LRPs and this difference will be the subject of this section. Experiment one's lateralised stimuli yielded a compatibility effect with a bimanual button response, detectable over motor cortex from 100-200ms however the grip-type stimuli of experiment two did not yield an effect until 200-300ms on the same sensors. All later experiments using lateralised stimuli also found their effect from 100-200ms however the only other experiment (experiment four) using grip-type stimuli failed to find an LRP effect, yielding only a behavioural RT effect. In the visual components (discussed in 7.5.1) the lateralised stimuli elicited compatibility effects in P1 and N1, however the grip-type experiment failed to yield any compatibility effects in visual components.

### *7.2.2 Intrinsic vs. extrinsic affordances; a representational explanation*

The different LRP timings found in the grip-type and lateralised experiments must be due to the different kinds of affordance used in each experiment, because other than the SR pair utilised the paradigms are ostensibly the same. Only a handful of studies have addressed this difference; Derbyshire, Ellis and Tucker (2006) discussed this issue and suggested a distinction between intrinsic and extrinsic object properties. They define intrinsic object properties as invariant object characteristics such as size or shape that do not vary based on presentation parameters and will always be part of viewing a particular object. These features necessarily co-occur with object presentation and so will always produce motor preparation, regardless of how the object is presented. Extrinsic properties are those that are based on the physical relation of viewer and object and so may vary with presentation parameters, such as handle orientation. These properties are called extrinsic because they are not a necessary part of the object representation. So, unlike intrinsic object properties the extrinsic object properties will not always yield the same affordance and instead their affordance is contingent on the way they are presented and the relationship of that presentation with the agent's effectors. Derbyshire et al. (2006) illustrate the difference as follows; objects with intrinsic affordances are those whose action-relevant properties are known when the objects identity is known, with no need to see the object. For example, one *does not* require visual input to know that the apple stimulus used in the grip-type experiment (experiment two) affords a power grip or that the nut affords a precision grip. In contrast, the lateralised affordances *do* require visual input to yield an affordance because their identity alone does not necessarily confer use by a particular hand without being oriented in a particular direction. So unlike objects with intrinsic affordances, these extrinsic affordance objects would not generate an affordance based on their identity alone. They suggest that this instantiation of object representations is compatible with Marr's (1982) suggestion that visual representations do not preserve non-identity properties such as orientation or colour but do include an object-centred spatial description of the object, preserving invariant object properties such as size, shape and other identity-critical features. This defines the compatibility effect observed in lateralised experiment (one), which found a compatibility effect in LRP at 100-

200ms, as a product of an extrinsic object property. In turn, it defines the compatibility effect observed in the grip-type experiment (two), which found an LRP effect from 200-300ms, as a product of an intrinsic object property. This does not however lead directly to an explanation of the observed differences; why would extrinsic object properties activate motor cortex sooner than intrinsic ones? Distinguishing between extrinsic and intrinsic object properties is dependent on the way stimuli are presented, offering a possible explanation based in presentation parameters; experiment two saw the grip-type stimuli centred in the stimulus image and mostly symmetrical around the midline, however in order to have lateralised stimuli experiment one necessarily had functional (e.g. hammer head, pan) and graspable parts (i.e. handles) of the stimuli on different sides of each image. This means that lateralised stimuli always cue a hand because the handle is always lateralised, regardless of whether it is the correct hand according to the response rule. So, when the object is identified and the rule-based response is determined one of two things will occur depending on the type of trial; on a compatible trial the compatible response that has already been primed by the visual input will be immediately deployed for the object-cued hand. On an incompatible trial, the response hand cued by stimulus laterality is not correct so the response primed by handle orientation must be abandoned and re-planned according to the response rule. In the grip-type experiment, the stimuli do not cue a particular response hand until the object has been identified and the response rule is parsed simply because the stimuli do not contain any laterality information. So according to Derbyshire et al.'s (2006) account, with grip-type SR pairs the process does not differ for compatible and incompatible trials as it does with lateralised stimuli, simply because there is no extrinsic affordance to cue a particular hand before object identification has taken place. This distinction makes clear predictions as to the source of the differences but does little to explain the mechanisms by which they may come about, a weakness of this explanation. So, experiments using intrinsic object properties (like the grip-type affordances from experiment two) might always yield a later LRP effect because compatibility is reliant on the object being categorised before a response hand is cued or selected, unlike lateralised stimuli which cue a response hand before the rule-based response is determined. This is similar to the explanation given elsewhere for slower responses on incompatible trials; the response is contingent on the categorisation being completed before the appropriate response can be cued and on incompatible trials this will always be mismatched leading to the longer RT. However, recent research has indicated that affordance effects are products of facilitation of compatible responses more than an influence of incompatibility (Galpin et al., 2011). Other studies have shown that the notion of inhibition by incompatible responses applies to spatial SRC experiments but not with affordance SRC experiments (Pellicano et al., 2010) where effects are driven by facilitation, so another explanation that accounts for the facilitatory nature of compatibility is required. An alternative explanation within the remit of Derbyshire et al.'s (2006) intrinsic vs extrinsic dichotomy may be drawn from the types of objects used in each experiment. The extrinsic, lateralised affordances used in experiment one were binary, with all stimuli orientated along the same rotation to the left or right. However for the intrinsic, grip-type experiment (experiment two), the dimension for compatibility was the variation in size (and therefore associated grip) which is a continuum. This could conceivably delay the processing of grip-type stimuli because their relationship with response is not binary, introducing an extra layer of processing to determine the relative scale of the object to the woodgrain background or other stimuli. This is necessarily conflated with the idea of intrinsic vs extrinsic affordances because size is an intrinsic object property, making it hard to isolate and address directly based on these data alone, but it does represent another difference between affordance classes that has received little attention and that could merit further investigation.

*7.2.3 Affordances of function and geometry*

Another view on different sources of affordance comes from Zhao and Zhu (2013) who attempt to distinguish different affordances classes in terms of a computational model for parsing visual scenes. They draw a distinction between functional and geometric affordances and suggest that functional affordances are critical to defining usable objects; the function of an object determines its use and often other characteristics too (e.g. materials), as well as how to interact with the object. Geometric affordances are described similarly to Derbyshire et al.'s (2006) intrinsic object properties in that they are invariant and contingent on the structure of an object and will be the same regardless of viewing angles, modes of presentation or other factors. However Zhao and Zhu (2013) go further than Derbyshire et al. (2006), saying that geometric properties necessarily subserve the functional properties because it is the shape of the objects that aids their use in goal-directed actions. By Zhao and Zhu's definition, man-made objects contain both functional and geometric affordances, with the geometric affordances indicating how to employ the functional affordances for goal directed actions, whereas most natural objects (or man-made objects without explicit functions) may only offer geometric affordances. In turn, they say that the functional affordance of an object is what connects man-made objects and human actions. On Zhao and Zhu's (2013) account, the lateralised affordance effect found both in the RT and LRP data in experiment one offers a good example of how geometric properties serve functional properties because the lateralised stimuli contained both functional and geometric affordances. The effects arose from a combination of the functional properties of the object, specifically the location of its manipulable component (usually the handle), and that components geometric orientation (left vs. right) with respect to the participant. By Zhao and Zhu's (2013) distinction the geometric configuration of the [functional affording] lateralised handles offered a geometric affordance (that was compatible or incompatible with left and right responses) that was critical to extracting the functional affordance (because it determined the orientation of the functional parts). However, breaking down the dichotomy with real lateralised objects in this way becomes quite self-contradictory, with geometric affordances yielding functional affordances that are still contingent on the geometric configuration of the objects, making a very unclear picture. This exposes another shortcoming in their distinction between functional and geometric affordances; the geometric affordance (that –on this model– subserves the functional affordance and which together generated the observed effects) in the lateralised stimuli *is* a variable object property. However their dichotomy states that geometric properties should be invariant. Moreover, it is the geometric configuration of the functional parts that yield the compatibility effect with the lateralised (i.e. geometric) responses, despite the variable object property of handle orientation being a variable property of the functional part of the objects. This demonstrates that Zhao and Zhu's (2013) dichotomy struggles to capture all of the dimensions involved in lateralised affordance SRC with real objects.

The grip-type stimuli share a similar problem to the lateralised stimuli; in the natural category the objects have no functional properties, instead offering only geometric affordances based on their size and shape and it was these geometric affordances that yielded the compatibility effect for the natural objects. However, the man-made objects lacked this clarity; some of the man-made objects in the grip-type experiment (two) offered both functional and geometric affordances that were the same (e.g. holding and drinking from a soft drink can requires the same grip). However others were not so clearly distinguished; for example, the pen stimulus was compatible with a precision grip, however this is not the grip that one would use to write with a pen. This same problem also applied to other stimuli such as the rolling pin or screwdriver. Similarly, the drinking-straw stimulus was compatible with a precision grip however its function (drinking) does not require any manual grip whatsoever. This suggests that whilst this distinction may be useful for explaining the hierarchy of functional and geometric properties that yield affordances, it is insufficient to handle the complexities of an affordance SRC paradigm with common household objects, at least with the SR pairs used in experiments one and two. This may be due to the paradigm being somewhat contrived compared to the real-world vision Zhao and Zhu (2013) set out to model. Their intention to model scene parsing in real rooms also entailed them considering very different objects in their modelling, such as wardrobes, chairs and stairs without reference to particular bodily states. These bodily states of course are critical to yielding compatibility in SRC paradigms. So to summarise, according to Zhao and Zhu's (2013) dichotomy, the affordances that yielded the observed effects in the lateralised and grip-type SRC affordance experiments (one and two) were mostly geometric, even when based on functional parts. And the distinction is further confounded because some of the man-made grip-type stimuli had the same functional and geometric affordances (e.g. soft drink can, bottle) whereas others were quite different (e.g. writing with a pen compared with merely picking one up). So, this does not offer a clear interpretation of these data.

Zhao and Zhu's (2013) study represents one of few attempts to distinguish different classes of affordance, meriting its inclusion here. However they did not set out to offer a model of affordance SRC, rather they attempted to model different classes of affordance for a computational model of scene parsing and so their model lacks sufficient reference to bodily states. In this way their model does not account for the full dimensions entailed in the relationship of stimulus and response that are critical to produce the observed effects and their dichotomy appears to put the quite different grip and lateralised affordances together in a single category. Whilst this distinction may be useful elsewhere, the lack of reference to responses by Zhao and Zhu (2013) make for a poor explanation of affordance in the context of SRC where effects arise due to a combination of affordance and body position. On this subject, it is notable that although Derbyshire et al.'s (2006) dichotomy was developed around behavioural affordance SRC data, it also gives little credence to the response. A third explanation will now be considered that focuses on the properties of the response in shaping the observed differences.

### *7.2.4 An embodied explanation*

Neither Zhao and Zhu's (2013) or Derbyshire et al.'s (2006) distinction lead to a fruitful explanation of the later LRP effect for grip-type affordances compared with lateralised. However both share a common feature; both are primarily concerned with the nature of the stimulus and do not consider the response, a strange characteristic for attempts to distinguish affordances, especially given the evidence cited above (e.g. Ellis & Tucker, 2000; Symes et al., 2008) that responses affect the way objects and affordances are perceived. This is an issue highlighted by Stins and Michaels (1997), who said that SRC effects are best characterised as compatibility between visual information and available actions and suggest that the role of the response (the available action) is typically underemphasised. This is particularly pertinent here where –as detailed above– the grip-type responses in experiment two were very different to the button press responses of experiment one, yielding a later LRP effect at 200ms instead of 100ms. With this in mind, a third, more comprehensive means of addressing this difference –one that also accounts for the differences in response– may be drawn from embodied cognition. As described in the introduction, embodied cognition seeks to offload cognitive effort onto the body in order to facilitate real-time interactions and reduce the complexity required to model cognition. Invoking the body in cognition is clearly in line with Stins and Michaels' (1997) suggestion that responses merit greater consideration. There is also a movement within embodied cognition to de-emphasise the role of complex and detailed mental representations in cognition (of the type that are problematic for Derbyshire et al., 2006) and instead focus on more direct accounts of perception that involve the body (embodied cognition) or the local environment (often called situated cognition). This makes an ideal candidate for explaining the compatibility and affordance effects, which were generated by interrelations between body and stimulus. An ideal explanation may be based on the Philosophical work of Andy Clark, an advocate of the embodied approach who suggests that the generation of complex internal representations is too costly to represent an effective strategy for real-time cognition (Clark, 1989; 1998). Instead, he cites what he calls the '007 principle' which states that agents (human or otherwise) need only acquire the information required to complete their goal and do not need to build detailed, complex mental representations to perform simple tasks and actions (Clark, 1989). Most important to this discussion, Clark (1989; 1998) suggests that this is mainly gathered from and supported by environmental features or the agent's body (Clark, 1998). He calls this support 'scaffolding'[1], referring to physical support for mental processes. This idea is particularly pertinent to distinguishing lateralised and grip-type affordances because each has participants make quite different responses which bear quite different relationships with the stimuli. The grip-type SRC experiment (two) saw a direct match between response grips and the grips required to interact with the stimuli and indeed had participants maintain the grips required to interact with the stimuli throughout the experiment and found a compatibility effect in LRP at 200-300ms. This was not true of lateralised SRC experiment one which found a compatibility effect in LRP at 100-200ms based only on a spatial relationship between the lateralised handles and the bimanual button press response; this SR pair shared spatial compatibility but did not share the identical action affordances seen in the grip-type experiments. Considered in terms of embodied cognition, these different body positions belie greater differences underlying

[1] The origins of scaffolding can be traced to Vygotsky's approach to developmental psychology, although he did not use this moniker (Stone, 1998) and originally described the possibility of improving learning by making specific interjections to aid children in learning how to complete novel and complex tasks that may otherwise be beyond their ability. Incidentally, this fits with the Gibsonian notion of affordance aiding interactions with novel objects, where the affordance provides the scaffolding.

the LRP timing differences between experiments one and two than other accounts given above and begin to offer a basis for the observed differences in ERP:

Examined in embodied terms, the maintenance of the grips throughout the grip-type experiment (two) suggests that the initial phase of affordance generation differed from the lateralised experiment because the participant's body position already reflected the afforded action. This means that participants' motor cortices also reflected the afforded action because it was supporting their hand position. This eliminates the need to generate an affordance when objects were presented because that affordance had effectively already been generated because maintaining the response grips was already producing and maintaining the motor activity afforded by the stimulus. Whereas in the lateralised experiment, the participants maintained their thumb over the response button which shared no physical characteristics with the handle affordances they were viewing, necessitating the generation of new affordance based on the visual stimulus. Approached in this way, two different courses of action open up for processing each different object affordance; the grip-type affordances match the body position of the participant, so the visual affordance is rapidly found to match the prepared response, reducing the temporal and computational demand to generate a new affordance because the affordance was already prepared and being maintained in motor cortex by virtue of the response devices. On this embodied account, maintaining grips reduces the pressure to generate an entirely new affordance because maintaining the grips activates many of the same populations of neurons that would generate an affordance effect upon viewing an object, scaffolding perception of the afforded grip (e.g. as in Symes et al., 2008). So effectively, maintaining the grips is scaffolding cognition by embodying elements of the visual input and provides stronger activation of the grip associated with the affording object than would be generated by the visual input alone, which would only be expected to generate quite low levels of activation of the afforded grip. This follows because that the affordance only generates a baseline level of activation of the afforded grip in order to facilitate using that grip, and so the status of this this facilitation as a precursor to an action may be reasonably suggested to be a smaller effect than the activity generated by actually making the grip, which means actually performing the afforded action. This is critical to the notion of affordance as being rapidly generated to facilitate action in real-time, but also rapidly disposed of in order to avoid interfering with actions or generating excess computational load. So, this offers a possible explanation where maintaining the grips alleviates the temporal pressure and explains the later effects for grip-type (200-300ms) compared to lateralised stimuli (100-200ms) that fits well with the present data and the relevant literature. This requires further investigation, but if this suggestion is correct it implies that the different LRP effects could even reflect different processes such as determining rule cued responses or facilitating responses, however this is merely conjecture at this stage.

In contrast, this idea suggests that the difference between the lateralised handle affordance and the button press responses in experiment one meant that the lateralised SR pair *did* require participants to rapidly generate the stimulus affordance within a motor system that was primed to make a different response. Because participants were primed to make a different response, when they received the visual input from the stimulus which did not match their prepared actions, the motor system rapidly and automatically generated the newly presented affordance in the absence of body position to support it. Indeed the early activity may represent the motor system determining the spatial compatibility of the SR pair during this 100-200ms activation however this is currently difficult to ascertain. Either way, these data indicate that the earliest stage of affordance generation is conducted very differently with grip-type SR pairs when compared with lateralised SR pairs and accounting for embodied factors such as hand position offers a reasonable starting point to explain the ERP/LRP differences between these behaviourally equivalent affordances. Indeed, the idea that different affordances may be processed differently opens up new possibilities in terms of how affordances are handled in general. In particular, the embodied explanation suggests that the 200-300ms ERP effect seen in the grip-type experiment (two) is not merely a delayed version of the activity seen in the lateralised experiment (one). Rather, it could represent something different to the 100-200ms effect seen in the lateralised experiment (one), which appears to index affordance generation because activity varied systematically with handle laterality. One possibility is that the later (200-300ms) activity observed in the grip-type experiment (two) reflected the motor system detecting compatibility between stimulus grip and response grip. Another possibility is that the activation was associated with determining the category of the stimulus in order to complete the task, which would necessarily involve parsing the whole object and according to some accounts given above, should activate the associated actions in the process. That the maintenance of a particular grip may influence visual and motor processing is not a new suggestion and is supported by Symes et al.'s (2008) change blindness study, which found improved change detection in complex, rapidly changing scenes when maintained grip was compatible with the target object. This study was conducted using the same grip-type response devices as experiment two and demonstrates that maintaining a hand posture affects the way stimuli are processed and perceived, with stimuli that are similar to body position subject to more rapid processing (detection in this case) compared with those that are dissimilar to body position. In this study the hand position embodied the goal for the visual search leading to shorter search times when hand position and target object shared an affordance. Other support may be gathered from Van Elk et al. (2010) who found that grasping compared with pointing at a power-grip response device elicited a different visual effect, much like the present thesis where lateralised affordance experiments all detected compatibility effects in visual components but grip-type experiments detected none. These references, considered alongside the results of the grip-type and lateralised experiments support the notion that hand position and its relationship with the stimuli not only produced the familiar SRC affordance effect but moreover that these behaviourally equivalent effects are potentially very different at a motor level simply due to the responses employed.

