

2021

# THE EVALUATIVE CHAMELEON: THE VALANCE OF OBSERVED ACTION OUTCOMES DETERMINES AUTOMATIC IMITATION

Sharps, Helen

<http://hdl.handle.net/10026.1/17087>

---

<http://dx.doi.org/10.24382/615>

University of Plymouth

---

*All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.*

**This copy of the thesis has been supplied on condition that anyone who consults it is understood to recognise that its copyright rests with its author and that no quotation from the thesis and no information derived from it may be published without the author's prior consent.**



# UNIVERSITY OF PLYMOUTH

## **THE EVALUATIVE CHAMELEON: THE VALANCE OF OBSERVED ACTION OUTCOMES DETERMINES AUTOMATIC IMITATION**

By

Helen Sharps

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

**DOCTOR OF PHILOSOPHY**

School of Psychology

**April 2021**

## **Acknowledgements**

I would like to thank my supervisor, Patric Bach, who has been a constant source of knowledge, enthusiasm, motivation and friendship. Despite many setbacks Patric has remained positive, compassionate, supportive and encouraging. It has been an utter privilege to have known such an incredible person, let alone have worked with him.

I would like to thank the technical staff at Plymouth University who have attempted to meet all of my requests over the years as well as Plymouth University Access to Learning Fund, without whom this thesis would never have been completed.

I would like to thank the members of Patric's 'Action Lab,' who have brought some light-heartedness to the process of completing the thesis. I have appreciated your friendship more than you know.

I would also like to thank my children who have allowed me to study late into the evenings, put up with me when I have been stressed and never complained about or questioned my motives – you have been amazing. As well as this, I would like to thank my astoundingly supportive partner and my wonderful family.

## **Authors 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 Doctoral College Quality Sub-Committee.

This thesis has been proofread by a third party; no factual changes or additions or amendments to the argument were made as a result of this process. A copy of the thesis prior to proofreading will be made available to the examiners upon request.

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

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

**Training:**

In addition to the program of advanced study which was undertaken, I also completed a course which included taught modules taken for the 7th Annual Visceral Mind Workshop (2015). A hand-on course in the Neuroanatomy of Cognition.

**Presentations at conferences:**

Sharps, H & Bach, P. (2017). Adults automatic imitation is mediated by action outcomes and requires identification with the observed actor- Poster presentation at the British Association for Cognitive Neuroscience Annual Meeting. Plymouth University, UK.

Sharps, H & Bach, P. (2017). Adults automatic imitation is mediated by action outcomes and requires identification with the observed actor- Poster presentation at the 9th Annual School of Psychology Conference. Plymouth University, UK.

Sharps, H. (2017). Win or lose? Outcome predictions modulate automatic imitation- Poster presentation at the 9th Annual School of Psychology Conference. Plymouth University, UK.

Sharps, H & Bach, P. (2017). Adults automatic imitation is mediated by action outcomes and requires identification with the observed actor- Poster presentation at the Concepts, Actions and Objects: Functional and Neural Perspectives Workshop. University of Trento, Italy.

Sharps, H & Bach, P. (2016). Adults automatic imitation is mediated by action outcomes and requires identification with the observed actor- Poster presentation at the Cognitive Institute Conference. Plymouth University, UK.

Sharps, H & Bach, P. (2016). Win or lose? Can automatic imitation really be affected by top-down processes- Poster Presentation at the Cognitive Institute Conference. Plymouth University, UK.

Sharps, H. (2015). Mediating automatic imitation. Talk at the Annual School of Psychology Conference. Plymouth University, UK.

Word count of main body of thesis: 37227



Signed.....

Date.....24/04/2021.....

**Helen Sharps**  
**THE EVALUATIVE CHAMELEON: THE VALANCE OF OBSERVED  
ACTION OUTCOMES DETERMINES AUTOMATIC IMITATION**

**Abstract**

Humans have a tendency to imitate the actions they observe in others, a process assumed to rely on an automatic bottom-up mapping of observed action features to one's own motor system. In contrast, imitation in children is goal-directed, aimed at achieving the same outcome as the model. This thesis examines whether such an outcome-dependence can also be observed in automatic imitation.

In six experiments, participants watched an actor make movements after observing the same movements and evaluated the valence of these outcomes with either compatible or incompatible responses. Chapter 2 showed that automatic imitation depends on action outcomes and showed that it is (1) independent from the visual perspective from which the action was observed, but (2) does require identification with the model. Chapter 3 showed that this outcome-dependency is observed in observations of human interactions but not when this element is replaced with non-human stimuli.

In chapter 4, 2 experiments in which, the participants' own action kinematics were measured in an alternating reaching task firstly replicated the well-known sIOR effect such that participants were slower to reach to the same target as the previous player. In contrast to other studies on this effect these experiments revealed tentative evidence that the effect depended upon whether the kinematics required to produce the response bore a similarity to the kinematics of the action one has just observed.