So, the LRP differences between experiments one and two provide an early indication that the differences between affordances theorised (Derbyshire et al., 2006; Zhao & Zhu, 2012) and described above also have measurable differences in the way that they are processed and this appears to be best accounted for by the embodied notion that prepared actions scaffold perception. This mode of explanation offers a starting point to further explore differences between affordance classes whilst accounting for an under-emphasised (Stins & Michaels, 1997) component of the affordance SRC paradigm, the response. It offers novel considerations for future work in the area and highlights some novel avenues for research which will be discussed later. However, before that is possible further clarity is required. Having been conducted on separate samples, these experiments offer relatively slim insights into the deeper questions raised by these differences and the use of separate samples leaves open the possibility of individual differences confounding the results. For that reason, experiments three and four probed this further by using a within subjects, rapid backward masking variation on experiments one and two in order to verify the differences observed in chapter four.

## *7.3 Masked experiments summary*

### *7.3.1 Key references and results*

In order to expand on the LRP timing differences observed between lateralised and grip-type SRC affordance paradigms in chapter four, the experiments in chapter five adopted a backward-masking variation on the paradigms. A within-subjects design was used in order to verify that the differences discussed in section 7.2 were not merely a product of using different samples and reflected genuine differences in the handling of different affordance classes. With most affordance SRC paradigms the direction of behavioural results are the same, finding reduced RT and error rates in compatible SR pairs compared with incompatible, regardless of the SR pair employed (e.g. Tucker & Ellis, 1998; Ellis & Tucker, 2000). The lateralised experiment (one) and grip-type experiment (two) in this thesis supported this, however the ERP data found considerable differences underpinning these behavioural effects. Unexpectedly, the timecourses of the LRP effects were very different, with lateralised stimuli eliciting earlier effects than grip-type stimuli. Additionally, only the lateralised affordances elicited any interactions/effects in visual components N1 and P1. This suggests that although the lateralised and grip-type affordance SRC effects may manifest in the same behavioural effects, they appear to be products of quite different processes. These unexpected differences in ERP metrics motivated experiments three and four to try to confirm and expand upon these differences using a within-subjects design. Looking to the literature, Tucker and Ellis (2004) and Vainio et al. (2011) employed masked paradigms on grip-type and lateralised stimuli, also revealing differences between the processing of these affordance classes. For reference, this evidence was reviewed in section 5.1.

A difference between grip and lateralised affordances was observed again in experiments three and four in line with the behavioural results cited above; experiment three (lateralised stimuli) found a negative compatibility effect in LRP commencing at 100ms, the same time as lateralised affordance SRC experiment one. The negative LRP effect is in line with the prediction from Vainio et al. (2011) who also found a negative compatibility effect with masked, lateralised affordances at similar SOAs. However no behavioural effect was detected, demonstrating that the LRP effect appears to occur when merely viewing an object but that this can be disrupted by masking without producing an RT effect. This experiment demonstrates that the early affordances observed in the LRP effect do not necessarily lead to a behavioural compatibility effect. This conclusion is supported by the masked, grip-type affordance SRC experiment (experiment four), where no LRP effect was detected but a typical SRC affordance effect was observed in RT for grip-type stimuli. The typical compatibility effect observed is in line with Tucker and Ellis (2004), who also found a positive compatibility effect with masked grip-type stimuli at similar SOAs. However, the lack of an LRP compatibility effect suggests the downstream influence of early motor activation is not the only route to generating a behavioural compatibility effect. These experiments form a double dissociation of the observed LRP and RT effects from the lateralised (experiment one) and grip-type (experiment two) experiments in a within-subjects design, confirming the differences observed between LRPs in experiment one and two are reliable and not attributable to the use of different participants. This dissociation shows that the RT effect is not necessarily contingent on the LRP effect and that an LRP effect doesn't necessarily cause an RT difference. This generates two questions; firstly the idea that the RT is not contingent on the LRP is interesting because in experiment one and two they both reflect the same compatibility effect and it appeared that the LRP effect caused the RT effect. This begs the question of what leads to this RT effect if not the LRP seen in previous experiments? Secondly, the idea that LRP does not necessarily cause an RT difference speaks to the assumption of automaticity; merely viewing an object is supposed to automatically yield its affordance, which should influence downstream processing and produce a compatibility effect. This was not the case in the masked, lateralised experiment (three) where an LRP effect was obtained, indicating that viewing the object produced a motor effect but without eliciting an RT effect, demonstrating that under backward-masking conditions, early LRP effects do not necessarily influence RT. Put another way, these data show that this influence may be disrupted by changes in the visual input. This section will first address the question of the RT effect found in the masked, grip-type experiment (four) where the LRP was absent, before returning to the question of automaticity at the end of this section and in 7.4.

Taken at face value, the masked, grip-type experiment (four) could be seen as indicating that the RT effect is not contingent on the early LRP effect. Whilst this may be true it is unsatisfactory, not least because no other significant LRP effects were observed in experiment four to explain how the RT effect occurred, suggesting there are other factors at work. In order to explain the differences between results the differences in the paradigms must be considered first; presentation, participants and all other characteristics were the same. The only difference between experiment three and four was the SR pair. As discussed in section 7.2, typically explanations focus on the stimulus affordance and do not consider the response or the correspondence in the SR pair, however as we will see, the response may be the most important factor in accounting for the unpredictable pattern of results observed in experiments three and four.

*7.3.2 Returning to the representational account*

The intrinsic vs. extrinsic affordance dichotomy advanced by Derbyshire et al. (2006) (described in 7.2.2.) offers one possible view on this that is embedded in the typical explanation from stimulus affordance alone. On this account, the lateralised experiment obtained a reversed LRP effect because the extrinsic affordances are not represented in the same way as the grip-type stimuli because it is not integral to the object. This point is both a strength and weakness of this explanation; a strength because it invokes the same object properties to explain the different results, with each explanation couched solely in the physical structure of the object. However, it is a weakness because it makes large, poorly-evidenced assumptions about the nature of mental representations, a notoriously elusive concept and one subject to considerable debate. For example, Ballard (1991) described in detail the problems with representational accounts, particularly with attempting to model phenomenological vision (the experience of vision) in robots capable of actions. The argument was pinned on the computational expense of generating, maintaining and referring to such representations and the necessary temporal costs of such extravagant models of the world. Ballard said, “it may be the case that maintaining such elaborate representations is unnecessary, since they can be rapidly and incrementally computed on demand.” She points out that when models move away from Marr’s (1982) notion of viewer-centred representations (integral to the intrinsic vs extrinsic dichotomy) and become world-centred, i.e. focus more on the agent’s environment, then locally effective features such as object colour –which by Marr’s (1982) account are not integral to an objects representation– are able to guide actions more cheaply and with greater efficacy in computational models. This idea about colour applies equally to object orientation; this is a variable feature that is not crucial to identifying an object but is a necessary consideration when directing behaviour towards an object because its orientation relative to the observer affects how the observer will interact with it. This is similar to the principle demonstrated in the literature on peripersonal space and affordance; affordance generation is contingent on factors that determine the immediate usefulness or usability of an object. For example, Costantini, Ambrosini, Tieri, Sinigaglia, Committeri (2010) conducted a series of experiments where they presented a lateralised affordance stimulus (a mug, similar to Tucker & Ellis, 1998) so that it appeared to be within reach or too far away to reach. They found that when the object appeared too far away to reach, no affordance effects were generated and that this remained true when controlling for visual angle subtended by the stimulus. They assert that affordances are not only reliant on what they call the ‘mutual appropriateness’ of affordance and available actions that the affording objects ability to produce motor activation is tightly bound to an individual’s opportunities to interact with it. This is echoed by other authors such as Chemero (2001; 2003; 2009) who contend that when accounting for factors such as reachability affordance generation becomes conditional on a three-way relationship between object properties, available actions and the agent’s environment, introducing features such as reachability or interference from the local environment as considerations in developing an ecologically valid understanding of affordances and object interaction in the wider sense. This supports the idea presented here that environmental considerations such as object orientation compared with effector location are critical to the generation of affordance and further questions the usefulness of Marr's (1982) emphasis on identity-related features in object representations.

Referring to the idea that object representations depend on these local, environmental and individual concerns (e.g. object orientation or location), Clark (1997) calls these 'personalised representations' because they are developed to meet an individual need of an individual agent in a particular situation. This is in contrast to the notion of generalised, fixed representations that focus on identity-related characteristics described by Marr (1982) and Biederman (1987) and found in Derbyshire et al. (2006). Clark extends the idea, suggesting that representational accounts tend to neglect the human tendency to structure environments to reduce computational loading and that accounts that allow for more direct reference from agent to environment offer equal or greater explanatory power at a much lower computational cost. On these accounts, properties defined by Marr (1982) as non-essential to a representation (e.g. colour, orientation) become more essential in terms of the practical aspects of guiding and executing the actions. One of the critical problems with representational accounts such as Derbyshire et al.'s (2006) dichotomy was described by Port and Van Gelder (1995), who suggest that representational accounts of cognition struggle to meet the temporal constraints of real-time behaviour due to the spiral of increasingly complicated and abstract ideas invoked to explain cognition. This point is critical to this thesis which was begun in the spirit of embodied cognition, a framework chiefly concerned with explaining real-time interaction (Wilson, 2002) and one that in many cases eschews representational accounts in favour of more direct accounts of perception. When considered in this framework the direction and temporal characteristics of the LRP and RT effects do not support the representational account because a reversal of the compatibility effect was observed in masked, lateralised experiment three where no effect should be observed if no laterality information was represented. Instead the reversed compatibility effect obtained in LRP indicates that some laterality information persisted and was suppressed. These points question the account offered by Derbyshire et al. (2006) because they show that affordance is not generated solely based on identity-critical features, as shown by the effect of the extrinsic property of orientation in the absence of the stimulus object. However the real problem for this account of the results comes from the data itself; if the results of the masked, grip-type experiment are to be explained in this way then it stands to reason that a compatibility effect should be detectable in LRP to corroborate the idea that the RT effect is a product of a mental representation, however no such effect was detected. Put another way, the motor advantage observed in RT for the masked grip type experiment was detected without a corresponding effect in motor cortex, implying that something else must be supporting the observed RT effect. That said, Derbyshire et al. (2006) does not make predictions about areas outside of the dorsal stream that might support this cognition and no other effects were detected in visual ERPs to support this (see section 7.5). Also, reiterating the criticism from section 7.2.4, this explanation of affordance SRC focuses exclusively on the stimulus with little to no reference to the response, something emphasised by Stins and Michaels (1997) and Chemero (2001; 2003; 2009). These factors cast Derbyshire et al.'s (2006) representational account of different affordance classes in a difficult light because there are several serious insufficiencies in the explanation when considering these data. This leads back to the embodied explanation advanced in section 7.2.4 which suggests, based on embodied principles (e.g. Anderson, 2003; Wilson, 2002) that the maintenance of the grips throughout the experiment is scaffolding perception of the stimuli and is likely to be effective in producing the compatibility effects, as evidenced by studies such as Symes et al. (2008) or Van Elk et al. (2010) who showed very different effects with affording stimuli that were modulated by participants' hand position. This explanation seems stronger when considering the lack of an LRP effect to correspond with the RT effect in this masked, grip-type experiment. The following subsection will discuss this.

### *7.3.3 Returning to the embodied account*

On the embodied account advanced in 7.2.4, a compatibility effect is observed in the masked, grip-type experiment (four) due to the nature of the response devices because participants maintained the grips required to interact with the stimuli, scaffolding the perception of the stimuli by partially activating populations of neurons associated with handling the object (e.g. Hommel et al., 2001). This account suggests that the motor preparation caused by maintaining the grips effectively embodies the object characteristics, scaffolding cognition and leading to the compatibility effect observed in RT in the masked, grip-type experiment (four). The compatible response is primed during the brief object presentation and because the grips are maintained the effect is detectable as a positive compatibility effect even after object offset. In turn, this explanation suggests that the negative compatibility effect observed in the masked, lateralised experiment (three) occurs because the lateralised SR pair does not have the same degree of overlap as the grip-type stimuli and so lacked the relevant features to still obtain a compatibility effect after the object had offset. Instead, as suggested in Vainio et al. (2011) the partial information gathered from the brief stimulus presentation is suppressed, producing the negative compatibility effect. This suggestion is borne out by the LRP data, which shows the incompatible wave does not differ from baseline and that the observed compatibility effect is a product of the statistically significant suppression of the compatible LRP.

This explanation is not necessarily at odds with the representational explanation advanced above but could subsume it; the differences in what is represented could be a product of the response employed in the different paradigms. However it may also be the case that this is better explained by a more straightforward account from embodiment alone and differentiating these possibilities is extremely difficult without a great deal of further experimentation. Nonetheless, the intrinsic vs. extrinsic dichotomy provides an unsatisfactory explanation of the results here for the reasons given above whereas the embodied explanation accounts for all facets of the data. This explanation receives wider support from other research in embodied cognition; Lakoff and Johnson (1999) suggest that cognition is inherently embodied due to human physiology; they posit direct neural connections between visual areas, motor areas and effectors to support real-time interactions by speeding interactions between brain and body, effectively extending the visuomotor claims discussed previously to include the effectors. Support for this may be drawn from Strigaro et al.'s (2015) demonstration that TMS pulses administered occipitally could produce motor facilitation or inhibition depending on their latency. Similarly Cantello et al. (2000) demonstrated a cortico-cortical connection between occipital and motor cortex with a transit time of 15ms by showing a visual flash stimulus excited motor cortex. This idea fits with the current data (where effector position affected perception) and is widely supported in the theoretical literature (e.g. Clark, 1998; Wilson, 2002; Johnson, Spencer & Schöner, 2008; Robbins & Aydede, 2009). This offers a view on physiology that is consistent with the observations here and elsewhere (e.g. Tucker & Ellis, 2000; Symes et al., 2008; Fagioli et al., 2007a; Van Elk et al., 2010; etc.) that body position is able to influence visual perception. When viewed in this way masked lateralised and masked grip-type experiments three and four demonstrate the principle behind Lakoff and Johnson's (1999) assertion that embodied cognition is fundamentally implied by the structure of the body and supported by direct connections between visuomotor areas and effectors because body/ hand position has been shown to have a profound effect on viewing affording stimuli. They go further, suggesting that in order to understand higher-order functions like reasoning the minutiae of the visual and motor systems must be understood first because all behaviour and higher-order cognition, including abstract concepts, is grounded in concrete physical and/or action concepts that rest on these tight, reciprocal connections between vision, action and effectors.

On this account affordance SRC paradigms represent a direct demonstration of these principles, however their characterisation as implicit elements of perception also make it difficult to tease out the precise mechanisms underlying embodiment. There is however considerable evidence that these interactions occur. Outside of the affordance SRC domain, Hommel et al. (2001) provide a convincing demonstration that viewing objects activates some of the same neural processes as using them. The present data extend this to show that a two-way relationship exists where the objects are viewed differently based on correspondence between the body position of the observer and the object affordance, as seen in Symes et al. (2008), Van Elk et al. (2010) and others. Bach and Tipper (2006) demonstrate the allied idea that even without explicit references to action, viewing the faces of sports stars activates areas used to control the actions that they are famous for. This is often called simulation and although several operational definitions exist a strong one may be drawn from Svensson, Lindblom and Ziemke (2007); in embodied cognition, simulation refers to the invocation of sensorimotor states to facilitate higher-order cognition, making use of partial simulations or emulations of sensorimotor processes through the reactivation of the neural circuits involved in previous or imagined instantiations of those processes. This is precisely the principle demonstrated in Symes et al. (2008), Fagioli et al. (2007a), Van Elk et al. (2010) and Hohlefeld et al. (2011) and in the present data. The idea of simulation by sensorimotor states accounts for the differences between the results of masked lateralised and masked grip-type experiments three and four, where the key difference was the SR pair employed in each experiment, including the use of the same response devices that produced the effect in Symes et al. (2008). Here the response devices made participants simulate the actions required to interact with the objects, invoking their associated sensorimotor states which persisted after stimulus offset simply because the grips were still maintained. This simulation offers a basis for the compatibility effect observed in the masked, grip-type experiment (four). In contrast, the negative compatibility effect in the masked lateralised experiment (three) can be explained just as the behavioural compatibility effect seen in Vainio et al.'s (2011) study of masked lateralised stimuli. That is, the motor activity elicited by viewing the stimulus is interrupted by the mask, leading to a suppression of incomplete visual information and an associated negative compatibility effect. This is shown in the timecourse of the LRP which became nonsignificant 50ms earlier in the masked lateralised experiment than in the unmasked lateralised experiment, despite using the same stimulus set. This does not occur for the grip-type experiment because the affordances were embodied by the hand position before the stimulus was presented, whereas the lateralised experiment shared no such physical relationship (only an arbitrary spatial one) meaning that there was nothing to embody or scaffold the lateralised affordance, leading to its suppression and the observed negative compatibility effect.