Together, the findings in this thesis reveal that imitation cannot simply be attributed to a simple bottom-up matching of observed actions to one's own action repertoires. Instead, similar to goal directed imitation in children, automatic imitation may be guided by hierarchical action-outcome representations that are dynamically established when watching others act.

# Contents

Title Page (I)	
Title page (II)	
Acknowledgements (III)	
Declarations and Consent (IV)	
Training and Presentations (V)	
Abstract (VI)	
Contents (VII)	

<b>Chapter 1: Introduction</b>	<b>page 1</b>
1. Two types of imitation	page 1
1.1. Automatic imitation	page 2
1.2. Goal-directed Imitation	page 8
2. Theoretical Approaches	page 13
2.1. Nativist Accounts	page 13
2.2. From action simulation to action prediction and ideomotor accounts	page 18
3. Thesis overview	page 24
<b>Chapter 2</b>	<b>page 28</b>
Experiment 1a	page 32
Method	page 37
Results	page 35
Discussion	page 39
Experiment 2a	page 40
Method	page 41
Results	page 42
Discussion	page 44
Experiment 3a	page 44
Method	page 47
Results	page 49
Discussion	page 52
Experiment 4a	page 53
Method	page 55
Results	page 57
Discussion	page 60
General Discussion	page 61
<b>Chapter 3</b>	<b>page 65</b>
Experiment 1b	page 68
Method	page 69
Results	page 74
Discussion	page 79

Experiment 2b	page 80
Method	page 81
Results	page 83
Discussion	page 89
General discussion	page 90
<b>Chapter 4</b>	<b>page 95</b>
Experiment 1c	page 101
Method	page 102
Results	page 105
Discussion	page 111
Experiment 2c	page 113
Method	page 114
Results	page 115
Discussion	page 119
General discussion	page 121
<b>Chapter 5: Discussion</b>	<b>page 124</b>
4. Summary of results	page 124
4.1 Summary of results: Chapter 2	page 124
4.2 Summary of results: Chapter 3	page 127
4.3 Summary of results: Chapter 4	page 129
4.4 Main findings	page 130
5.1. Relation to prior studies captured by a recent meta-analysis	page 133
5.2. Relation to studies in children's goal directed imitation	page 135
5.3. Theoretical implications	page 138
5.4. Future directions	page 142
6. Conclusions	page 145
References (248)	page 146
Appendix A	page 160

**Tables:**

1a - Chapter 2 – Page: 35

2a – Chapter 2 – Page: 48

3a – Chapter 2 – Page: 57

**Figures:**

1a - Chapter 2 – Page: 35

2a - Chapter 2 – Page: 38

3a - Chapter 2 – Page: 44

4a - Chapter 2 – Page: 48

5a - Chapter 2 – Page: 51

6a - Chapter 2 – Page: 56

7a - Chapter 2 – Page: 59

1b - Chapter 3 – Page: 71

2b - Chapter 3 – Page: 73

3b - Chapter 3 – Page: 76

4b- Chapter 3 – Page: 78

5b - Chapter 3 – Page: 83

6b - Chapter 3 – Page: 85

7b - Chapter 3 – Page: 87

1c - Chapter 4 – Page: 103

2c - Chapter 4 – Page: 106

3c - Chapter 4 – Page: 109

4c - Chapter 4 – Page: 117

5c - Chapter 4 – Page: 118



## Chapter 1: Introduction

### 1. Two Types of Imitation

Imitation is a behaviour in which an individual observes and replicates another's behaviour. It is observed in human adults and children, in non-human primates and several other species (see Flanders, 1968, for a review; Horner, Whiten, Flynn, & de Waal, 2006). Already in the 19<sup>th</sup> century, theorists have argued about how this phenomenon should be understood and characterized. Darwin (1871, p. 47), for example, described imitation as a brutish, blind and irrational force in human affairs, driven by a complex instinct separate from human reasoning abilities.

“...much of the intelligent work done by man is due to imitation and not to reason; but there is this great difference between his actions and many of those performed by the lower animals, namely, that man cannot, on his first trial, make, for instance, a stone hatchet or a canoe, through his power of imitation. [...] The principle of *Imitation* is strong in man, and especially in man in a barbarous state”.

Others however, considered imitation to be a sophisticated cognitive process, crucial for enculturation and development (Washburn, 1908). Washburn (1917, p. 12) believed imitation to be driven by our self-consciousness and our conception of others' beliefs and desires and the key to understanding their experiences.

“First, since it is only on the basis of our own inner experience that we can interpret the inner experience of others, it becomes clear that the greatest contribution to the development of ejective consciousness will come from those forms of social behaviour where individuals perform like functions”.

Investigations into the current literature on imitation reveal that both these interpretations could be valid, as they match onto two distinct types of imitation that are

typically observed and tested in psychological experiments. The first type – termed automatic imitation – describes simple involuntary replication of observed behaviours, seen in the human tendency to mimic other people’s gestures, body language, accent, posture and other behaviours with no awareness or strategic intent (Van Baaren, Maddux, Chartrand, de Bouter, & van Knippenberg, 2003; Chartrand & Bargh, 1999). The second type – often termed goal-directed imitation or imitation proper – is more complex (Heyes, 2003), describing an intentional act to achieve the same (rewarding) outcomes as the model, for example for purpose of acquiring novel behaviours (Tomasello, 1996).

### **1.1 Automatic imitation**

The unintentional type of imitation is easily demonstrated using the simple child’s game of ‘Simon Says’. In this game, young children stand in a line facing the leader (‘Simon’) who gives them verbal action instructions which Simon also models. These actions are varied but simple, such as to hop on one leg or touch one’s nose. Importantly, these actions must be imitated by the other children only when the order begins with the phrase “Simon says”. Any child, who imitates the action without the prefix “Simon Says”, is out of the game. All players are aware that the goal of the game is only to imitate after the correct instruction is given. Despite this, the incorrect imitation of Simon persists throughout the game.

In the lab, automatic imitation began to be studied in the 1990’s (e.g., Craighero, Fadiga, Rizzolatti & Umiltà 1998; Byrne & Russon, 1998). It led to the development of a specific version of the stimulus-response compatibility (SRC) paradigm, in which the same body movements are used for both stimuli and responses (e.g., Brass, Bekkering

and Prinz, 2001; Stürmer, Aschersleben, & Prinz, 2000). In this paradigm, participants have to execute different responses as quickly as possible in response to task-relevant, imperative cues. These cues are presented in synchrony with task-irrelevant cues, which either match the movement required for a correct response (imitative), or do not match this movement (non-imitative). Responses elicited by matching trials are faster and more accurate than trials that are non-matching, revealing an imitation-based compatibility effect based on constituent bodily movements.

In a seminal study, for example, Brass, Bekkering and Prinz (2000) compared participants' ability to produce finger-lifts when seeing matching versus mismatching finger-lifts on the screen. They found that matching (imitative) responses were performed faster than non-matching (non-imitative) responses. These findings were replicated by a large range of other investigations that revealed similar effects for other action types, such as finger movements (Bertenthal, Longo & Kosobud, 2006), hand grasps (Heyes, Bird, Johnson & Haggard, 2005), arm, leg, and head movements (e.g., Bach & Tipper, 2007; Bach, Peatfield & Tipper, 2007; Gillmeister, Catmur, Liepelt, Brass & Heyes., 2008; Heyes & Ray, 2004), as well as kinematic features of movement trajectories (e.g., Kilner, Hamilton, & Blakemore, 2007; Bach, Bayliss & Tipper, 2010). The effects have been described with many labels, from "visuomotor priming" (Craighero, Fadiga, Umiltà & Rizzolatti, 1996), "movement compatibility" (Brass et al, 2000), "motor facilitation by action observation" (Edwards, Humphreys & Castiello, 2003), "body part priming" (Bach & Tipper, 2007), "effector priming" (Gillmeister et al., 2008), "movement interference" (Gowen, Stanley & Miall, 2008) and "motor mimicry" (Spengler, Brass, Kuhn & Schütz-Bosbach, 2010). It is now commonly referred to as Automatic imitation (Liepelt, von Cramon & Brass, 2008; Heyes, 2010).

Since then, research has started to investigate the characteristics of these effects. For example, several studies have shown that imitative compatibility is, at least to some extent, independent from spatial compatibility, persisting when controls for other compatibility relationships are in place (e.g., Catmur & Heyes, 2011; Bertenthal, Longo & Kosobud, 2006). For example, when the above finger tapping experiment by Brass and colleagues (2000) was replicated and included a condition where the hand stimuli were static, and responses were cued by an 'x' appearing on the finger nail of the hand, responses times were markedly reduced and followed not imitative compatibility, but a pattern of spatial compatibility (Brass, Derrfuss & von Cramon., 2005).

Others have tested if the facilitation of imitative responses is truly automatic. Catmur (2015), for example, found that imitative compatibility effects were present under both low and high perceptual load. Others have shown that they persist even when attention is directed away from the observed action (Brass et al., 2000; but see Bach, Peatfield & Tipper, 2007) although these effects may be reduced. Due to findings like these, it is now a widely held assumption that imitation is indeed automatic and occurs in the face of conflicting goals and intentions (Stürmer, Aschersleben & Prinz, 2000). Theorists therefore describe it as “unintentional” (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007), “unconscious”, “non-conscious” (Belot, Crawford, & Heyes, 2013; van Baaren et al., 2003), or, indeed, “automatic” (Obhi & Hogeveen, 2013; Heyes, 2011).

A related phenomenon might be people's tendency to copy their interaction partner's behaviours and body posture (Stel, & Vonk, 2010) in everyday social interactions, first measured by Chartrand and Bargh (1999). As in automatic imitation, people are typically not aware of its occurrence, and they use it non-strategically and non-intentionally. However, while this behaviour seems to be similar on the surface, there is

evidence that it might reflect an independent process, being not correlated with automatic imitation as measured in the lab (Genschow, van Den Bossche, Cracco, Bardi, Rigoni, & Brass, 2017).