One of the difficulties of this embodied explanation is that it offers little in the way of explicit mechanisms for embodiment; instead it says that simply by virtue of our evolutionary history our perceptual and motor systems are inextricably linked and form the basis for higher-order cognition (e.g. Johnson, Spencer & Schöner, 2008). Sadly, it will require many experiments to fully understand the differences between grip-type and lateralised SR pairs however the experiments presented here form a valuable indication of underlying differences that are scarcely even implied by the behavioural data. The simplest way to expand on these differences would be to determine a way to reverse the SR pairs, using grip-type responses with lateralised stimuli and lateralised responses with grip-type stimuli in order to see if the effects were bound to stimulus or response. However this offers little chance of insight because these dimensions fail to yield comparable dimensions for compatibility when compared to the current experiments; grip-type stimuli contain no implicit lateralised information so lateralised responses would not work with them and although lateralised stimuli employed in experiments one and three were generally power-grip compatible there were few precision-grip compatible stimuli, again leaving no direct SR relationship even before controlling for laterality. This suggests that in order to understand these differences a different approach must be adopted, one removed from the typical SRC affordance paradigm. To move toward a complete explanation of these unexpected differences a better understanding of the parameters for affordance generation must be developed. This is particularly pertinent given the questions about automaticity raised by the dissociation observed in masked lateralised and masked grip-type experiments three and four. Automaticity has also been recently raised in the literature; Tipper et al. (2006) and Pellicano et al. (2010) questioned automaticity when they found that when viewing the same stimuli, a Simon or affordance effect could be elicited simply by varying the judgement that participants performed on a stimulus. When asked to make a colour discrimination a Simon effect was observed and when asked whether an object was upright or inverted an affordance effect was observed with the same bimanual keypress response used in both findings. The authors suggested that this was a product of which object features were being processed in order to answer the question. As they point out, this questions the notion of automaticity which states that merely viewing an object is sufficient to yield its affordance, regardless of action intentions. This finding is one of few against automaticity, also showing a difference not apparent in the behavioural literature. This is not dissimilar to the different results observed in experiments one to four, where laterality and grip-type object properties produced different visuomotor effects. This similarity indicates that this is a useful area to refocus attention in order to better understand affordance generation, with a view to explaining why grip-type and lateralised affordances are processed differently. This will follow on from Pellicano et al. (2010) with an examination of the assumption of automaticity and the SRC task structure focussed on manipulating the relationship between stimulus and response. The dissociation of RT and LRP effects also questions automaticity because no LRP effect was observed in masked, grip-type experiment four suggesting that viewing objects may not be sufficient to activate their associated actions, regardless of action intentions. For this reason the response was removed for experiment five to determine whether an affordance would be generated in the absence of the intention to act on it, investigating the assumption of automaticity.

*7.4 Testing assumptions in affordance SRC*

Experiments one to four revealed unexpected differences between grip-type and lateralised affordances that are best explained by the response devices employed. This emphasis on response questions the assumption of automatic activation of affordances by visual information alone, particularly considering the dissociation of RT and LRP effects in the masked experiments. So, to better understand these unexpected differences experiment five and six manipulated response conditions to test two pervasive assumptions about affordance. Experiment five tested the assumption of automaticity, the idea that merely viewing an object is sufficient for it to yield its affordance, regardless of an intention to act on it. This assumption indicates that task factors (e.g. action intentions) should not influence the automatic generation of an affordance. However, what do we classify as evidence of affordance? Experiment three (masked lateralised) provided evidence for lateralised affordance in LRP, but not in RT measures. While in the masked, grip-type experiment (four), there was evidence for grip-type affordance in RT but not in LRP. Given that most of the evidence on automaticity comes from RT studies, does the detection of an LRP effect in the absence of an RT effect qualify as automatic affordance generation? Equally, what does the lack of an LRP affordance effect mean for automaticity in the presence of an RT effect? The dissociation of grip-type and lateralised affordances observed in the masked experiments appears to be attributable to the response devices; as described in 7.2.4. It is this task-specific difference that raises questions on the automaticity of affordance, which would suggest that the mere observation of an object should generate motor affordance, irrespective of task. Support for the influence of grip-maintenance on object perception may be drawn from Symes et al. (2008) or Fagioli et al.(2007a&b)(discussed above), who both show that body position affects how objects are perceived, suggesting that it is possible for task factors such as response to interact with affordance generation, just as shown by the dissociation observed in the masked experiments. The key evidence questioning automaticity may be drawn from Tipper, Paul and Hayes (2006), Pellicano et al. (2010) and Iani et al. (2011) (described in detail in section 5.4), who showed that it is possible to view an affording stimulus without eliciting an affordance effect, simply by varying the judgement or response parameters. So, in order to address this issue of response parameters in affordance generation, experiment five modified the usual forced-choice manual-response used in the lateralised SRC paradigm of experiment one to a go/no-go vocal response to see if the same LRP effects were detected in the absence of an intention to make any motor response to the stimuli. Experiment six also looked at response parameters and automaticity but from a different perspective; experiment six saw a novel variation on the SRC affordance paradigm where participants saw a neutrally rotated stimulus roughly two seconds before the target stimulus appeared. Participants were told that the neutrally rotated stimulus was always the same as the target stimulus, signalling the category of the target. This sought to determine whether the LRP or RT effect was still detected when participants had already completed the categorisation required by the task. This followed the logic from Pellicano et al. (2010) where different categorical judgements produced different effects with the same affording stimuli. Experiment six will be discussed in greater detail later.

### *7.4.1 Affordance generation in the absence of response*

Experiment five is unique in its approach to automaticity, looking for direct evidence of motor activation by seen objects in the absence of a response. As discussed, most SRC affordance studies conclude in favour of automaticity, however they do so when participants are making motor responses to every stimulus. This creates a potential confound where researchers investigating motor preparation by seen objects have their participants prepare motor actions as part of their tasks. This also suggests that the results typically observed in SRC affordance experiments may be products of the response affecting perception as much as the correspondence in the SR pair or the automatic potentiation of afforded actions. So, experiment five took the form of a go, no-go experiment; on go trials participants were asked to detect and verbally announce when the objects conformed to the category of kitchen items, for the remaining 'tool' items the participants made no response. Therefore participants made the same categorical judgement employed throughout this thesis and in the literature, but did not respond with any manual responses.

The results of this experiment showed the familiar 100-200ms LRP compatibility effect was observed even in the absence of the intention to make a response to the objects, just as observed in lateralised experiment one and masked lateralised experiment three *with* bimanual responses. The direction of the effect was the same as experiment one, indicating a preparation of the compatible effector for all trials, varying with the orientation of the stimulus. These data show that merely viewing an object in the absence of the intention to act on it is sufficient to yield an affordance and supports the case for viewing objects automatically activating their associated actions. That said, given the differences discussed in section 7.3 this conclusion only applies to lateralised affordances because grip-type affordances have been shown to behave differently in the earlier experiments in this thesis, and this is argued to be due to the response devices employed.

These data also inform the discussion from 7.3 by showing that the LRP activity elicited by *lateralised* affordances is not contingent on a response being deployed because the same effect has been observed with and without response when viewing the same stimuli. This supports the differentiation of grip-type and lateralised affordance effects along the lines of the relation between each SR pair advanced above, where grip-type affordance effects appear to be driven by maintaining the response grips which are identical to the seen objects. In contrast, lateralised affordance effects appear to be visually driven because the spatial SR relationship was not inherently about properties of the objects, rather the lateralised stimuli simply provided a visual cue to which effector to use. The occurrence of an LRP affordance effect in the absence of response provides clear evidence in favour of the proposition that lateralised affordance effects are visually driven.

This finding indicates that the results from Fagioli et al. (2007a), Symes et al. (2008), Van Elk et al. (2010) and others cited above (that demonstrate the phenomenon of prepared grip affecting visual perception) may be bound to grasping affordances only and that hand position is a not prerequisite for generating lateralised affordance effects because participants prepared no manual response at any point during this experiment. This highlights another key difference between grip-type and lateralised affordances and supports the differentiation of grip and lateralised affordances based in body position discussed in 7.2.4 and 7.3.3. The LRP effect in the absence of the intention to make a manual response to the objects suggests that lateralised responses are not scaffolding perception in the way that grip-type responses are suggested to in the previous sections, where LRP and RT effects were dissociated using a masking procedure. This is unsurprising given the abstract, non-specific relationship in lateralised SRC compared with the direct 1:1 relationship seen with grip-type SRC. Instead, the occurrence of an LRP effect corresponding to the object in the go, no-go experiment suggests that these lateralised effects are visually driven.

*7.4.2 Representational and embodied accounts*

Following on from the discussion in 7.2 and 7.3, the extrinsic vs. intrinsic dichotomy advanced by Derbyshire et al. (2006) offers little insight into the findings of the go, no-go experiment because their explanation of extrinsic affordance requires a response to satisfy the criteria of "*depend*[ing] *on some relation with the viewer or viewing conditions*". Instead the go, no-go experiment (five) finds that merely viewing a lateralised object yields the same LRP effect that was observed in a typical lateralised affordance SRC experiment (one). By Derbyshire et al.'s (2006) definition of an extrinsic affordance, changing the response set means that the LRP effect should not be detectable in go, no-go experiment five as it was in the earlier lateralised experiments. This is because on their definition, the changed response set would no longer offer the same 'relation with the viewer' which is required to generate the effects. Instead, the go, no-go effects suggest that it is not the response set but the visual input that is critical to these lateralised affordance effects; if the effects are products of the viewer relating the visual input to the immutable presence of their left and right hands (instead of the specific responses afforded by the experimental response set) then this offers better fit with an embodied model over a representational model because this explanation is still fundamentally couched in a tightly bound visuomotor process, focussed on the role of the body in cognition and not based in overlapping mental representations of the SR pair. Put another way, the presence of affordance effects in the absence of manual responses undermines Derbyshire et al.'s (2006) emphasis on SR relations in affordance generation. The visual effects bear this out too; the go, no-go experiment yielded a P1 effect, which appears to be associated with the visual extraction of action possibilities from a stimulus but critically, was the only lateralised experiment to fail to detect an action effect in N1, a component that has been indicated to have a relationship with action intentions generated by response sets (Van Elk et al., 2010; visual effects discussed in detail in 7.5). This shows that merely viewing an object results in detection of its action relevant features without requiring a relationship with a response, but also indicates that response sets exert an influence on later processes (i.e. N1).

The poor fit of the representational account of different sources of affordance from Derbyshire et al. (2006) again leads back to the embodied explanation advanced above. There it was argued that the critical difference between lateralised experiments (one and three) and grip-type experiments (two and four) was the hand position adopted in the grip-type experiments, which was said to scaffold cognition by shaping perception, in line with the literature (e.g. Symes et al., 2008; etc.). In turn, this description suggests that the lateralised affordance SRC effect was due to compatibility between the SR pair, even along the abstract dimension of orientation. However that is not borne out here where no response existed to lend a dimension for compatibility. Instead, following the logic from 7.2 and 7.3 a distinction may be drawn between affordance classes; the lateralised effects appear to be visually driven where the grip-type effects were response driven.

On this basis, these effects are best explained by the embodied view that cognitive effort is offloaded to body and world and that using vision to constantly reference and re-reference the world is more efficient than building complex internal representations (Brooks, 1990; Wilson, 2002; Anderson, 2003). In the go, no-go case (and potentially the wider lateralised affordance literature as a whole) lateralised affordances appear to be grounded in the visual system, elicited by laterality cues from the stimulus only. This does not preclude the possibility of participants' effectors still playing a role in the go, no-go effect because the presence of the effectors cannot be muted, however the key finding here is that visual input alone is sufficient to elicit the LRP effects seen in earlier experiments.

*7.4.3 Comparing findings on automaticity*

Pellicano et al. (2010) and Tipper et al. (2006) (described in 5.4) concluded that their colour judgements did not entail attending to the action relevant object properties whereas their judgements of inversion and shape did. Their categorical judgements on inversion and shape are similar to the kitchen vs. tool and organic vs. manmade categorical judgements employed in this thesis insofar as they require participants to examine the entire object before they can complete the judgement; each of the experiments show that participants must make a judgement on the whole object (not merely a single element such as colour) in order to elicit the affordance. Proverbio et al. (2011) (detailed above), the most similar study to the go, no-go experiment (experiment five), can be explained this way too. They used a passive viewing experiment and also found an affordance effect in ERP without response on their passive-viewing trials. Their results can be explained as a product of the categorical judgement participants had to make to determine whether to respond or not; to identify a catch trial they had to identify the object and determine whether it was a plant or a tool, forcing them to consider the entire object and its properties, just as in Tipper et al. (2006) and Pellicano et al. (2010). It is worth considering whether the different results of different judgements are a product of categorical judgements inducing participants to access semantic object information, or whether it comes from colour judgements operating at a lower-level; semantic access has been typically associated with the N400 component, occurring “remarkably consistently” at around 200-600ms after stimulus onset (Kutas & Federmeier, 2011). Although typically associated with semantic violations in linguistic stimuli, recent evidence has shown N400-like effects with visual object stimuli too; Van Elk, Van Schie and Bekkering (2010) found a larger anterior N400 for the preparation of meaningful compared with meaningless actions. Participants were instructed to perform an action (moving stimulus object toward their mouth or toward their eye) on one of two objects that would be meaningful (e.g. moving a cup toward their mouth or a magnifying glass toward their eye) or meaningless (e.g. moving a cup toward their eye or a magnifying glass toward their mouth). Their N400 effects were detected between 280ms and 590ms over central electrode locations. This shows that whilst semantic effects *do* occur with object stimuli, they do not occur rapidly enough to affect the results in the present thesis. These findings are supported by Supp et al. (2005) who reported that N400 varied with the recognisability of their common household object stimuli. They found unrecognisable or meaningless objects elicited greater N400 amplitude from 400ms to 550ms and suggested that this was related to increased processing difficulty due to the lack of semantic information contained within the stimulus. They concluded that their finding of an N400 effect with objects fits with the linguistic literature on the component and suggests that N400 is generalizable as a component marking semantic access. Balconi and Caldiroli (2011) support these findings, showing increased N400 amplitude when actions depicted in a video were incongruous with a target object compared to when they were congruous. They suggested that although N400 has typically been associated with semantic mismatch with linguistic stimuli, their experiment (and others cited here) show that N400 semantic mismatch effects may also be obtained with non-linguistic (object) stimuli and may be better characterised as indexing the difficulty in accessing semantic memory, regardless of modality. Goto et al. (2009) also used N400 to index cultural differences in object perception by placing objects over congruous backgrounds (e.g. a crab over a beach scene) or incongruous backgrounds (e.g. a crab over a car park) and elicited greater negativity in N400 for Asian-Americans than European-Americans when background and object were incongruous. Van Elk, Van Schie and Bekkering's (2010), Supp's (2005), Goto et al.'s (2009) and Balconi and Caldiroli's (2011) N400 semantic effects with objects are considerably later than the LRP effects which have consistently commenced at 100ms after stimulus onset in this thesis, suggesting that semantic access is not required in order to elicit an affordance effect in

LRP. In turn, colour judgements do not require this semantic access and are typically handled very in early in the visual cascade; e.g. Conway, Hubel and Livingstone (2002) demonstrated colour discrimination in macaque V1, an area associated with processing the first wave of colour information from the eyes at around 60-80ms in humans (Thorpe, Fize & Marlot, 1996). This indicates that the colour information is available considerably earlier than the observed motor effects or semantic access and lays the emphasis for the differences observed in Tipper et al. (2006) and Pellicano et al. (2010) on the colour judgement being completed before any action or affordance-related processes commenced at around 100ms, downstream in motor cortex. It appears then that the rapid availability of colour information compared with semantic or action-information means that the task-goal of making a colour identification can be completed before affordance detection and given the lack of an affordance effect in Tipper et al. (2006) and Pellicano et al. (2010), this presumably halts the processing of the affording aspects of the object. Further investigation would be required to confirm this, but it appears that the reason for a lack of an affordance effect with the colour judgement comes down to a distinction in levels (and latencies) of processing between the rapidly processed, lower-level colour judgements and the (only slightly) later, higher-level action preparations.

So, taken together these experiments suggest that affordance generation is contingent on what stimulus features are attended and implies that affordance generation has only appeared automatic in the literature to date because the majority –if not all– studies that have found for automaticity have had participants make a categorical judgement that has entailed participants attend the whole object.

This emphasis on attended object features returns the discussion to the findings from Symes et al. (2008), Van Elk et al. (2010), Hohlefeld et al. (2011) and others (described above), who have demonstrated that prepared actions influence what action-relevant features of a scene are attended. This clearly feeds into the assertion from Tipper et al. (2006) that affordance generation is contingent on what object properties are attended. Taken with the present experiments this suggests a three-stage, looping, system where bodily states affect what is attended (e.g. Symes et al., 2008; masked grip-type), what is attended (whether due to task or bodily state) affects what affordances are generated (e.g. go, no-go; Tipper et al., 2006; Pellicano et al., 2010) and what affordances are generated affects bodily states in terms of deploying responses (e.g. experiments one and two; Tucker & Ellis, 1998) as well as what motor activity they generate (e.g. dissociation seen in masked experiments compared with grip, lateralised and go,no-go experiments). This forms a loop where bodily states and visual action possibilities are constantly influencing each other with no apparent prime mover, with prepared actions (as in Symes et al., 2008; etc.), visual input (Tucker& Ellis, 1998; etc.) or attending different aspects of a stimulus (Tipper et al., 2006; etc.) able to organically influence the following step(s). Interestingly, this also offers a means to account for intentional actions as well as non-task influences like affordance because explicit action intentions also affect what is attended, as shown by Tipper et al. (2006) and Pellicano et al. (2010). This idea of a loop draws support from a variety of sources (cited above) in the affordance literature and offers a means of crystallising the explanation of the difference between grip and lateralised response advanced above; in this loop, grip-type SRC affordance effects are driven by the prepared grips and lateralised SRC affordance effects are driven by the salient visual features, but each uses the same system to handle the effects but each affordance class ‘joins' the loop at different stages, also (pending further investigation) offering a mechanism to explain the different ERP timecourses. This explanation is still couched in an inherently embodied notion of constant referencing and re-referencing of the relationship of body and space (e.g. Ballard, Hayhoe, Pook & Rao, 1997) but clarifies this notion by showing that this may be influenced by three things; body position, attended stimulus properties and goal states.

*7.4.4 Considerations from the literature for go, no-go experiment five*

The idea that lateralised affordances are driven by visual input and that grip-type affordances are response driven is consistent with the discussion in 7.2.4 and 7.3.3, revealing more about the influence of response parameters on afforded motor activity from different sources.

As mentioned above, Proverbio et al.'s (2011) passive viewing experiment is similar to go, no-go experiment five and supports the idea that what object features are attended determines whether an affordance is generated, however the study raises other issues too. They found a greater motor effect when viewing tools than non-tools, significant at approximately 250ms after stimulus presentation. This result supports the findings of the go, no-go experiment insofar as demonstrating affordance effects in ERP in the absence of response. However, their 250ms effect is considerably later than in the go, no-go experiment (five) conducted in this thesis. As above, this difference may be explained in terms of the variety of affordances contained within their stimulus set. The key result here is the detection of affordance effects in ERP in the absence of response and the timing difference is explicable in the same way as the different timing with grip and lateralised experiments in this thesis (experiments one to four); on the basis of the stimuli (i.e. affordances) employed.