The discovery of mirror neurons provided the first evidence of a physiological perception-action link that may underlie automatic imitation. Mirror neurons are neurons in the monkey premotor F5 region, recorded at a single cell level using microelectrodes, known to be involved in the control of the monkey's own simple actions, such as reaching and grasping, or opening a peanut. The surprising finding was that some of these neurons would also fire if the monkey was completely passive but saw the same (or a similar) action being executed by someone else (di Pellegrino et al., 1992; Rizzolatti & Craighero, 2004; for a recent review, see Hamilton, 2015). For example, a neuron that fires during the monkey's own reach towards a small (but not large) object would also fire if the monkey was completely passive but observed somebody reach for a small object. While these neurons were first recorded in area F5 of the premotor cortex of monkeys (Di Pellegrino et al., 1992; Gallese Fadiga, Fogassi & Rizzolatti, 1996) they were later also found to be present in the inferior parietal cortex (Fogassi et al., 1998; Gallese et al., 2001) and to capture not only the action's visual but also their auditory properties. As an example, a mirror neuron that fires when a monkey tears a piece of paper also responds when the monkey observes another tearing a piece of paper and to the sound of paper tearing without visual input (Keysers, Kohler, Umiltà, Fogassi & Gallese, 2003).

Recording single neurons is less practical for the study of human brains. Therefore, most of the evidence for mirror neurons in humans comes about indirectly (although see Mukamel, Ekstrom, Kaplan, Iacoboni, & Fried, 2010), using measures such functional

magnetic resonance imaging (fMRI). Despite the difficulties, these studies have revealed homologous regions in human brains in the inferior frontal gyrus (IFG) and areas of the inferior parietal lobe, which together are referred to as the Mirror Neuron System (Binder, Dovern, Hesse, Ebke, & Karbe, 2017; Rizzolatti et al., 2004). Since then, mirror properties have been discovered in other areas of the brain including the Supplementary Motor Area (but not pre supplementary motor area) (Zentgraf & Munzert, 2005), Insula (Acharya & Shukla, 2012), Primary Somatosensory Cortex (Keysers & Gazzola, 2010) and anterior cingulate cortex (Rizzolatti & Fabbri-Destro, 2008; for a review see Rizzolatti, & Luppino, 2001). Together, these regions may form a “mirror system” that maps observed behaviours onto behaviours the observer can execute themselves. This matching is assumed to provide the observer with an internal motor model of the actions they are observing, which can drive imitation (e.g., Iacoboni, 2005; Rizzolatti, 2005).

While the above studies typically measure the automatic copying – or at least faster execution – of the observed body movements, automatic imitation does not always need to happen on the level of the body movements or action kinematics. Instead, several studies suggest that observers can also automatically copy actions on a higher level, capturing their goals or intended outcomes. For example, Liepelt and colleagues (2008) have shown that people imitate the inferred goal of an action (intending to lift a finger) rather than what is actually observed (finger held in place by a clamp). Similarly, Bach, Bayliss and Tipper (2011) have observed that observed reach directions are only mirrored if the reach seemed to be directed to an available goal object, and actions have been found to be imitated particularly if they are assumed to reflect the behaviour of an intentional agent (Bertenthal, Longo, & Kosobud, 2006) rather than an inanimate virtual computer hand.

Other studies have investigated the role of biological and non-biological stimuli in driving automatic imitation. Human movements were compared to ball movements in a study by Kilner, Hamilton & Blakemore (2007). These movements either followed a biological bell-shaped curve, or a non-biological constant directional movement profile. They found that the shape of the moving agent (human/ball) did not matter, as both human and ball movements interfered with own action kinematics equally. The movement profile, however, proved important: interference was observed in the human-biological movement condition but not in the non-biological movement condition. A study by Stanley and colleagues (2007) provided similar results. Moving dot stimuli were presented with either a biological or non-biological velocity profile, but it was manipulated whether participants believed the observed movements to be computer-generated or produced by a human actor. Automatic imitation effects were only found when participants attributed the movements to a human agent (for similar results, see Longo, et al., 2009).

These results confirm that automatic imitation occurs for a broad range of stimuli but may be tied to the observation of intentional agents, with biological motion trajectories. They have prompted the argument that automatic imitation arises from interplay of both the observed action and the actor's current goals (Wohlschläger, Gattis, & Bekkering, 2003), potentially linking it to the other, goal-directed form of imitation.

## 1.2 Goal directed imitation

Goal-directed imitation involves a person observing another performing a goal-directed action and then replicating that action themselves, with the goal of achieving the same outcome as the model. This form of goal-directed imitation, or “imitation proper”, has been argued to guide behaviour at all ages but is mostly studied in human children and primates (e.g., Call & Carpenter, 2002; Gattis, Bekkering & Wohlschläger, 2002; Tomasello, Kruger & Ratner, 1993; Bach, Allami Khalaf, Tucker & Ellis, 2014). It has been argued to provide a foundation for skill acquisition, avoiding time-consuming trial and error learning (Bekkering, Wohlschläger & Gattis., 2000). It is viewed as a top-down guided, “rational” process, in which the imitator links seen body movements (the “means”) to the changes they produce in the environment (the “ends”), and then uses these means-ends-relationships to achieve the same outcomes (for a review, see Elsner, 2007).

Goal-directed imitation is often investigated using errors of reproduction. In a classic study, Bekkering and colleagues (2000) sat children at a table opposite an experimenter who instructed them to ‘do what I do’. The experimenter then placed either their left or right hand onto the table ipsilaterally (right hand placed onto the right side of the table) or contralaterally (right hand placed onto the left side of the table) to their seated position. In all cases children imitated both components, using the correct hand and the correct placement (left or right) on the table. However, in a further experimental session, the experiment was modified to include a target for the movements: a large red dot or target placed on the table. The experimenter then placed their left or right hand onto the target which again would produce an ipsilateral or contralateral movement, identical to that of the other session. Children imitated ipsilateral movements with great

accuracy but made many imitation errors in the contralateral condition, often using the arm closest to the target rather than the arm used by the experimenter. This suggests that the presence of the target had altered how children conceptualized the goal of the interaction. The goal had been converted from imitating the kinematics of a movement to imitating the reach towards a particular target, with less weight given to how it was achieved. This type of imitation is now referred to as goal-directed imitation because observers do not focus on the imitation of isolated bodily movements. Instead, they imitate the goal of the observed act (Bekkering, Wohlschläger, & Gattis, 2000; Gattis, Bekkering, & Wohlschläger, 2002).

In a similar study (Gattis, Bekkering, & Wohlschläger, 2002), 12 and 18-month-olds took part in an imitation experiment where the experimenter moved a toy mouse across the table. In one condition the experimenter moved the mouse to one of two houses using a hopping motion. In another condition, there were no houses present, but the experimenter made the same hopping action with the mouse and placed it in one of the two locations. As in the study of Bekkering and colleagues (2000), the presence of the houses as potential action goals determined how the action was imitated. When the house was present both age groups were more likely to simply move the mouse to the correct location and ignored the manner of movement. In contrast, when the houses were not present, children were more likely to move the mouse in a similar way to the experimenter, recreating the hopping action. Thus, even though children in both conditions were shown identical actions, they selectively imitated differing aspects dependent on whether the action seemed to have a goal (houses present) or not (houses absent). This suggests that even children of a young age interpret the actions of others in relation to a means-end relationship or goal hierarchy and select the most important goals to imitate, while ignoring others (Bekkering et al., 2000; Gattis et al., 2002).

Several other findings have revealed such goal-directed modes of imitation in children. From 12 months of age onwards, children particularly imitate actions that produce salient outcomes (Hauf, Elsner, and Aschersleben, 2004; Corriveau, Min, Chin & Doan, 2016; Huang, Heyes & Charman, 2002), learn new action-outcome relations from observation (Gergely, Bekkering, & Király, 2002; Meltzoff, 1988a), and during imitation, they focus on reproducing these outcomes and check whether they were indeed achieved (Carpenter, Call, and Tomasello, 2005; Carpenter, Nagell & Tomasello, 1998b; Elsner & Aschersleben, 2003). As they become older, imitation becomes more flexible, but the fundamental outcome-guidedness remains. For example, they distinguish between a model's intended and incidental outcomes and primarily imitate the former (Carpenter, Akhtar, & Tomasello, 1998; Bellagamba & Tomasello, 1999), they correct observed unsuccessful actions during imitation (Meltzoff, 1995; Over & Gattis, 2010), and they readily use different body movements, should they allow them to achieve the outcome more effectively (i.e. "emulation", Tomasello, 1996; Gergely, et al., 2002; Buttelmann, Carpenter, Call, & Tomasello, 2007).

Despite the above review, children's imitation does not always focus on an action's higher-level aspects, such as goals and outcomes. Studies have revealed that infants under school age sometimes imitate an action's form with great fidelity, even if not required to achieve the action's goal, to the extent that a cost is incurred to the efficiency of such actions (Lyons, Damrosch, Lin, Macris, & Keil, 2011; Whitten, McGuigan, 2009). This phenomenon of "over-imitation" has motivated different explanations, each of which however still sees it as a further instance of goal-directed imitation, or whether it may be more closely linked to forms of automatic imitation in adults.

The “automatic coding hypothesis” and the associated “copy-all-refine-later hypothesis” propose that over-imitation happens as a consequence of infants encoding all of the intentional actions performed by an adult as causally meaningful (Lyons et al., 2011). In this view, the infant still imitates in a goal directed manner. However, they experience causal confusion, erroneously believing that the additional irrelevant actions are necessary for successful task performance. The pervasiveness of over-imitation in so many studies is often taken to support this hypothesis, despite conditions which attempt to minimise its occurrence by teaching children in advance the manner required to identify ‘silly’ actions (Lyons, Young & Keil, 2007), or giving children the opportunity to attempt tasks in advance of an inefficient demonstration (Nielsen & Tomasello, 2010).