Wider support for this kind of interpretation of the results and surrounding experiments may be drawn from the literature; as discussed above, embodied cognition holds that constructing costly mental representations is unnecessary because a more efficient strategy is to use the world as its own best model (Brooks, 1990), suggesting that the visual system is well suited to extracting this kind of action possibility from the environment. Here, object laterality is not critical to identifying the stimulus object or its function (important to cognitivist and representational accounts) but the go, no-go experiment demonstrates that this property still yields an affordance effect in LRP merely by viewing it. As discussed above Clark's (1997) notion of 'personalised representations' would suggest that this is because the visual system extracted the most relevant object property to initiate the action of using the object; which effector would allow the participant to pick it up. This marries the notions of affordance and embodiment, where both are concerned with speeding interactions in a complex world of novel and familiar objects without appealing to mental representations or stored object knowledge but by referencing the action relevant information available in the environment. Indeed others argue that humans are uniquely well equipped to operate in this way; Ballard et al.'s (1997) model suggests that saccadic eye movements are a critical part of this kind of strategy of rapid visual referencing to the environment in order to relieve the computational expense of detailed mental representations. This suggestion is supported by studies from Thomas and Lleras (2007) who found improved task performance when guiding participants' eyes via a tracking task or Grant and Spivey (2003) who go as far as suggesting a direct, implicit connection from eye-movements to cognition, saying that whilst it is intuitive to think that cognition directs eye movements it may be more accurate to describe a two-way connection where information gathered during eye movements guides cognition too. This suggestion goes hand in hand with findings from Symes et al. (2008), Van Elk et al. (2010), Fagioli et al. (2007), Ballard et al. (1997) and others (including this thesis) that indicate that bodily states (visual or motor) have a two-way relationship with cognition, which also represents a core tenet of embodied cognition (Anderson, 2003). The LRP affordance effect in the absence of a response fits too because participants generated the afforded response when viewing the object, without reference to responses, bodily states, or other factors. The effector afforded by the object lateralisation was activated on each trial in a way that is not predicted by representational accounts of object perception (e.g. Derbyshire et al., 2006; Marr, 1982; Biederman, 1987) that suggest that features such as orientation do not yield an affordance because they are contingent on a response or because critical features are not represented without a response due to the nature of the affordance. The preparation of effectors by visual input alone observed in the go, no-go experiment is consistent with references that suggest that physical features of the visual system (e.g. saccades) and motor system (e.g. effector posture) guide perception toward similar action-relevant information (such as affordances) in order to aid real-time cognition. Put another way, the results are fundamentally incompatible with any account that states that lateralised affordance SRC effects require a response to occur. This is all consistent with the loop idea advanced above, where action intentions and prepared actions may well generate an affordance effect, however as these data and other experiments discussed here show, what is attended will also produce an effect.

#### *7.4.5 Closing remarks on the go, no-go experiment*

Sadly it was not possible to conduct a comparable go, no-go experiment with grip-type stimuli for a variety of reasons. Chiefly because grip-type stimuli do not implicitly cue a particular hand in the same way that lateralised stimuli do. To achieve this participants would have had to hold the response devices, which is the very thing suggested here to produce the effects. Indeed Symes et al.'s (2008) core finding was that maintaining those very grips elicited a compatibility effect with viewed objects. Without using the response devices, the lack of a hemisphere cue on the stimuli would preclude the use of LRP measures too, making it difficult to compare directly with the rest of the experiments here and potentially introducing a new confound.

This experiment shows direct evidence for automatic affordance generation by seen objects, as long as participants attend the entire object and this is not contingent on a response. The lack of a response here supports the argument that lateralised affordance effects are driven by visual cuing of the effectors. However it is restricted to lateralised affordances by the earlier findings of this thesis. One issue here is that this experiment used the same categorical judgement as the previous experiments and the key findings from Tipper et al. (2006) and Pellicano et al. (2010) were that different judgements yielded different effects with the same affording stimuli. For this reason, experiment six attempted another manipulation of this in order to address the question from another angle; experiment six saw participants make the categorical judgement ahead of time on a neutrally rotated stimulus. Participants then deployed their categorical judgement using a bimanual button press response some two seconds later when a lateralised version of the same stimulus provided the cue to respond. By removing the judgement from the stimulus, we can see if Pellicano et al.'s (2010) findings demonstrate a requirement for deeper processing to generate an affordance than a Simon effect, or whether affordance effects occur when attending to anything other than superficial features like colour. It also affords an opportunity to tests the claim that lateralised SRC affordance is visually driven, as the lateralised stimulus operated purely as a cue to deploy the prepared response.

*7.4.6 Delayed response*

The final experiment (six) sought to probe the results from go, no-go experiment five on the assumption of automaticity and the role of the categorical judgement in generating affordances. The go, no-go experiment demonstrated direct evidence for automatic affordance generation by demonstrating that viewing affording stimuli elicits motor activity even in the absence of a motor response, similar to Proverbio et al.'s (2011) findings with passive viewing. However, Tipper at al. (2006) and Pellicano et al. (2010) (described above) questioned automaticity by showing that different judgements on the same affording stimuli elicit different effects. The go, no-go experiment (five) found in favour of automaticity by detecting an affordance effect in LRP in the absence of a response, but still required participants to make the same categorical judgement used in experiments one to five and throughout the literature (discussed in detail previously). For example, Vainio et al. (2008) suggest that making categorical judgements necessarily entails processing action-relevant aspects stimuli. So, experiment six asked if the categorical judgement is imperative to generating an affordance or if affordance generation is simply automatic upon viewing an object, as suggested by the go, no-go experiment. Thus, experiment six manipulated the temporal proximity of the categorical judgement and the response to determine whether the categorical judgement enlisted a particular manner of viewing and processing the stimuli that generated an affordance effect.

In doing this, this experiment sought to probe automaticity from another angle; by removing the *imperative* to examine the affording stimulus at the point of response for the task, suggested by Proverbio et al. (2011) and Tipper et al. (2006) to affect the generation of an affordance. This does not mean that participants did not attend the second stimulus, merely that the task did not *require* them to do so at the point of response in the same way that previous tasks have done. Participants saw a neutrally rotated image of an object, in which the handle was pointed directly down. The stimuli were selected so that they did not indicate a usage preference in this orientation and so did not offer dimensions for compatibility with either lateralised response. Participants viewed the neutral stimulus for one second and made their categorical judgement before waiting up to another full second to deploy their response using the familiar bimanual button press upon the onset of a second image of the same object, this time lateralised left or right. This meant that the second stimulus was in no way relevant to response, so if Tucker and Ellis (1998) and other's claim that object affordance is automatic because it yields an effect even as a non-task property is true, then we should observe the same RT and LRP effects in this experiment too, because the affordance is still a non-task property and is still present at response, but is no longer conflated with the categorical judgement. This design meant that there was no requirement to make a categorical judgement during the second, lateralised presentation; it only served as a cue to deploy the judgement that was made during the presentation of the initial, neutrally rotated stimulus. Doing this meant that participants made their categorical judgement on a stimulus that did not offer a lateralised affordance but deployed their judgement during the presence of a lateralised affordance, effectively separating these elements in time by up to two full seconds and removing the imperative to make a judgement at the point of response. By separating these elements, this offered a chance to rule-out the possibility that it is *necessary* to perform a categorical judgement on an affording stimulus in order to elicit the correct kind of viewing or processing of the stimulus to detect an SRC affordance effect. In turn, this design is able to show that the mere visual presence of an affording stimulus, acting only as a cue to deploy a response, is *sufficient* to elicit an affordance effect when deploying a pre-prepared response.

This experiment showed the familiar LRP compatibility effect 100-200ms after the onset of the affording stimulus, along with a significant RT compatibility effect. This was found even though participants were making their categorical judgements to the first, neutral, stimulus, presented up to two seconds before deploying their responses to the second, lateralised, stimulus. This supports the argument given above that lateralised affordance effects are driven by visual action-information cuing the effector ipsilateral to the handle orientation because the lateralised stimulus acted only as a cue to deploy the response. This means that the stimulus was able to generate an affordance effect even when the task did not require participants to attend to its properties, affording or otherwise. The RT and LRP effects show that participants did attend the second stimulus and so shows that the mere presence of visual action information is sufficient to yield the affordance effect and that this is not reliant on a task judgement leading participants to examine a stimulus in a particular way. As discussed above, Tucker and Ellis (1998) and others have argued that because object affordances were non-task properties, their effect is automatic. The present findings support and extend this, showing that the mere visual presence of the object was sufficient to elicit an affordance effect and that there is no need for an explicit requirement (e.g. categorical judgement) to attend an affording stimulus for it to yield an affordance effect. Instead it shows that merely fixating a lateralised affording object should be sufficient to yield its affordance. However, Tipper et al.'s (2006) and Pellicano et al.'s (2010) experiments found that attending superficial object features, such as colour, will not generate affordances related to the object. Thus, it would appear that the principle of affordance automaticity is broken if attention is trained to a specific low-level action-irrelevent property of an object such as colour. Affordances are otherwise automatically generated when the attention to the object is more 'holistic' and encompasses its functional properties, even if attending these properties occurs incidentally as shown by delayed-response experiment six.

So the widespread assertion of automaticity appears to be due to the design of experiments that are intended to demonstrate automaticity; typically they have participants make a judgement on the object that is unrelated to the object affordance (e.g. Tucker & Ellis, 1998; Pellicano et al., 2010) which allows researchers to draw conclusions about automaticity, but also requires participants to attend the whole stimulus even if only a part of it yields the affordance (e.g. Ellis & Tucker, 2000), ensuring that participants attend the affording features and ultimately skewing experiments toward concluding in favour of automaticity. That said, the go, no-go experiment and this delayed response experiment provide evidence in favour of automaticity when merely viewing objects, even without an intention to make a manual response (go, no-go experiment five) and also when merely viewing an affording object with no imperative to consider the object (delayed response experiment six). So, these experiments suggest that affordances are *effectively* automatic, meaning that an affordance will be elicited from a seen object, on the condition that participants do not have explicit intentions to attend to a low-level object property that is not action relevant (e.g. colour).

This interpretation fits with what is known about the cascade of visual information through occipital cortex (also discussed in 7.4.3), where colour information is processed at the earliest stages including in V1 from 40-60ms in macaques (Conway, Hubel & Livingstone, 2002). In humans, this has been shown to occur a little later at around 60-80ms (e.g. Thorpe, Fize & Marlot, 1996) but still represents the extraction of colour information at the earliest stages of visual processing. This suggests that colour information is available considerably earlier than semantic information that would help to determine category; work on the N400 component, which indexes semantic access, has consistently shown that the N400 is detectable in a range of 200-600ms (e.g. review by Kutas & Federmeier, 2011), commencing after the afforded (lateralised) LRP effects (100-200ms) in the experiments in this thesis had offset. This suggests that colour information is available before affordances are generated in motor cortex and considerably more rapidly than semantic access, suggesting the lack of an affordance effect with a colour judgement is a product of directing attention to this lower level visual property and crucially, away from properties of the object itself. Of course, more research is required and one interesting method would be to combine the method of Tipper et al. (2006) with the metrics used here to determine whether an LRP effect would still be detected in the colour judgement condition in the absence of a subsequent RT affordance effect. However in lieu of additional data, the findings of this thesis in concert with the literature suggest that the categorical judgement is not required to elicit an affordance effect and neither is a manual response, but an affordance effect will not be elicited when participants are instructed to attend to lower-level object features.

*7.4.7 Later effects*

Some differences were observed when compared with the earlier experiments; mean RTs (306ms) were shorter than previous experiments. This is readily explained by participants having made their judgement in advance and merely waiting to deploy it, however this had two effects on the LRP. Firstly, because the second stimulus remained on screen after response and RTs were short, epochs which had been obscured by the response (300-600ms) in the previous experiment could be examined. Secondly, these epochs showed maintaining the response rule in the absence of an affording stimulus led to a strong and persistent preparation of the rule-cued response, even after response, for as long as the stimulus persisted on the screen. So, this meant that although the typical compatibility effect was observed in LRP, all of the LRP activity was negative-going (indicating a preparation of the rule-cued response hand), with the affordance effect reflecting a sub-threshold positive inflection in the LRP between 100-200ms. This LRP effect adopted the same formation as it did in previous experiments except that the incompatible wave remained negative-going throughout, never reaching a positive value. When the categorical judgement is made at the same time as response (as per experiments one to five), the incompatible wave has a positive polarity from 100-200ms (after affording stimulus onset) and the compatible wave has a negative polarity. However in the delayed response experiment both waves were negative overall, with only a positive inflection in the incompatible wave in the critical 100-200ms epoch.

The RT effect was still obtained as normal, which suggests that the affordance effect occurred as in previous experiments and that the overall negativity did *not* affect the behavioural output. The LRP effect was also obtained as normal, suggesting that the overall negativity reflected a feature of the design that did not affect affordance generation. Indeed, the overall negative values provide a novel demonstration of a task influence on motor processing; preparing the rule-cued responses for two seconds before deploying them not only allowed participants to respond quicker, but this preparedness also saw them continue to prepare the correct response, even when faced with a conflicting stimulus on the incompatible trials. This motor preparation appears to reflect the continued preparation of the rule-cued response in the presence of the conflicting incompatible affordance, showing that when the afforded response is not deployed then motor preparation continues, as suggested by Miller and Hackley (1992) and Zhang et al. (1997). This presumably did not happen on compatible trials because there was no conflict between the rule and the afforded response. This continued preparation supports the idea of the facilitatory nature of affordance because the presence of the affording object continued to produce a motor effect only when participants had *not* deployed the afforded response. This fits well with the argument from Galpin et al. (2011) and others (described above) that affordance effects are products of facilitation by compatible responses rather than inhibition by incompatible responses.

The overall negativity observed here provides a cautionary tale to future research wishing to use LRPs with questions of affordance; although affordance generation may be effectively automatic (see above), affordance is not the only factor in determining the electrophysiological manifestation of the effect. When determining analyses based on correct responses as in the LRP calculations in this thesis (using the derivation from Coles, 1989), asking participants to maintain responses had a profound effect on polarities. Similarly, the LRP for the go, no-go experiment contained much more noise that the other experiments with bimanual responses. However, that this overall negativity (a result of a task factor) did not affect the overall findings is more interesting; this provides an unexpected confirmation of the argument for automaticity because the same RT and LRP effects were obtained regardless of differing presentation and response parameters which yielded the negative polarity. This shows that the visual action-information contained in the lateralised stimuli will still generate motor activity as long as it is visible, even when task factors vary and yield artefacts in the data (e.g. overall negativity).

### *7.5. Affordance effects in early visual processing*

This section will first offer a brief summary of the visual P1 and N1 effects before considering their broad implications and their relationship with the limited literature on the connection between these early visual components and affordances.

#### *7.5.1 Affordance effects in VEPs*

As discussed in the introductory chapters, a good deal of behavioural research has made the claim that in order for affordance SRC effects to arise there must be coaction of visual and motor areas that are so tightly linked that they are better characterised as visuomotor than as discrete visual and motor modes of cognition. This notion has not been widely challenged and like other brain claims from behavioural research that have been discussed above, there has also been little *direct* evidence for the claim. Some fMRI studies of affording objects, such as Grezes et al. (2003) or Grezes and Decety (2002) have failed to find effects in occipital cortex when participants viewed affording objects. However as discussed in the introduction, this may simply be a limit of the poor temporal resolution of fMRI combined with the low-level, transient nature of early visual components. With this in mind, this thesis sought to employ the superior temporal resolution of ERPs to provide evidence on the visuomotor processes suggested in the literature. Examining visual activity yielded some of the most startling observations in the thesis; effects of SR compatibility on early visual components P1 and N1, which show that even low-level visual processes are influenced by the relationship between the afforded actions and the observer during the earliest possible stages of perception. However, this was only true for the lateralised stimuli, with no effects in visual components for any of the grip-type studies. The go, no-go data extend this, demonstrating that the intention to act does not influence the P1 component, but when there is no intended response compatibility effects were no longer observed in N1. This provides another novel insight into the relationship between vision and action, indicating that action intentions, dictated by available responses, exert an influence over early stages of visual processing. That these compatibility effects in visual components were limited to the lateralised stimuli furthers the distinction between grip and lateralised affordances advanced above, where it is suggested that the response devices used with grip-type stimuli caused participants to simulate on the actions afforded by the stimulus, affecting the timing of the LRP component and the generation of visual effects. Also, when the typical SRC affordance paradigm was varied (experiments three, five and six) the two-way interaction of object category and handle orientation from experiment one was not detected and instead interactions with electrode hemisphere and/or position were detected (discussed in 7.5.2.), all of which demonstrated a bias to sensors in the left hemisphere and/ or occipital cortex. This suggests that different presentation parameters may have had an effect on the visual components too and as we shall see, these interactions are compelling when considered alongside the fMRI research demonstrating left hemisphere bias in object processing (Grezes & Decety, 2002; Grezes et al. 2003; Johnson-Frey, Newman-Norland and Grafton, 2005) because they represent agreement in the data from two different imaging modalities, one spatially acute and one temporally acute. As will be discussed, these findings also recommend a reconsideration of the role of occipital cortex in attempts to model affordance processing.