On the other side of the coin is the “social affiliation hypothesis”. It interprets over-imitation as an active attempt to create affiliation with others (Nielsen, 2006).

Accordingly, children imitate irrelevant action parts not because they want to achieve the action’s outcome, but because they want to signal similarity with the model. This account is supported by evidence that children selectively imitate irrelevant actions which they include in the presence of an inefficient demonstrator but omit in the presence of an efficient demonstrator (Nielsen & Blank, 2011). Again, however, it suggests that over-imitation is goal-directed, where the child flexibly decides what aspects of the action is the most important aspect for its own goals (signalling similarity), and then imitates this aspect in particular.

Finally, it has been argued that “over-imitation” may reflect a different mode of goal directed learning, which focusses on copying an action’s conventional forms, rather than those required for achieving a particular outcome (Watson-Jones, Legare,

Whitehouse, & Clegg, 2014). In other words, for conventionally defined actions (e.g. how to greet someone), the particular form *is* the outcome that needs to be achieved. This form of imitation is therefore believed to underpin affiliation with others and facilitate cooperation, whilst avoiding ostracism (Over & Carpenter, 2012). Consistent with such conventional learning accounts, children have a greater tendency to over-imitate when conventional verbal cues are used to frame the task. For example, 3 to 6-year-olds were presented with a video clip in which actors used a specific order of actions to take pegs from a board. The framing of the task demonstration was either conventional – the model “always” does it this way – or oriented towards the potential outcome: the given actions gets the pegs “up”. Children imitated the model’s lower level body movements in the conventional condition with great accuracy and justified their actions afterwards (“I had to do it the way they did it”). In contrast, children focussed on achievement of the outcome, when the task instructions were presented as outcome related. These children justified their behaviour instrumentally as independent agents (“I can do what I want”) (Festinger & Carlsmith, 1959).

Together, therefore, goal-directed imitation in children is a sophisticated process. Different action components (causal nature, action goal or effector used) may become salient during the observation of actions, and cause imitation to be focussed on them, depending on the context of the action and the child’s own goals. Goal-directed imitation may therefore closely map onto automatic behaviour in adults, which similarly can show a focus on the actions’ form, or the outcomes it produces, suggesting that the mechanisms involved in both may similarly overlap.

## **2. Theoretical approaches**

Different theories have been proposed to account for imitation. They differ on which form of imitation they address – goal directed or automatic imitation – and whether they can account for the copying of the action’s forms (the observed body movements; e.g. Meltzoff & Moore, 1979; Meltzoff, 2002) or their higher-level goals (the outcomes to be achieved; e.g. Dindo, & Schillaci, 2010). They also differ in whether they take a generalist view, assuming imitation to be based on domain-general learning mechanisms (Greenwald, 1970; Heyes, 2001), or a specialist view that presupposes a specifically evolved mechanism (e.g., Gallese & Goldman., 1998). The following section reviews the most important approaches.

### **2.1 Nativist vs. Learning Accounts**

Nativist accounts of imitation (e.g., Meltzoff, 1993; Chartrand & van Baaren, 2009) propose a direct link between perception of others and one’s own behaviour that has arisen through evolutionary history, giving rise to a specific cognitive “module” for imitation. In particular, they argue that the reproductive advantages engendered by imitation – learning of instrumental and conventional behaviours – makes it likely that it falls into the “adaptation” category for behaviour, for which specific brain mechanisms have evolved through natural selection and which are now stored in the genome. For example, Meltzoff and Moore (1997) argued that infants are born with innate imitative abilities specialised for imitation of specific stimuli (such as facial movements), which require little environmental input in order to develop. They called this innate module a specialised super-intermodal mechanism that matches observed actions to self-produced actions, potentially helping to understand each other’s behaviour. Others (e.g., Lakin et

al., 2003) suggest that imitation was selected for because it can take the form of ‘social glue’ that helps create affiliations and to aid communication between members of a group (see the discussion on over-imitation above).

Evidence for nativist accounts is derived from monkey/human neonate studies. In an early study, very young infants were shown to have imitated tongue protrusion, pouting, mouth opening movements and even sequential finger movements (Meltzoff & Moore, 1977). One of their participants was under 45 minutes old. The authors argued that if infants are able to imitate within hours or days of first human contact, then this ability could not be based on learning, but must have arisen over our evolutionary history.

Similar findings come from monkey neonate studies (Ferrari, Bonini & Fogassi., 2009). Using macaque monkeys at days one, three, seven and 14 days postpartum, Ferrari and colleagues compared the neonate tendency to imitate lip-smacking, tongue protrusion, hand opening and mouth opening. They found that three-day-old macaques imitated tongue protrusion and lip-smacking behaviours, clearly linking imitation to our evolutionary relatives.