That an effect of compatibility would be detected in early visually evoked potentials (VEPs) is surprising because typically, these VEPs have been associated only with very simple visual stimuli and as described by Luck (2005), will always be elicited by any visual input and will only show minimal variation with task, illustrating the simplicity of the stimuli that evoke this component. For example, Van Voorhis and Hillyard (1977) used flashes of light at pseudorandom intervals to evoke a visual P1 component. Mangun and Hillyard (1991) also found that the P1 component did not vary with task, eliciting the same component whether using simple or choice-RT measures with arrow-primed flashes of light. They did however find a small task influence on N1, with choice RT eliciting an effect on N1 where simple RTs did not, leading the authors to suggest that N1 indexes visual discrimination. So, N1 has been shown to have a wider response than P1, for example Mangun (1995) reviews considerable evidence that N1 varies with spatial attention. That said, spatial attention cannot explain the effects observed in this thesis because experiments featured centrally presented images which were compared like-for-like in different conditions. That is, the stimuli in congruent and incongruent affordance conditions had exactly the same distribution of left and right orientated objects, thus controlling for potential effects of spatial attention. N1 has also been shown to act as a sensory gain control mechanism (Eimer, 1993; Vogel & Luck, 2000; Luck, Woodman &Vogel, 2005); by directing attention to a particular visual field, N1 effects will increase to stimuli presented in that visual field, demonstrating how attention filters perceptual information. This is similar to Symes et al.'s (2008) finding that preparing a grip directed attention to similar objects in a visual search task. The lateral occipital N1 component has been shown to be larger when participants are performing discrimination tasks (Hopf et al., 2002; Ritter et al., 1979; Vogel & Luck, 2000) which were not dissimilar to the categorical judgements employed in the experiments here. However this cannot be the *sole* explanation for the N1 effects observed in this thesis because no compatibility effects were observed for grip-type stimuli in P1 or N1 despite an equivalent discrimination being made with both grip-type and lateralised stimuli. This returns the discussion to the other key difference between grip and lateralised experiments; the response devices. If, as discussed above, the response devices really are scaffolding perception and embodying object characteristics by having participants maintain the required grips, then the lack of N1 discrimination effects for grip type stimuli could again be explained by the response devices causing participants to maintain the grips, scaffolding the perception of the grasp-related features of the stimuli (Van Elk, Van Schie, Neggars and Bekkering, 2010; discussed below).

To clarify, the lack of visual effects in grip-type experiments constitutes evidence of *motor activity scaffolding object perception*, i.e. the motor activity induced by preparing the grips embodies the object characteristics before the object appears on screen, so perception is scaffolded by motor preparation of the actions to be performed with the objects, with the maintained grips pre-activating the same neurons as viewing/interacting with the object and so facilitating behaviour by virtue of having already activated this network before the stimulus was visible. So, this suggestion is an effect from motor preparation to visual perception, as seen in Symes et al. (2008) and others discussed throughout. The mechanism for this is simple; maintaining the prepared grips activates the neurons associated with interacting with the object, and does so to a greater degree than the object affordance alone. This is because affordances represent a low-level action preparation designed to facilitate actions *if* they are required, hence being a subordinate and presumably smaller effect than actually executing the prepared grip, which is precisely the kind of motor act that affordances are suggested to aid. This is supported by findings from studies that indicate N1 is elicited in reach-to-grasp (Riehle, Wirtssohn, Grün and Brochier, 2013) and is more responsive when making a grasp to a target object than a point (Van Elk et al., 2010).

Whilst main effects of category observed in N1 for the go, no-go and masked experiments support the classic interpretation of N1 as indexing visual discrimination, the present experiments belie further factors at work; here an interaction of action possibilities physically available to the participant (left or right handed button press) and action possibilities dictated by the stimulus have caused the compatibility effect in N1 in lateralised experiments. By contrast, the scaffolding provided by preparing the grips in grip-type experiments means that the grips afforded by the stimuli are already completed by maintaining the response grips, removing the requirement to generate the affordance in the same way as in lateralised experiments. In this way, motor activity elicited by the grips scaffolds perception of the object and this scaffolding eliminates the need for a visual process to extract an affordance in order to activate motor areas associated with the afforded grip, precisely because they are already activated by the response devices. This is startling because it suggests that the initial phases of processing visual stimuli may be deeper than previously thought (e.g. Luck, 2005), with action intentions (determined by the available responses) 'filtering' perception of the stimuli in a way that produces (or for grip-type, fails to produce) the observed affordance effects in N1 and P1. This principle has been demonstrated by Symes et al. (2008), Hohlefeld et al. (2011) and others (discussed above), who showed that action intentions and available actions affected perception of object stimuli, demonstrating a two-way influence of action and vision.

So, despite limited evidence suggesting a link between early visual components and object affordances every lateralised SRC experiment in this thesis has found at least one compatibility effect or interaction in these visual components. For lateralised experiments, the P1 component was consistently detected with a peak at approximately 100ms, which was also the onset time for the motor activity detected in LRP. In the same experiments, N1 consistently peaked at around 150ms, around halfway through the critical epoch for motor processing as revealed by the LRP results. This concurrent activation speaks to the notion of visuomotor processing advanced in the behavioural literature, with compatibility effects detected simultaneously and for similar durations in visual and motor areas. Other studies such as Kiefer, Sim, Helbig and Graf (2011) have found similar coactivation and also attributed it to visuomotor causes; they had participants name objects, two in sequence on each trial whilst recording ERPs. Trials could be congruent, where both objects afforded similar actions, or incongruent where they afforded different actions. They found motor effects from 100ms, similar to the experiments here. They concluded that the rapidity of the effect indicated an influence of action priming even within 150ms of object presentation, fitting exactly with the findings in this thesis; that action intentions, dictated by available responses, affect stimulus perception at the earliest stages. This assertion is supported by convergent evidence from other ERP studies; for example, the simultaneous compatibility effects in visual and motor cortices fit well with the proposition from Handy, Grafton, Shroff, Ketay and Gazzaniga (2003) that action relevant object properties are detected rapidly and integrated with early sensory perception. Handy et al.'s (2003) proposition offers a basis for the compatibility effects observed in visual components in this thesis, with action relevant object properties detected visually and fed into motor cortex by 100ms, eliciting the LRP compatibility effects seen with lateralised stimuli in this thesis. They showed this by measuring P1 response to tools and nontool objects and found that the action properties of tool objects rapidly biased perception and yielded a significant difference in P1 amplitudes when compared with nontools. This occurred very rapidly, in line with the findings from this thesis with P1 peaking from 100-150ms. Overall, they found that the detection of irrelevant action possibilities biased attention to particular visual fields and yielded the difference in P1, following the assertion of visuomotor processing being automatic, i.e. not contingent on intention. This experiment provides good converging evidence for the P1 effects observed here, with action relevant properties demonstrating systematic influence over these early stages of visual perception.

Other researchers have made similar assertions; Kumar, Yoon and Humphreys (2012) also draw similar conclusions from their coactivation of visual and motor P1 and N1 effects when participants viewed objects that were either held with the proper grip or with an atypical grip. These objects were either normal objects or nonobjects that were composites of parts of other objects, such as scissors with a hammer head instead of blades. They measured P1 and N1 on two sensor groups, one aimed at measuring motor activity and another aimed at measuring visual activity. They found coactivation on visual and motor sensors in both components at both sites, strikingly similar to the results in the present thesis; visual and motor effects commencing around 100ms and persisting until around 200ms that varied with the action possibilities contained within the stimuli. They suggested that their P1 effects were marginal but that the greater P1 amplitude for congruent grips represented enhanced processing of action possibilities, fitting well with the findings in the present experiments. In turn, they also found greater N1 effects for congruent than incongruent grips, which themselves elicited a greater N1 component than non-objects. This suggests that the action possibilities conferred by the pictured grips were also systematically influencing the N1 component. It is important to note that this was not a typical SRC experiment, with stimuli depicting typical or atypical grips for interacting with the pictured objects supporting the assertion that the effects in visual components represent the extraction of action possibilities from the visual input, rather than reflecting task factors, such as the rule-cued response, which would be too high-level (i.e. requiring too many other processes to be complete, e.g. object identification, response selection) to have an effect on early visual processes. This also led the authors to suggest that whilst N1 was systematically varying with action possibilities in all three stimulus classes, their P1 effect was unlikely to be due to the same kind of action enhancement seen in Handy et al. (2003) but rather was attributable to stimulus incongruence (both mismatched object parts and mismatched grips) which nonetheless reflects extracting the action possibilities (or lack thereof) contained within the stimulus.

It is interesting to note that Kumar et al. (2012) also detected some interactions with grip-congruency and electrode hemisphere, however where the effects in this thesis were biased to the left hemisphere theirs were biased to the right hemisphere. This however may reflect differences between the normal object stimuli in this thesis and the stimuli used by Kumar et al. which contained a variety of mismatched objects and grips, as well as non-objects composed of parts of familiar objects. Researchers such as Grezes et al. (2003), Johnson-Frey et al. (2005) and Cisek (2007) (discussed variously) that have described a left hemisphere network for tool use and associated action effects have done so based on evidence from typical object stimuli, so the unusual composite non-objects may explain the partial right hemisphere lateralisation for anterior N1 effects observed by Kumar et al. (2012), which differs from the generally left-lateralised object network. Without further research, it is difficult to determine the accuracy of these assertions but regardless, the finding still betrays action-sensitivity in these early visual components.

An action effect in N1 was also detected by Van Elk et al. (2010). They found increased N1 amplitude when participants grasped a response device compared with pointing at it. They suggested that this indexed the extraction of action possibilities according to action intentions because grasping required participants to account for many more object properties in order to successfully grasp the stimulus (e.g. relating hand position to stimulus position, calculating reach trajectory and grasp aperture) whereas pointing does not require participants to attend to any properties of the object itself, merely its location. This fits very well with the SRC affordance effect obtained in N1 in the lateralised experiments where the intention to make particular responses (provided by the response rule) was influencing the detection of the visual properties of the stimulus and simultaneously discriminating which category the object belonged to. This may also go some way to explain why the N1 (and indeed P1) effects were limited to lateralised stimuli; as discussed above, maintaining a particular grip scaffolds perception just as demonstrated by Symes et al. (2008) and this scaffolding should reduce the load on visual cortex, facilitating detection of relevant object features, just as it does on motor cortex. Van Elk et al.'s (2010) explanation fits here too, because their N1 was described as determining how to grasp the device, which is markedly different from viewing a grip-type stimulus whilst already making the relevant grip; as above, when the grip is being maintained and there is no intention to grip the stimulus object, then participants need not parse the visual-action information with the aim of grasping it as they did in Van Elk et al. (2010) because they have already prepared the grasp. Focussing less on the stimulus and more on the intentions provided by the response set explains the different effects of viewing stimuli with otherwise equivalent affordances in SRC paradigms, including the spread of motor and visual effects found in this thesis, as well as the effects from the literature reviewed here. This approach unites visual and motor effects with both responses under a single explanation that sticks closely to the existing literature.

Broadly, the compatibility effects found in visual components in this thesis support the conclusions from elsewhere in the literature and demonstrate them in a new way using simple variations on the affordance SRC paradigm. Action intentions and available actions have been shown to affect the way visual information is parsed leading to effects of object *and* response typically assumed to be too high level to affect these early visual components. Taken with studies such as Kiefer et al. (2011) these observed effects are attributable to an unexpectedly rapid influence of a combination of the actions available to the participant, which in these SRC studies are dictated by the response devices. The following subsections will attempt to unravel this further by considering the differences between experiments and how they may inform this discussion.

*7.5.2. Left Hemisphere interactions with compatibility*

An interesting difference emerged between experiment one and the subsequent variations on the lateralised affordance SRC paradigm (experiments three, five and six). Experiment one made the striking observation of a compatibility effect in N1 and P1, however in both experiment three (masked version of original experiment) and six (delayed-response experiment) the main effect changed to an interaction with electrode hemisphere indicating greater activation in the left hemisphere. It is notable that these were the only experiments that required participants to represent the stimulus after it was no longer visible in order to make their responses. This has similarities to the evidence from Grezes and Decety (2002) and Grezes et al. (2003), demonstrating greater left-hemisphere activation in their affordance SRC experiments for both lateralised and grip-type stimuli. Grezes and Decety (2002) had participants perform three tasks on affording objects; categorical judgement, motor imagery and silent noun/ verb generation. Using PET they found that each of these tasks (including those where the stimulus was not visible) activated a left hemisphere network including left iPL, left SMA, left pars triangularis and left precentral gyrus. Because this network was active in all three tasks, irrespective of whether stimuli were visually present or not, it was associated with object *representation*. Grezes et al. (2003) extended these conclusions to include grip-type stimuli, finding very similar activations using fMRI. In their motor imagery and word generation tasks, there was no visible stimulus and they found greater left-hemisphere activation indicating the representation of the object properties. This evidence suggests that the greater N1 and P1 amplitudes in the left hemisphere in the masked lateralised and delayed-response experiments are attributable to the stimuli offsetting before response, calling this left-hemisphere network to represent them in their absence. This interpretation is supported by Johnson-Frey et al. (2005) and Cisek (2007) who reviewed a variety of literature showing that object properties are handled by a left hemisphere network and have proposed models focussed on the left-hemisphere localisation of these effects.

The masked lateralised (three) and delayed-response experiments (six) offer further insight when considering the nature of the LRP effects too; while the masked lateralised experiment (three) showed a negative compatibility effect in LRP, this was not reflected in the visual activity, which exhibited a typical, positive compatibility effect. This hemispheric interaction in N1 and P1 is unlikely to be related to the direction of subsequent motor effects, as it was also found in experiment 6, where the LRP exhibited normal polarity. The finding that visual and motor affordance effects do not exhibit the same behaviour under masking shows that affordance effects in visual components and LRP are distinct, with the former reflecting the extraction of action-relevant object properties (that vary with handle orientation) that may *later* produce the motor compatibility effect. Masked and unmasked experiments showing the same early visual effects suggests that these early stages of visual processing were the same, regardless of task demands or the LRP and RT effects that would follow. So, this suggests that the compatibility effects observed in P1 and N1 were not compatibility effects per se, but instead represent *precursors* to compatibility effects; initial stages of object processing best characterised as the extraction of the affording object properties from the visual input that will later lead to compatibility effects in RT and LRP. Distinguishing the visual effects from full compatibility effects is critical so that the compatibility effects in P1 and N1 are not overstated or misrepresented by implying that they represent the overlap of stimulus and response, which could not be reasonably expected to be resolved at such an early stage in processing (P1 from 70ms). For this reason, the visual 'compatibility effects' may be better described as affordance effects, because they seem to represent the extraction of action possibilities from visual input that will later yield compatibility effects. In so doing, they reflect the core idea of affordance; the online extraction of action possibilities from seen objects.

*7.5.3 Affordance effects in visual components in absence of response*

Elaborating on the summary from 7.5.1, the go, no-go experiment (five) is quite different from the masked, lateralised experiment (three) and the delayed response experiment (six). As in previous experiments an interaction of affordance and left hemisphere was detected in P1, however this also interacted with electrode position and indicated greater amplitudes on left occipital sensors when viewing the stimuli without an intention to respond to them. The occipital locus of these effects is quite surprising too, because models such as Cisek (2007), Johnson-Frey et al. (2005) and studies such as Grezes et al. (2003) and Grezes and Decety (2002) have not specified occipital cortex in their networks for handling object properties. This highlights the theoretical significance of detecting affordance effects in visual components, not only are the affordance effects observed in the visual components startling in terms of how rapidly action possibilities exert an influence, but also in terms of where they were detected; always strongest in the left hemisphere and on occipital sensors O1 and O2, rather than P7 and P8 as would be predicted by the literature, e.g. Cisek (2007) who focuses on parietal over occipital areas. This difference between experiment one and subsequent experiments has two implications; firstly it extends the idea of a left-hemisphere network and in doing so also recommends reconsidering the role of visual areas, especially during the earliest phases of affordance processing. Secondly, previous investigations have failed to identify this early visual activity and have instead focussed on motor and parietal activations for reasons of techniques employed, demonstrating the value of using temporally sensitive metrics when investigating visuomotor processes such as affordance. Examples of previous investigations focussing on parietal effects discussed so far include but are not limited to Grezes and Decety's (2002) PET study, Grezes et al.'s (2003) fMRI study, Castiello et al.'s (2000) PET study and Johnson-Frey et al.'s (2005) and Cisek's (2007) models, each of whom made extensive use of cerebral blood flow data in predicting their networks and few other methods.

The left occipital locus of the P1 effects was not the only surprising finding of the go, no-go experiment (five), which also failed to observe an N1 effect and was the only lateralised experiment in this thesis to not detect an effect or affordance interaction in N1. To reiterate, the key difference between the go, no-go experiment and other lateralised experiments is the lack of a manual response, instead using a verbal response to half of the stimuli (kitchen) and no response to the other half (tools) stimuli. This means that there was no manual response set to shape object perception as demonstrated by Symes et al. (2008), Van Elk et al. (2010), Hohlefeld et al. (2011) and others (discussed throughout). So, the lack of an affordance effect in N1 in the absence of a manual response suggests that this difference between the go, no-go experiment and those with bimanual responses could be interpreted as another demonstration of a response set affecting how a stimulus was perceived. This would suggest than N1 is sensitive to action intentions and/or prepared actions dictated by response set and may reflect the motor effect on visual perception seen in Symes et al. (2008), Van Elk et al. (2010) and others. This is a contentious assertion but one that may garner considerable support from the literature; Luck, Woodman and Vogel (2000) demonstrated that the visual N1 component indexes attentional selection effects, so without a response set to guide attention to the action relevant stimulus properties (as in Symes et al., 2008, etc.), perhaps objects were not selected for attention in the same way as experiments with bimanual keypress responses that offered compatibility with the stimuli. Franconeri, Hollingworth and Simons (2005), Yantis and Hillstrom (1994), Yantis (1993) and others (discussed in greater detail below) have shown that objects capture attention regardless of factors such as novelty, presentation, task relevance, luminance and other factors so taken with the go, no-go effects this implies that the key factor in generating this N1 effect is the relationship between stimulus and response. Perhaps then, the attention capturing properties of manipulable objects (e.g. Franconeri et al., 2005; Tucker & Ellis, 1998; Yantis & Hillstrom, 1994; Yantis, 1993) are sufficient to yield the LRP and P1 effects in the absence of the intention to act (Kiefer et al., 2011) but without a response or action intention to shape stimulus perception (Symes et al., 2008; Ellis, 2009; etc.) the sensory gain function ascribed to N1 (Eimer, 1993; Vogel & Luck, 2000; Luck, Woodman &Vogel, 2005) is not amplifying the relevant object features in the go, no-go experiment as it did in the forced-choice, bimanual response, lateralised affordance experiments. This explains the observed differences between the go experiments and the go, no-go experiment (i.e. no affordance effect in N1 for go, no-go experiment five) and ties them to the existing literature on N1.

The detection of a P1 effect in the go, no-go data suggests that the P1 effects with lateralised stimuli are automatic upon viewing the object, similar to the LRP effects. However this is far from certain as participants were still under speeded response conditions and still made a categorical judgement and so these task factors could affect the detection of P1. The effect on no-go trials could represent an influence of speeded response conditions leading participants to view the objects in a particular way and further investigation is required to elucidate this, particularly into purely passive viewing of affording objects without any kind of judgement to make. However this creates a problem in determining suitable catch trials. Proverbio et al. (2011) conducted a passive viewing paradigm without speeded response but did have participants make a categorical judgement on the stimuli to determine whether a trial was a catch trial requiring a response. They found that objects elicited a motor cortex effect much later than the present go, no-go experiment. This implies that the effects observed here may have been influenced by the speeded response, an argument supported by the idea of response sets and action intentions affecting perception. This may also apply to the visual components, with no effects reported by Proverbio et al. (2011) until much later, from 210ms. That said, this experiment could be said to make a poor comparison here due to the variety of stimuli employed by Proverbio et al. (2011) featuring a variety of different affordances, including handled objects as well as objects with unclear affordances, such as puzzle cubes and typewriters. A direct comparison using a single sample and a homogeneous stimulus set is required to assess this. That said, because the same P1 effects were obtained regardless of the intention to act on the stimuli then the findings of this thesis suggest that the effect detected in lateralised experiments in the P1 component is automatic, reflecting the detection of action-relevant object features.

Based on all of the P1 data, it seems that the effects in P1 index the detection of action possibilities contained within the stimulus. Because P1 is detected without responses, it is not contingent on action intentions created by the response set, speaking to early conceptions of affordance as occurring when simply viewing objects. This suggestion is supported by experiments that have demonstrated the attention capturing properties of affording objects without using matched SR pairs or SRC paradigms; Franconeri et al. (2005) used a visual search task during which a new object stimulus was added and found that that objects captured attention regardless of novelty. Relatedly, Yantis and Hillstrom (1994) also used visual search to show that presentation alone is sufficient to capture attention and that this attention-capturing effect is not contingent on luminance changes. Yantis' (1993) discussion reviewed evidence from non-SRC paradigms and suggested that task-relevant or irrelevant object features may capture attention when a task requires participants to attend stimulus, similar to the argument advanced in 7.4 that as long as participants do not have an explicit intention to attend to subordinate object features (e.g. colour) then merely viewing an object will elicit its affordances. Each of these findings fit perfectly with the experiments in this thesis and with the wider affordance literature too (e.g. Tucker & Ellis, 1998; affordance effect from task-irrelevant handle).

The differences between these experiments leads to a potential distinction between P1 and N1 components in terms of action compatibility/ affordance effects; P1 appears to index the detection of action possibilities (potentially explaining attention-capturing properties of objects) without reference to the participant's available actions, as evinced by its detection in all lateralised affordance SRC experiments, including the go, no-go experiment which lacked a manual response but applied identical data transforms and obtained nearly identical results. This assertion offers the possibility of P1 being treated as a neurophysiological marker of the attention capturing properties of objects (Franconeri et al., 2005; Tucker & Ellis, 1998; Yantis & Hillstrom, 1994; Yantis, 1993) and/or the first stage in the extraction of object affordance from visual input. Further evidence for this comes from the main effect of category that appeared in P1 in all experiments, which implies that when viewing the objects in order to complete the categorical judgement, participants also automatically extract the visual action-information therein, as suggested by Tucker and Ellis (1998), Vainio et al. (2008) and others. It would be possible to test this by using the same stimuli without a categorical judgement in a purely passive viewing experiment although determining suitable catch trials is problematic. Following the idea of P1 as indexing extraction of action-information, the lack of N1 for the go, no-go experiment suggests that the N1 affordance effect may be contingent on the relationship between perceived action possibilities and the perceiver's action intentions (dictated by response) because when participants had no intention to act, no effects were detected in N1. As discussed above, this fits with literature such as Van Elk et al. (2010) that also suggests a connection between action intentions and N1 effects. In turn, the lack of a response in the go, no-go experiment also suggests that the P1 effect is not contingent on a response. These suggestions require further investigation, but offer a novel view on affordance in P1 and N1 that fits the literature; P1 was obtained on all lateralised experiments (Luck, 2005) showing only minor latency variations (Van Voorhis & Hillyard, 1977; Mangun & Hillyard, 1991) and affordance effects in N1 were only detected when participants intended to make a manual response (and were not preparing the grip associated with the object), fitting with the notion of N1 as controlling sensory gain based on action intention/ object attention (e.g. Eimer, 1993; Vogel & Luck, 2000; Luck, Woodman & Vogel, 2005). Furthermore, the lack of N1 effects on grip-type experiments fits with the explanation from Van Elk et al. (2010), who suggested that N1 was extracting action-relevant object parameters in order to guide their reach-to-grasp response, an assertion that also fits with the lack of N1 effects with grip-type stimuli, where maintaining the response grips throughout the experiments is suggested to have embodied the salient action-information/

object properties, eliminating the need to extract the information from the visual input because it is already partially activated by effector position. This distinction on N1 is also supported by Proverbio et al. (2007) who found greater N1 effects when responding to objects than animals (responding with a bimanual keypress response as in the lateralised experiments here) and Proverbio et al. (2011) who found no N1 effects during their passive viewing paradigm where participants made no response to object stimuli. Future research could begin by replicating the different N1 effects using a single sample before attempting to elicit this component with other affording stimuli under a variety of response conditions in order to probe the assertion that visual N1 to affording objects is connected with observer's action intentions.

In summary, the small differences in visual components across lateralised experiments in this thesis are attributable to the systematic task variations and together offer some insight into some factors that may influence these components. When the object was not visible during the masked and delayed response trials, greater left hemisphere activity was elicited to represent the objects. When there was no response set, no N1 effect was obtained (as between Proverbio et al., 2007 and Proverbio et al., 2011), indicating that action effects in N1 have a relationship with intention (see also Van Elk et al., 2010). The occurrence of P1 effects in these experiments means that affordance effects in P1 could be argued to be automatic (i.e. not contingent on action intentions), although this requires further experimental clarification. Overall, the effects are remarkably consistent, with all lateralised experiments featuring a speeded categorical judgement and eliciting effects of affordance in P1 that are consistent with the visual extraction of action possibilities and eliciting N1 effects in all lateralised experiments with manual responses. Similarly, the lack of a P1 or N1 action effect in the grip-type experiments is consistent with the explanation given above for the LRP results, where maintaining the grips embodies object characteristics.

*7.5.4. Differences between grip-type and lateralised affordances in visual components*

As mentioned in 7.2.1, there were considerable differences between grip-type and lateralised LRP effects and this extended to the visual components too. No effect of affordance was observed in P1 or N1 for either of the grip-type affordance experiments. This is remarkable when considering the overall similarities in the paradigms, with only the class of affordance used in the SR pair changing between the grip and lateralised experiments. The lateralised affordance experiments used a bimanual keypress response (or a verbal response for the go, no-go experiment) however the grip-type experiments used response devices that mimicked the actions afforded by the objects. Participants held the devices throughout the experiment and maintaining a grip has been both hypothesised (Clark, 1997; Hommel, Müsseler, Ascherleben, & Prinz; 2001) and shown (Fagioli et al., 2007; Symes et al. 2008; Hohlefeld et al., 2011) to influence the perception of objects, so this difference in methods also explains the differences in the visual components.

The explanation given for the different LRP latencies in grip-type and lateralised experiments is that maintaining the grips throughout the experiment is shaping the perception of the stimuli, with some of the requisite motor processing being scaffolded by maintaining the grips, effectively 'pre-loading' the actions in motor cortex and scaffolding perception by partially activating the relevant neuronal populations before the stimulus is visible, reducing time-pressure and yielding later effects. This also explains why differences emerged between grip-type and lateralised affordance effects in visual components; the embodied/ scaffolding explanation hangs on the actions available to the participants through the response set, which are said to affect visual perception, as seen in various studies cited throughout (e.g. Fagioli et al., 2007; Symes et al., 2008; Hohlefeld et al., 2011; etc.). This explanation is similar to the explanation from Van Elk et al. (2010) who found enhanced amplitude in P1 and N1 when participants completed a reach-to-grasp on a grip-type response device, compared to pointing at the same device. Van Elk et al. (2010) also concluded that the actions available to the participants (dictated by the response set, pointing vs. grasping) were shaping perception of the objects, with the reach-to-grasp eliciting greater N1 effects because in order to complete the movement, participants had to visually detect the relevant object properties to determine factors such as grasp aperture, distance, and timing among other concerns. This explanation also fits for the lateralised stimuli in this thesis, where the response devices merely shared an abstract spatial relationship with the stimuli and so required participants to extract action-relevant properties in order to yield the observed affordance effects in RT and LRP. This mode of explanation is also supported by the wide variety of research cited above that shows a two-way relationship between vision and action, where available actions affected perception (e.g. Fagioli et al., 2007; Symes et al. 2008; Hohlefeld et al., 2011).

This differentiation also supports the suggestion above that these effects in visual components are better described as affordance effects than as compatibility effects because if the explanation from Van Elk et al. (2010) is correct and the early visual effects represent the extraction of action-relevant object properties (also indicated by the present data) then this suggests that the visual effects observed in the lateralised experiments are not the same as the compatibility effects observed in LRP and RT. Instead, it suggests that the affordance effect observed in P1 indexes the extraction of action-relevant object properties and that N1 is part of relating the same action-relevant object properties to the available actions (i.e. response sets). This is borne out by the lack of an N1 effect in the go, no-go experiment. Put another way, it means that the affordance effects observed in early visual components in lateralised experiments are not compatibility effects in the same way as in RT and LRP, indeed it would be bizarre to suggest that the relationship between an SR pair had been resolved by the earliest stages of visual processing (~70ms). Instead, these early visual 'compatibility effects' appear to represent precursors to the familiar LRP/ RT compatibility effects, detecting the object properties which yield compatibility with the actions available to the participants. These object properties necessarily vary with object compatibility, hence their manifestation in analyses of compatibility. Both handle orientation and available actions are represented in the ANOVA models so it seems the compatibility effects in visual cortex represent a lower-level effect of these variables. Based on the literature and the spread of effects in this thesis, that lower-level effect seems to be one of extracting action-relevant stimulus features (P1) and subsequently relating them to the available actions (N1).

An advantage of this mode of explanation is that it accounts for the observed results, including the differences in grip and lateralised experiments, without ascribing high-level processing such as object identification and completing categorical judgments to such low-level visual components and instead couches it in the detection/ discrimination of visual features in a choice-RT paradigm, fitting with Mangun and Hillyard's (1991) and Mangun's (1995) treatments of N1 as varying with spatial attention. It also provides a mechanism by which the influence of action intentions and/or available actions on visual processing may be exerted and begins to offer a neural basis for these effects. Another advantage is that this explanation is couched in the notion of affordance as being a rapid and fundamental means for an agent to relate bodily states to environment. This explanation takes advantage of the principles of embodied cognition described in the introductory chapters, particularly embodied/ situated cognition, which encompasses the scaffolding explanation. One way to test this assertion would be to conduct an experiment in which participants view the same set of grip-type stimuli whilst either maintaining the response grips in one condition or completing a reach-to-grasp action to the same response devices in another condition, similar to Van Elk et al.'s (2010) response.

One thing that may be learned from the difference between grip and lateralised experiments is that it does not appear that these early visual components represent automatically extracting the object affordance *per se*, because were that the case we would predict an effect on the grip-type experiments too. Instead, perhaps a better way to consider the P1 and N1 effects for lateralised stimuli is as detecting the visual cues to the relationship between stimulus and effector. To put it more simply still, these visual components may be seen as detecting visual cues to the usability of the objects, particularly P1. Viewed in this way, the visual effects in this thesis are novel but do not require great revision of the ideas they are based on and offer good fit with variations within and outside this thesis.

### *7.5.5 Conclusions on visual components*

The suggestion that N1 is influenced by action intention fits perfectly with the idea that N1 effects indicate sensory gain based on intention and attention (Eimer, 1993; Vogel & Luck, 2000; Luck et al., 2005), because (as discussed throughout) participants' action intentions and available actions affect the way stimuli are perceived and N1 provides a candidate mechanism for this. Evidence supporting this comes from the lack of N1 effects when participants do not make response (e.g. go, no-go experiment five; Proverbio et al., 2011) compared to when they do make a response (e.g. lateralised SRC experiment one; masked lateralised experiment three; Proverbio et al., 2007; Van Elk et al., 2010). Furthermore, when participants prepare the responses throughout, no N1 effects are detected (grip-type experiments two & four) and this explanation suggests that this is because maintaining the grips already partially activated the same neuronal populations as viewing the affordances, hence the sensory gain function ascribed to N1 is not detected because its action is already completed by the response devices. So, the influence of response parameters on visual detection of affordances may be given a mechanism through the sensory gain control function of the N1 component.

The idea that maintaining grips scaffolds object perception has received wide support in the literature and also supports the interpretation of P1 as representing an initial stage of extracting object possibilities without reference to action intentions.  This is supported by the detection of P1 effects on all lateralised experiments with responses, but not on the grip-type experiments, where response devices led participants to prepare the afforded actions throughout the experiment, removing the need to visually extract the afforded actions.

These findings not only elucidate a critical difference between two behaviourally equivalent sources of affordance (lateralised and grip-type) but they also offer a novel insight into the function of P1 and N1 components that follows naturally from the classic interpretations of them, merely extending these low-level processes into handling object properties.  In turn, this explanation offers a chance to explain some of the more striking findings which display a two-way relationship between vision and action.

### *7.6 Conclusion*

The experimental work presented in this thesis has demonstrated consistent patterns of early visuomotor activation elicited by viewing affording objects, providing some of the first direct evidence on the timecourse of visuomotor processing of different classes of object affordances. The experiments indicate that viewing a lateralised affording object will not only yield an automatic behavioural affordance effect, it will also yield concurrent motor activation and visual activation, measurable from 100ms in LRP and from 70ms in ERP components P1 and N1, respectively. As well as providing novel evidence on the concurrent activation of visual and motor cortices when viewing lateralised affordances, three findings have emerged that were not predicted by the behavioural literature. These findings offer new insight into affordance processing:

*a)* This thesis has shown fundamental differences between grip-type and lateralised affordances in terms of the visual and motor effects they elicit that were not predicted by the literature. This finding questions whether the label 'visuomotor' is applicable to processing grip-type affordances in SRC paradigms because they failed to elicit visual effects under the same conditions as lateralised affording objects, which always elicited an effect in visual P1 and/or N1. These findings represent some of the only empirical evidence on this difference and one of few attempts to quantify these differences. These results suggest that lateralised and grip-type affordance SRC experiments represent quite different processing routes to achieve the same behavioural outcomes. This difference appears to be attributable to the bodily states induced by holding the grip-type response devices compared with making a button-press response and as such recommends a reconsideration of the role of responses or prepared actions in models of affordance SRC. To date, the literature has focussed on how the action information contained within the stimulus affects motor processing, however the present data is in-line with a growing literature showing that bodily states (such as prepared responses) affect visual perception.

The differences between affordance classes observed in this thesis suggest that lateralised SRC affordance effects are driven by stimulus information but that grip-type affordance SRC effects are driven more by the responses shaping the perception of the stimulus. This thesis recommends future investigations and models of affordance account for the influences of response devices and affordances classes because they have a profound effect on what electrophysiological activity is elicited.

*b)* Perhaps the most surprising finding was the effect of affordance on visual components P1 and N1, which have typically been thought of as being elicited by all visual input without selecting for higher order object properties such as affordance. The evidence presented here constitutes a consistent set of affordance effects in these components, replicated over a series of four experiments and elicited by viewing lateralised affording objects, regardless of the intention to act or task requirements to direct attention to them. These findings make two recommendations; a reconsideration of P1 and N1 components in terms of vision for action and a revision to existing models proposed for handling object properties, to include very early occipital cortex activation represented by these components. The findings also offer a tentative delineation of P1 and N1 as marking different stages of object perception and so, marking different stages in the production of an affordance; P1 appears to index the extraction of object properties from the visual input, including (but not limited to) the affordance-relevant object properties. This appears to represent an early stage in a cascade of visuomotor processes leading to the generation of an affordance. In contrast, the detection of N1 was contingent on the presence of a response in this thesis and varied with responses in the literature and this indicates that affordance-related effects in N1 must bear a relationship with response. Future research may use this as a starting point to better understand the contribution of occipital cortex to vision for action.

*c)* This thesis has used the observed electrophysiological activity to provide direct evidence to confirm the assumption of automaticity by using two entirely novel variations on the affordance SRC paradigm to demonstrate first evidence that neither an intention to act nor a categorical judgement is required to elicit affordance-related visuomotor activity with lateralised stimuli. Viewing the same lateralised affordances consistently produced rapid visuomotor activation that varied systematically with the object affordance and did not change with task parameters such as the intention to make a motor response or task requirements to attend the stimulus. The use of electrophysiological measures allowed a direct demonstration of the core principle of affordance; that merely viewing an object is sufficient to yield preparation of the actions that it affords. An addendum to this is that an N1 effect was not obtained with lateralised stimuli in the absence of response, suggesting that only the P1 and LRP effects have automatic components.

Overall, this thesis demonstrates that electrophysiological measures offer considerable insight into mechanics of object affordance and are a powerful means to examine some of the more esoteric claims and assumptions in the literature. In doing so, it has demonstrated surprising differences between behaviourally equivalent affordances and emphasises the role of the response and of visual cortices in affordance SRC effects. Taken together, these surprising findings build on the suggested two-way relationship between vision and action (e.g. Ellis, 2009; Symes et al., 2008; etc.) to suggest a three-stage loop, where bodily states affect object attention, object attention affects what visuomotor activity is elicited, and that visuomotor activity affects bodily states, which in turn affects attention, with no apparent prime mover. This proposed loop accounts for how the different visuomotor activity elicited by different affordance classes can produce the same behavioural facilitation effect; because these three stages exist in a state of constant flux, each influencing each other in a continual effort to facilitate goal-directed action in our rich and complex environment.