More recently, such nativist accounts have been challenged. For example, a meta-analysis revisited the data on neonate imitation and found that the only imitation effect that was reliable was tongue protrusion (Ansfield, 1996). Other recent replication attempts also failed to find any evidence of infant’s ability to imitate other than tongue protrusion (Jones, 2006), and showed that other arousal stimuli were able to induce the tongue protrusion as well (e.g., mouth opening or gaze direction). Tongue protrusion by itself can therefore no longer be deemed as evidence for an imitative effect, and nativist accounts have fallen somewhat out of favour.

The discovery of mirror neurons is also often taken as evidence for such nativist accounts. As described above, mirror neurons are neurons that fire both when executing a particular action and when observing the same action when carried out by another (Rizzolatti, Fogassi, & Gallese., 2001). This apparent linkage of observed actions to own motor performance may therefore provide the neuronal mechanism through which this imitation “module” is realised in the brain (e.g. Iacoboni, 2005; Rizzolatti & Sinigaglia., 2010). More recently, several theorists have pointed out that mirror neurons, and the imitation they may engender, need not be a specific adaptation for social perception, but could be explained in terms of more domain-general learning mechanisms.

Associative sequence learning (ASL) theories of automatic imitation posit that imitation is not innate but based on simple learned associations between motor and perceptual events (Ray & Heyes, 2011; Cook, Press, Dickinson, & Heyes, 2010). Whenever we carry out an action, we can observe its outcomes through our senses (e.g. visual, proprioceptive, auditory). The theory assumes that associations between a motor command and a sensory outcome are created when action events, both performance and observation thereof, consistently occur together such that one event predicts another (Heyes, 2010). For example, a child might notice that certain motor commands that it can send will consistently move its hand in a certain direction, and as consequence both motor command and perceptual consequence become associated. An important factor is that these associations can be made not only whilst performing an action and observing its consequences, but also when others’ actions that are contingent to one’s own. For example, one does not often observe one’s own facial expressions. However, care providers have a tendency to imitate the expressions simultaneously with the person

they are supporting, providing an alternative means of how actions and perceptual consequences can become linked (Ray & Heyes, 2011).

The idea is that this coupling of actions and their perception over the lifespan is what caused the development of mirror neurons and the tendency to imitate others. Whenever we see an action of someone else, the previously established association could pre-activate the same action in ourselves. Such a view makes specific predictions about how such a system could develop and be altered by experience. An associative account of mirror neuron function would predict that crucial to its development would be the synchrony in which actions and their observations occur. If incongruent pairings were to be repeated often enough, alternate vision-action pairings could be learned and achieve “counter mirroring”. As an example; the observation of a hand movement might be able to produce similar cortical activation as one’s own performance of foot actions, after a period in which these incongruent associations are consistently linked (Heyes, 2010).

Exactly this pattern has been observed in multiple studies (e.g., Newman-Norland et al., 2007; Ocampo, Kritikos & Cunnington, 2011). In one example (Bardi, Bundt, Notebaert & Brass, 2015), participants were shown clips of index or middle finger movements. In the congruent condition, participants were asked to make the same action as they observed (e.g. produce an index finger movement to the observation of an index finger movement). Participants in the incongruent condition, however, were asked to make the opposite movement (produce an index finger movement to the observation of a middle finger movement and vice versa). After this training period, motor evoked potentials were measured from the middle and index finger of the participant whilst they observed the same actions that they were exposed to during training. Participants that performed congruent actions during the training phase evoked MEPs from the congruent digit to

that which they observed. In contrast, those trained to make incongruent action responses generated MEPs in the non-imitative digit, in other words, that which they would have moved, not the one they had observed. Nativist accounts, which argue that action-perception links are innate, are unable to explain this counter-mirroring (Catmur, Walsh & Heyes, 2009). Instead, these and other similar studies (Wu, Evans & Adank, 2019 (visual speech); Heyes, 2011; see Cambell & Cunnington, 2017, for a review) give weight to the argument that the perception of action evokes motor responses that have been previously associated rather than a pre-formed innate mapping (Catmur, Walsh & Heyes, 2007).

A problem with both the above nativist and associationist accounts is that they can account very well for the forms of automatic imitation that captures the action's outward forms, such as the seen body movements (e.g. Brass et al., 2000), or the phenomenon of over-imitation in children (e.g., Keupp, Behne & Rakoczy, 2013). However, it is questionable to what extent they can account for the more flexible forms of imitation, in which children appear to select, on the fly, which aspect of an action to imitate, based on their own goals or the salience of the behaviour (e.g., Gergely, Bekkering & Kiraly, 2002), or in which a child selects an action that achieves the same goal as the model, but more effectively. At least in their standard form, both nativist and associate sequence learning accounts appear instead to be restricted for instances in which a close mapping between observed and own behaviour exists on the level of the observable kinematics which are – either innately or through learning – linked to the associated motor commands.