*8. Chapter eight*

*Appendix – stimuli*

*8.1 Lateralised stimuli for experiments one, three and five*

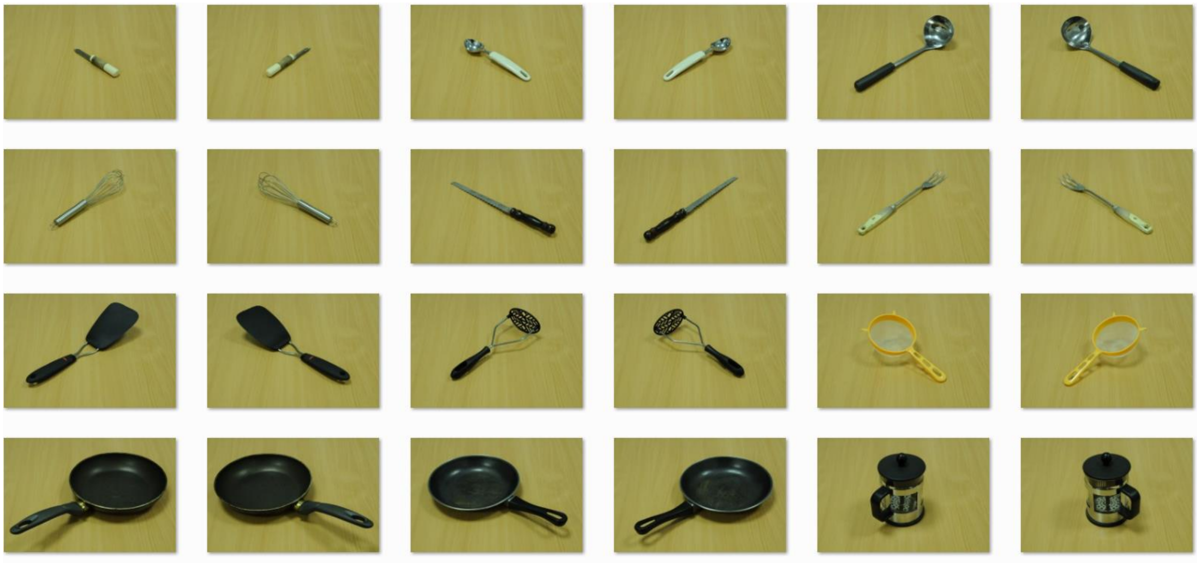
*8.1.1 Stimulus table*

*Table 2. Table of stimuli for experiments one, three and five*

| | Kitchen items with a left-facing handle | | Kitchen items with a right-facing handle | | Tool items with a left-facing handle | | Tool items with a right-facing handle |
|---|---|---|---|---|---|---|---|
| 1 | Frying pan | 22 | Frying pan | 43 | Saw | 64 | Saw |
| 2 | Saucepan | 23 | Saucepan | 44 | Wrench | 65 | Wrench |
| 3 | Breadknife | 24 | Breadknife | 45 | Claw Hammer | 66 | Claw Hammer |
| 4 | Cafetiere | 25 | Cafetiere | 46 | Power drill | 67 | Power Drill |
| 5 | Cup | 26 | Cup | 47 | File | 68 | File |
| 6 | Salad fork | 27 | Salad fork | 48 | Grips | 69 | Grips |
| 7 | Jug | 28 | Jug | 49 | Large paintbrush | 70 | Large paintbrush |
| 8 | Kettle | 29 | Kettle | 50 | Mallet | 71 | Mallet |
| 9 | Ladle | 30 | Ladle | 51 | Machinists hammer | 72 | Machinists hammer |
| 10 | Mash | 31 | Mash | 52 | Medium paintbrush | 73 | Medium paintbrush |
| 11 | Milk jug | 32 | Milk jug | 53 | Clamp | 74 | Clamp |
| 12 | White mug | 33 | White mug | 54 | Needle pliers | 75 | Needle pliers |
| 13 | Brown mug | 34 | Brown mug | 55 | Pliers | 76 | Pliers |
| 14 | Peeler | 35 | Peeler | 56 | Paint roller | 77 | Paint roller |
| 15 | Ice cream scoop | 36 | Ice cream scoop | 57 | Small paintbrush | 78 | Small paintbrush |
| 16 | Sieve | 37 | Sieve | 58 | Small hammer | 79 | Small hammer |
| 17 | Small frying pan | 38 | Small frying pan | 59 | Coping saw | 80 | Coping saw |
| 18 | Small saucepan | 39 | Small saucepan | 60 | Small wrench | 81 | Small wrench |
| 19 | Spatula | 40 | Spatula | 61 | Tin snips | 82 | Tin snips |
| 20 | Teapot | 41 | Teapot | 62 | Crimping tool | 83 | Crimping tool |
| 21 | Whisk | 42 | Whisk | 63 | Pointing trowel | 84 | Pointing trowel |

*8.1.2 Appendix Stimulus Images for experiments one, three and five*

*8.1.2 Stimulus images used in experiments one, four and five continued…*



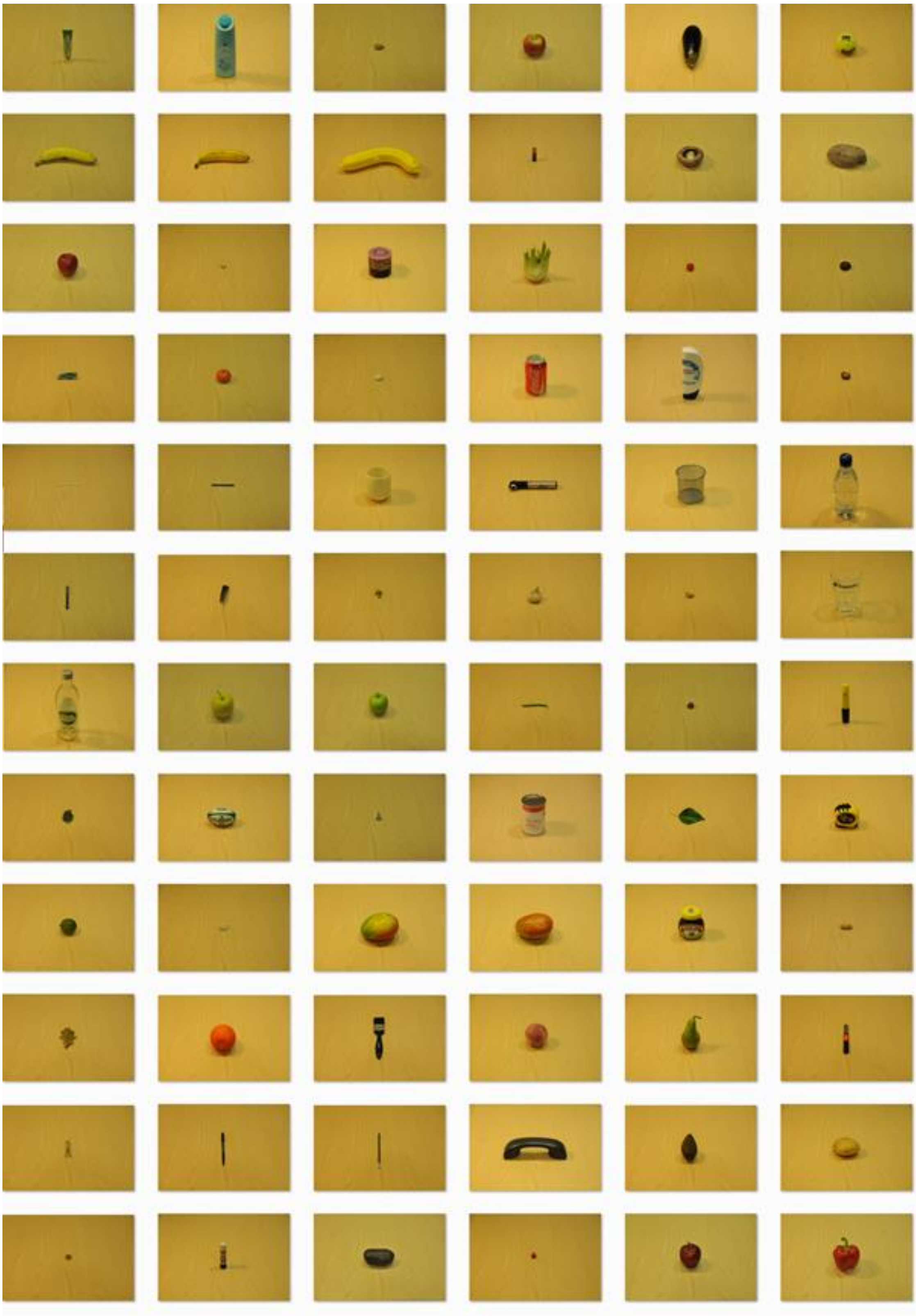
*8.2 Stimuli used in grip-type experiments two and four*

*8.2.1 Stimulus table*

*Table 3. Table of stimuli for Experiments two and four*

| | Manufactured objects with a power grip response | | Manufactured objects with a precision grip response | | Organic objects with a power grip response | | Organic objects with a precision grip response |
|---|---|---|---|---|---|---|---|
| 1 | Aftersun | 25 | Adhesive | 49 | Apple | 73 | Almond |
| 2 | Ball | 26 | Battery | 50 | Aubergine | 74 | CherryTomato |
| 3 | BananaCase | 27 | ButterflyNut | 51 | Banana | 75 | Chestnut |
| 4 | Candle | 28 | ChewingGum | 52 | BananaBrown | 76 | Clementine |
| 5 | CokeCan | 29 | CottonBud | 53 | BigMushroom | 77 | CockleShell |
| 6 | Conditioner | 30 | Ring | 54 | BigPebble | 78 | Conker |
| 7 | Cup | 31 | Crayon | 55 | Braeburn | 79 | Feather |
| 8 | Cycle Pump | 32 | DrillBit | 56 | Celeriac | 80 | FlowerHead |
| 9 | Desk Tidy | 33 | Highlighter | 57 | GoldenDelicious | 81 | GarlicBulb |
| 10 | Drench | 34 | Key | 58 | GrannySmith | 82 | GarlicClove |
| 11 | Glass | 35 | Peg | 59 | Mango | 83 | GreenBean |
| 12 | Glass Bottle | 36 | Pen | 60 | MangoPink | 84 | Hazelnut |
| 13 | JugglingBall | 37 | Pencil | 61 | Orange | 85 | HollyLeaf |
| 14 | KidneyBeanTin | 38 | Pound | 62 | Peach | 86 | Leaf |
| 15 | LeverLock | 39 | PrittStick | 63 | Pear | 87 | Lime |
| 16 | MarmiteJar | 40 | Reel | 64 | PineCone | 88 | Limpit |
| 17 | PaintBrush | 41 | Scissors | 65 | Potato | 89 | MonkeyNut |
| 18 | Peeler | 42 | Screw | 66 | PurplePotato | 90 | OakLeaf |
| 19 | Phone | 43 | ScrewDriver | 67 | RedDelicious | 91 | RedBerry |
| 20 | RollingPin | 44 | Staple | 68 | RedPepper | 92 | RunnerBean |
| 21 | StylingPaste | 45 | Straw | 69 | Rock | 93 | Shell |
| 22 | SunLotion | 46 | Twopence | 70 | Squash | 94 | SmallMushroom |
| 23 | TomTin | 47 | USBStick | 71 | Stick | 95 | SmallPineCone |
| 24 | Vase | 48 | Whistle | 72 | YellowPepper | 96 | Twig |

*8.2.2 Images used in experiments two and four*



*8.2.2 Images used in experiments two and four continued*

## *8.3 Stimuli used for lateralised, delayed response experiment six*

### *8.3.1 Stimulus table*

*Table 4. Table of stimuli for experiment six*

| | Kitchen objects with left facing handles | | Kitchen objects with right facing handles | | Tool objects with left facing handles | | Tool objects with right facing handles |
|---|---|---|---|---|---|---|---|
| 1 | Spatula | 26 | Spatula | 51 | Chisel | 76 | Chisel |
| 2 | Spoon | 27 | Spoon | 52 | Large paint brush | 77 | Large paint brush |
| 3 | Whisk | 28 | Whisk | 53 | Blue screwdriver | 78 | Blue screwdriver |
| 4 | Mash | 29 | Mash | 54 | Chisel 2 | 79 | Chisel 2 |
| 5 | Black ladel | 30 | Black ladel | 55 | Clippers | 80 | Clippers |
| 6 | Black Spoon | 31 | Black Spoon | 56 | File | 81 | File |
| 7 | Cup | 32 | Cup | 57 | Garden fork | 82 | Garden fork |
| 8 | Frying pan | 33 | Frying pan | 58 | Long pliers | 83 | Long pliers |
| 9 | Iron pan | 34 | Iron pan | 59 | Needle file | 84 | Needle file |
| 10 | Ladel | 35 | Ladel | 60 | Paint brush | 85 | Paint brush |
| 11 | Mash | 36 | Mash | 61 | Pliers | 86 | Pliers |
| 12 | Mug | 37 | Mug | 62 | Pointing Trowel | 87 | Pointing Trowel |
| 13 | Saucepan | 38 | Saucepan | 63 | Red Screwdriver | 88 | Red Screwdriver |
| 14 | Silver spoon | 39 | Silver spoon | 64 | Rubber Mallet | 89 | Rubber Mallet |
| 15 | Silver ladel | 40 | Silver ladel | 65 | Scraper | 90 | Scraper |
| 16 | Fish slice | 41 | Fish slice | 66 | Screwdriver | 91 | Screwdriver |
| 17 | Small frying pan | 42 | Small frying pan | 67 | Small Brush | 92 | Small Brush |
| 18 | Spaghetti strainer | 43 | Spaghetti strainer | 68 | Tin snips | 93 | Tin snips |
| 19 | Small saucepan | 44 | Small saucepan | 69 | Small paintbrush | 94 | Small paintbrush |
| 20 | Spatula 2 | 45 | Spatula 2 | 70 | Small scraper | 95 | Small scraper |
| 21 | Silver fish slice | 46 | Silver fish slice | 71 | Torch | 96 | Torch |
| 22 | Sharpening steel | 47 | Sharpening steel | 72 | Long brush | 97 | Long brush |
| 23 | Tea cup | 48 | Tea cup | 73 | Wire brush | 98 | Wire brush |
| 24 | Tongs | 49 | Tongs | 74 | Wire strippers | 99 | Wire strippers |
| 25 | Wooden spoon | 50 | Wooden spoon | 75 | Wooden mallet | 100 | Wooden mallet |

*8.3.2 Neutrally rotated Images used in experiment six*

*8.3.3 Lateralised Images used in experiment six*

*8.3.3 Lateralised Images used in experiment six continued…*

*9. Chapter nine*

*Appendix – Publications*

*9.1 Published study: Electrophysiological examination of embodiment in vision and action*

Goslin, J., Dixon, T., Fischer, M. H., Cangelosi, A., & Ellis, R. (2012). Electrophysiological examination of embodiment in vision and action. *Psychological Science*, *23*(2), 152-157.

Research Report

Psychological Science
23(2) 152–157

DOI: 10.1177/0956797611429578
http://pss.sagepub.com
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# Electrophysiological Examination of Embodiment in Vision and Action

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**Abstract**

A wealth of behavioral data has shown that the visual properties of objects automatically potentiate motor actions linked with them, but how deeply are these affordances embedded in visual processing? In the study reported here, we used electrophysiological measures to examine the time course of affordance resulting from the leftward or rightward orientation of the handles of common objects. Participants were asked to categorize those objects using a left- or right-handed motor response. Lateralized readiness potentials showed rapid motor preparation in the hand congruent with the affordance provided by the object only 100 to 200 ms after stimulus presentation and up to 400 ms before the actual response. Examination of event-related potentials also revealed an effect of handle orientation and response-hand congruency on the visual P1 and N1 components. Both of these results suggest that activity in the early sensory pathways is modulated by the action associations of objects and the intentions of the viewer.

**Keywords**

cognitive neuroscience, electrophysiology, vision, motor processes

Received 3/9/11; Revision accepted 9/6/11

Theories of embodied cognition (Wilson, 2002) posit an intimate link between perception and action, in which the visual system provides direct information on the behavioral possibilities afforded by objects. Data said to demonstrate the affordance provided by visual objects has been reported in studies using a stimulus-response compatibility as a paradigm (e.g., Michaels, 1988; Thorpe, Fize, & Marlot, 1996; Tucker & Ellis, 1998), in which participants classify objects faster when their motor response is congruent with that afforded by the judged object than when it is incongruent. For example, participants would classify an orange faster than a grape as a type of fruit if their response required a power grip, the pattern being reversed when performing a precision grip. These compatibility effects have been shown for the hand used (Tucker & Ellis, 1998), wrist rotation, and hand shape (Ellis & Tucker, 2000).

The primary question in the study reported here is at which level of processing are these affordances established? Does visual processing proceed independently, with links to the motor system occurring only at the point of response selection? Or do the visual and motor responses of the brain form a far more integrated and dynamic system, with exchanges at very early stages, as is commonly assumed in accounts of the behavioral data on the affordances provided by visual objects (Ellis, 2009)?

In the study reported here, we examined temporal characteristics of object-response compatibility by recording electrical brain activity during a standard stimulus-response-compatibility experiment. In this experiment, participants were required to use their left and right hands to make category judgments about pictures of household objects with left- or right-facing handles. In this case, affordance would lead to facilitation when the hand with which participants responded was congruent with the direction the handle of the object was facing, and affordance would lead to inhibition when the handle orientation and the response hand were incongruent. Measurement of the lateralized readiness potential (LRP) during the task provided an indication of when this affordance takes place.

The LRP is measured from electrodes situated over the primary motor cortex, and it reflects the lateralization that occurs as a result of left- or right-handed response preparation (e.g., Coles, 1989). The LRP provides a real-time measure of the transmission of information from perceptual to motor processes,

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and thus an estimate of when particular information is used in response preparation. If action selection is driven by the semantics of participants' experience with an object (Chao & Martin, 2000; Grafton, Fadiga, Arbib, & Rizzolatti, 1997), we would expect that the lateralized effect of affordance would be reflected in the LRP around the same time as the response selection to the semantic categorization task. However, if action is integrated with earlier sensory activation (Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003), then response selection should take place within the time frame of early visual perceptual processes, usually before 200 ms of stimulus onset, which is well before response activation.

If this were the case, we would also expect that the action intentions of participants would be reflected in modulations of event-related-potential (ERP) components related to early visual processing, such as the posterior P1 and N1 components, which reflect activity from low-level extrastriate visual cortical areas. These components are most often associated with studies of spatial-attention cuing (Handy & Mangun, 2000; Luck & Hillyard, 1995; Mangun & Hillyard, 1988), but they have also been shown to be sensitive to nonspatial and potentially object-based features, such as orientation (Karayanidis & Michie, 1997; O'Donnell, Swearer, Smith, Hokama, & McCarley, 1997). Therefore, we would fully expect that these components would be modulated by the visual cue provided by the orientation of the object handles. However, if embodiment really is deeply embedded in early visual processing, we would also expect that the P1 and N1 components would in turn be modulated by the motor intentions of the participants.

## Method

### Participants

Seventy volunteers (26 male, 44 female; mean age = 20 years, *SD* = 1.60) from the University of Plymouth were paid £6 for participation in this experiment. All reported being right-handed and having normal or corrected-to-normal vision. The data of 5 participants were removed from analyses because of excessive electroencephalogram (EEG) artifacts (> 30% of segments contaminated in any one condition).

### Stimuli

Eighty-four color pictures of 42 common household objects were used as stimuli in this experiment. Each object was photographed with its handle facing leftward and with its handle facing rightward. Half of the objects fit the semantic category of kitchen utensil, and half fit the category of tool (see Fig. 1a for examples).

### Procedure

Participants were asked to make a speeded judgment to categorize each stimulus as a kitchen utensil or a tool, which they did by pressing a button with their left or right hand. Participants were given no instructions regarding the orientation of the objects' handles. Each trial began with a fixation cross presented in the center of the screen for 1,000 to 1,200 ms. This was immediately followed by the stimulus image, which remained on the screen until the participant made a response but not longer than 2,000 ms. Finally, between 400 and 600 ms after the offset of the stimulus image, a rest symbol was presented for 1,400 ms. Participants were asked to blink or move their eyes only when they saw the rest symbol and not during the other parts of the trial.

Each participant was presented with six blocks of stimuli, with each block consisting of the entire stimulus set of 84 pictures presented in a different random order. There were two trials types: On congruent trials, the response hand and the orientation of the stimulus's handle were the same; on incongruent trials, the response hand and the orientation of the stimulus's handle were opposite. In the first three blocks, the participants responded with one mapping of response hand to category, switching to the reverse mapping for the remaining blocks. The mapping order was counterbalanced across participants. To familiarize the participant with the procedure, we presented a short practice block before the main experiment.

### EEG recording

EEG data were collected from 30 actively amplified Ag/AgCl electrodes (actiCAP, Brain Products, Gilching, Germany) mounted on an elastic cap. Electrodes were referenced to the left mastoid and re-referenced off-line to the average of left and right mastoid activity. Vertical eye movement was monitored by a suborbital electrode, and horizontal eye movement was monitored using left and right electrodes on the external canthi. Electrode impedances were kept below 20 kΩ. EEGs were amplified using a BrainAmp MR Plus amplifier (Brain Products), continuously sampled at 500 Hz, and filtered off-line with a band-pass filter from 0.1 to 40 Hz. ERPs were computed by averaging artifact-free EEGs associated with correct behavioral responses (> 93% of trials). These EEGs were time-locked to 200 ms before the stimulus onset to 800 ms afterward, and then they were baseline-corrected using the period prior to stimulus presentation.

## Results

### Behavioral data

Reaction times for category judgments were calculated for the 93.62% of responses that were correct, with further exclusion of responses outside of the time window between 200 and 1,200 ms after stimulus onset or 2.5 standard deviations of the mean cell value. Repeated measures analyses of variance (ANOVAs) with between-participants factors of object category (kitchen utensil vs. tool) and response-hand/handle-orientation congruency (congruent vs. incongruent) revealed a

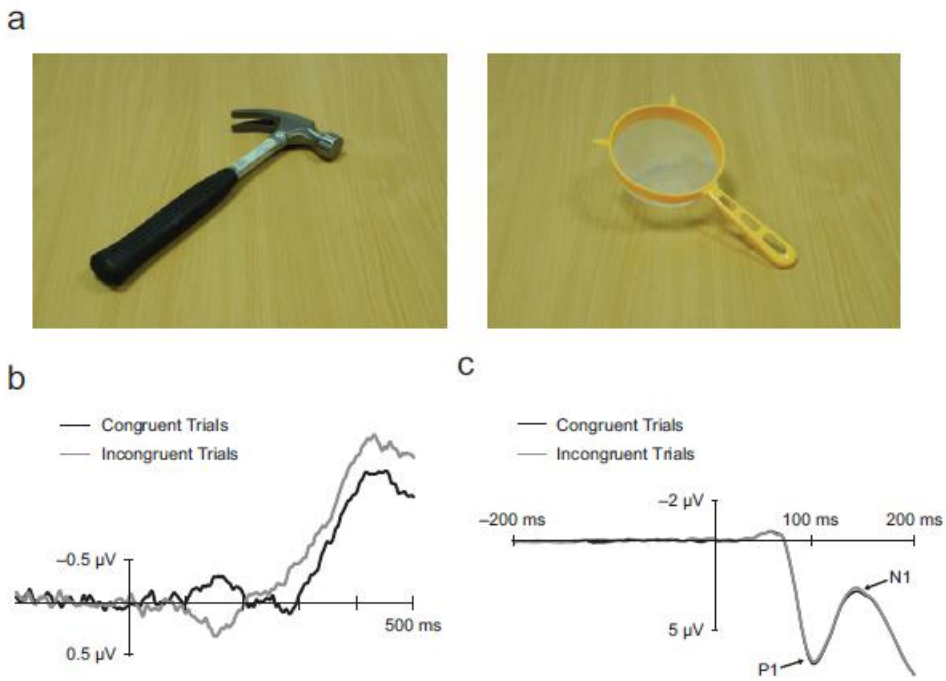


**Fig. 1.** Example stimuli and results illustrating object-based affordances. Stimuli (a) consisted of photographs of two categories of objects (tools and kitchen utensils) with their handles facing either left or right. Stimulus-locked lateralized readiness potentials (b) were calculated separately for the congruent condition (in which the direction the object's handle was facing and the response hand of the participant were congruent) and the incongruent condition (in which the direction the object's handle was facing and the response hand of the participant were incongruent). Event-related potentials (ERPs; c) pooled from the P7, P8, O1, and O2 electrodes show the posterior-occipital P1 and N1 components. Waveforms for the congruent and incongruent conditions are illustrated separately. The bar that shows the ERP magnitude is positioned at stimulus onset.

significant main effect of congruency, $F(1, 64) = 6.53$, $p = .012$, plus an interaction between category and congruency, $F(1, 64) = 16.81$, $p < .001$. Participants showed faster reaction times when the responding hand was congruent with the orientation of the object handle (542 ms) than when the response hand and handle orientation were incongruent (547 ms). The Category × Congruency interaction revealed a significant effect of congruency for the objects in the tools group (i.e., responses in congruent trials were 10.31 ms faster than responses in incongruent trials for the tools group), $F(1, 64) = 20.38$, $p < .001$, but not for the objects in the kitchen-utensils group ($F < 1$).

### LRP data

Separate LRPs for congruent and incongruent trials of both object categories were calculated using the Coles (1989) derivation. That is, the LRP for congruent trials was calculated by subtracting the C3 potential from the C4 potential for objects with left-facing handles requiring a left-handed response, subtracting the C4 potential from the C3 potential for objects with right-facing handles requiring a right-handed response, and averaging these two values. The LRP for incongruent trials was calculated by subtracting the C3 potential from the C4 potential for objects with right-facing handles requiring a left-handed response, subtracting the C4 potential from the C3 potential for objects with left-facing handles requiring a right-handed response, and averaging these two values. The resulting LRPs, shown in Figure 1b, had a negative polarity for preparation of the correct response hand and a positive polarity for the preparation of an incorrect response.

Average LRP amplitudes were analyzed over the five contiguous 100-ms time windows from 0 to 500 ms after stimulus onset using ANOVAs with within-participants factors of object category and congruency. The only significant effect ($p < .05$) was that of congruency in the 100- to 200-ms time window, in which congruent trials led to the preparation of the correct response hand and incongruent trials led to the preparation of the incorrect hand, $F(1, 64) = 24.84$, $p < .001$, $\eta^2 = .280$.

## ERP data

Figure 1c shows average ERPs pooled across posterior and occipital electrodes P7, P8, O1, and O2 for congruent and incongruent trials. Figure 2 shows waveforms for each of these electrodes separately, for each of the four trial types. Average ERP amplitudes for the visual P1 and N1 components evident at these electrodes were calculated, respectively, for the time windows between 70 and 100 ms and between 120 and 170 ms after stimulus onset. These values were analyzed using repeated measures ANOVAs with within-participants factors of response hand (left vs. right), handle orientation (left vs. right), electrode hemisphere (left vs. right), and electrode laterality (posterior vs. occipital).

An interaction between hemisphere and handle orientation was revealed in both time windows—P1: $F(1, 64) = 5.98$, $p = .017$, $\eta^2 = .085$; N1: $F(1, 64) = 100.87$, $p < .001$, $\eta^2 = .611$—with the voltages in the hemisphere contralateral to the orientation of the object's handle more positive across the P1 and more negative across the N1. Handle orientation also interacted with the response hand used by the participant—P1: $F(1, 64) = 6.91$, $p = .011$, $\eta^2 = .097$; N1: $F(1, 64) = 5.49$, $p = .022$, $\eta^2 = .079$—resulting in more positive voltages for congruent than for incongruent trials across both the N1 and the P1 time windows (shown in Fig. 1c). An additional ANOVA showed that this interaction did not occur within the time period used for baseline calculation (0 to 200 ms before stimulus onset: $F < 1$). There were also indications that congruency was modulated by object category—P1: $F(1, 64) = 2.73$, $p = .1$, $\eta^2 = .041$; N1: $F(1, 64) = 3.74$, $p = .057$, $\eta^2 = .055$—as in the behavioral results. Indeed, further ANOVAs specific to each object category showed that the congruency effect between handle orientation and response hand was only significant for the tools category—P1: $F(1, 64) = 10.99$, $p = .001$, $\eta^2 = .146$; N1: $F(1, 64) = 12.40$, $p < .001$, $\eta^2 = .162$—and not for kitchen utensils—P1 and N1: $F < 1$.

## Discussion

The results of the study reported here confirm the intimate link between vision and action posited by theories of embodied cognition. Our findings provide evidence that even low-level visual processes are modulated by the relation between the

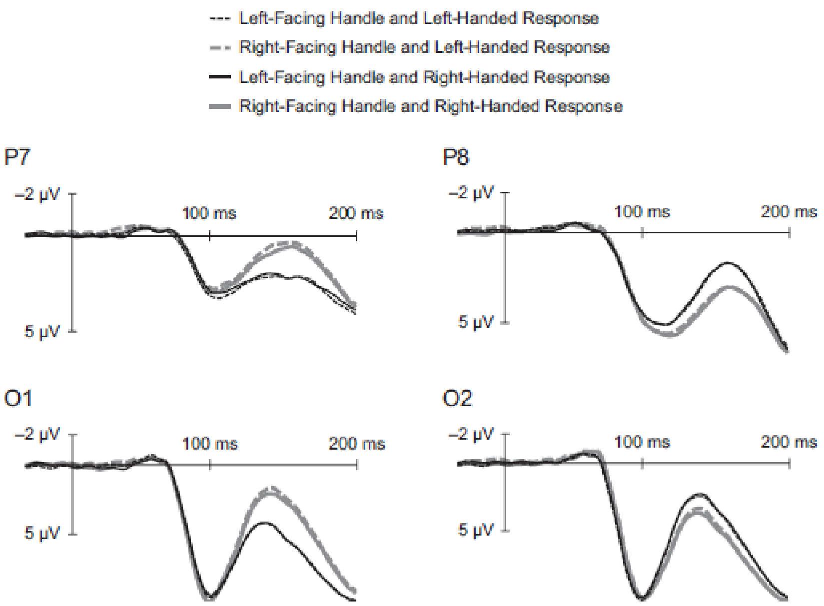


**Fig. 2.** Average event-related potentials (ERPs) for electrodes P7, P8, O1, and O2. For each handle orientation, separate waveforms are shown for trials requiring a left-hand response and trials requiring a right-hand response. The bars that show the ERP magnitude are positioned at stimulus onset.

action associated with a depicted object and the action intentions of the observer. The behavioral results of the present study revealed the expected lateralized affordance effect seen in previous studies (e.g., Tucker & Ellis, 1998), with actions facilitated when the handle of the object is congruent with the intended response hand.

Analyses of LRPs revealed that this affordance effect was reflected within 100 ms of stimulus onset in the preparation of the correct response hand during congruent trials and the preparation of the incorrect hand during incongruent trials. Such an early effect on motor activation suggests interactions between the visual and motor systems prior to object categorization and the subsequent selection of the overt response. This is not to suggest that all affordance effects depend on these early influences. The finding that the names of objects potentiate the grips associated with them (Tucker & Ellis, 2004) clearly supports semantic sources of affordance. Rather, our intention here was to reveal the neural interactions that underpin behavioral effects that have been assumed to demonstrate automatic or direct links between the visual and motor systems, such as micro-affordance (Tucker & Ellis, 1998, 2004), but also many other effects that may be generally described as visual-to-motor priming (e.g., Craighero, Fadiga, Rizzolatti, & Umilta, 1998; Rumiati & Humphreys, 1998).

The observed modulation of the posterior visual P1 and N1 components also indicates that exchanges between the visual and motor systems occur at early stages. In the present study, we found that the orientation of the object handle evoked increased P1 and N1 amplitudes in the hemisphere contralateral to handle orientation. Although when participants are asked to select stimuli on the basis of their horizontal-vertical orientation, the amplitudes have been found to increase in the P1 component (Karayanidis & Michie, 1997) and the N1 component (O'Donnell et al., 1997), the hemispheric modulation of the effect observed here is similar to that seen with spatial cuing (Handy & Mangun, 2000; Luck & Hillyard, 1995; Mangun & Hillyard, 1988), as if the visual asymmetry of the objects were shifting attention laterally.

The relation between handle orientation and the response hand of the participant is of potentially greater theoretical interest: Congruent relations generated more positive amplitudes for the N1 and P1 components across both hemispheres than did incongruent relations. This broad posterior increase in ERP amplitude has similarities to the selection negativity (Czigler & Geczy, 1996; Eimer, 1997; Heslenfeld, Kenemans, Kok, & Molenaar, 1997), but it is distinguished by differences in polarity, early onset (70 ms vs. 150 ms), and, most important, the manner in which it is elicited.

This compatibility effect cannot, of course, be explained in terms of the visual properties of the stimuli, as the differences were found between presentations of the same visual stimuli and were modulated only by the expected motor response of the participant. It is also unlikely that the compatibility effect results from changes in spatial attention that may be a consequence of a decision to respond with a particular hand. Such decisions can be reached only after object categorization, which is surely too late to affect these early visual responses. The relation between observed behavioral affordances (reaction times) and these ERP findings is also highlighted by similar interactions between affordance and stimulus category in the two domains. That is, the affordance-related effects on reaction times and early visual ERPs were both stronger for the objects in the tools category than for the objects in the kitchen-utensils category.

We believe that our discovery of an action-compatibility effect on what have been thought of as purely visual responses may have considerable theoretical significance. This discovery shows that some of the brain's earliest responses to an individual visual object are modulated by the relation between the action associated with the object and the action intentions of the observer. We suggest that these action effects on early visual responses may be a neural signature for object-based visual attention (Egly, Driver, & Rafal, 1994). Elsewhere (Ellis, 2009), we have argued that affordance is the outcome of object-based attention and that visual-object representation in the brain is achieved by the binding of visual and action-related responses. We believe that findings showing both the rapid onset of object-based affordances seen in LRPs and the modulation of early visual ERP components due to intended actions are entirely consistent with this view. Moreover, these findings suggest that vision and action binding occurs very early in the sensory pathways, which supports the concept of deep embodiment.

## Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

## Funding

This research was supported by the Engineering and Physical Sciences Research Council under the Cognitive Systems Foresight program (EP/F028598/1).

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*9.2 Abstract in conference proceedings:*

*Dixon, T., Goslin, J., & Ellis, R. (2012). Affordance in the absence of the intention to act on seen objects. Cognitive processing, 13, S39-40.*

Cogn Process (2012) 13 (Suppl 1):S37–S54

**Affordance effects in the absence of the intention to act on seen objects**

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There now exists an impressive experimental literature that suggests that when viewing objects, the actions that may be performed with them are potentiated in the observer. More recent work has used Event Related Potentials (ERPs) to study the timing of the neural events underpinning these effects and variously found action effects from 75-250 ms after stimulus onset. However, the overwhelming majority of these data have been collected from tasks in which the participant is preparing a response to every stimulus. The present research takes a novel approach to the question of object affordances by asking whether this preparation of a response is a necessary prerequisite to the generation of an affordance effect. ERPs were recorded during a go, no-go task using stimuli with left and right facing handles that are known to elicit lateralised affordance responses. Instead of a lateralised manual response, participants made a vocal (i.e. non-lateralised) response when they saw a kitchen utensil (50 % of trials) and made no response to tool items (50 % of trials). Equivalent responses were observed for go and no-go trials, with early significant effects of object affordance from 125-175 ms ($F(1,33) = 4.130$, $p = 0.05$) and150-200 ms ($F(1,33) = 7.600$, $p = 0.009$). These results are analogous with those from previous research that involved response preparation to every stimulus, refuting the idea that the preparation of a motor response is necessary to elicit a motor affordance effect, suggesting that affordance processes represent an automatic link between processing in visual and motor areas.

*10. Chapter ten*

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