## **2.2 From action simulation to action prediction and ideomotor accounts**

Simulation theories claim that automatic imitation happens as an epiphenomenon. It comes about because observers internally re-create – using their own motor system – observed actions in order to understand the behaviour of the other person (Pickering & Garrod, 2004; Gallese, 2007). Playing through – simulating – an action in this way may allow the observer insight into the feelings and intentions of their interaction partner. According to simulation theories, mirror neurons have evolved to make such simulations possible (Ferrari & Coude, 2018; Gallagher, 2015; Gallese et al., 2004). Accordingly, observation of an actions results in the observer’s motor system ‘resonating’ with the observed action, as if they were currently executing the action as well (Rizzolatti et al, 2001). Once an action is mentally re-created in such a manner, this simulation can be the gateway to deriving all knowledge associated with the action, encompassing, perhaps, not just the outcomes of actions, but also the mental states and goals of the actor. Imitation, in such models therefore, happens not because a specific mechanism for imitation is activated, but as accidental outflow of motor activation that happens because observers attempt to understand (not imitate) the other person.

Evidence for this view comes from the finding that mirror neurons, at least those so far recorded in macaque monkeys, only fire for goal directed actions. Thus, when a monkey performs or observes a goal directed action, such as grasping food, mirror neurons fire (Rizzolatti, 2001). If, however, the monkey observes a pantomimed action, for example the experimenter makes the same grasping action in the absence of food, the activation does not occur. The mirror neuron normally activated for the food grasping action remain silent (Gallese et al., 1996). For simulation theorists, this indicates that the

monkey did not understand the action as an instance of food grasping. Mirror neurons do not become activated because, in this instance, the observed action has no meaning.

One prediction of such theories is that imitation – or activation of mirror neurons – should be closely linked to action understanding in human studies as well. However, studies which provide direct evidence for this prediction are rare. One of the few studies has shown that when automatic imitation of facial expressions is prevented by physical restraint, participants are slower to identify observed facial expressions (Stel & van Knippenberg, 2009). Additionally, using Botox to reduce feedback during imitation of emotional faces was found to attenuate amygdala activation known to be concerned with processing of emotional states (Hennenlotter, Dresel, Castrop, Ceballos-Baumann, Wohlschläger, & Haslinger, 2008). These studies therefore show that preventing imitation directly affects the understanding of the action, in this case of facial expression.

Another prediction is that, if imitation in humans emerges from such a mechanism then it should – like the mirror neuron activation in monkeys – be found specifically for actions with clear goals. However, while some studies initially supported such a proposal (e.g., Longo, 2009; Bach, Bayliss & Tipper, 2011), it was not substantiated in a recent meta-analysis (Cracco et al., 2018). In fact, this study showed that automatic imitation was stronger for actions without goals. Mirror neuron activation as well as automatic imitation are commonly found even for goal-less actions, leading to the argument that the human mirror system is tuned differently than that of monkeys (Hickok, 2009).

An alternative to direct action matching accounts is that of action reconstruction (Csibra, 2008). In this approach, motor activation during action observation follows

from – rather than causes – the understanding of the action, in a hierarchical, top-down process. Once an initial idea – or hypothesis – about an action’s goal is derived, for example through contextual cues such as objects (e.g., Bach, Nicholson & Hudson, 2014) or facial expressions (Roseman, Wiest & Swartz, 1994), the motor system tries to predict an action with which it could achieve this goal. By comparing this prediction to the action that is observed, the observer can therefore work out if the higher-level intention attribution was correct. Action reconstruction in this sense is therefore not an imitation of observable actions, but the reproduction of the observable end-states of predicted actions in a manner achievable by the observer (emulation rather than imitation, Csibra, 2008).

Evidence for this view comes from the observation that imitation of goal directed actions will often bring about the same goal as the observed action but, as Gergely and colleagues (2002) demonstrated, not necessarily the same motor action. When infants observed an actor use their forehead to illuminate a light panel on a table, with the actor’s hands unencumbered and placed on either side of the table, they performed the action with the head as well. However, when the actor performed the same action, but could not use their hand because they were wrapped in a cloth, infants used their hands instead. The reason for this difference is, according to Gergely and colleagues (2002), that the children generally focussed on achieving the goal (turning on the light) but performed the action in a way that was most convenient for them. Only if the use of the head seems necessary for goal success – why else would an actor with their hands free use their head? – they copied this low-level component of the action as well. Similar results have now been reported in replications of this study in encultured chimpanzees (e.g., Buttelman et al., colleagues, 2007) and even dogs (Range, Viranyi, & Huber, 2007). Importantly, such findings are even seen in studies on adult automatic imitation.

For example, as described above, Liepelt and colleagues (2007) reported that people often have a tendency to respond faster with a response that matches the goal of the action (lifting a finger) rather than the action that was indeed observed (finger being held down by a clamp), as well as differentiation of the action goal from the action style (infants imitate action style rather than action outcome when communication renders style more pertinent) (Southgate, Chevallier, & Csibra, 2009) and several other studies provided similar findings (see Thill, Caligiore, Borghi, Ziemke, & Baldassarre, 2013 for a review).

Ideomotor approaches (e.g., Greenwald, 1972; Prinz, 2005; Hommel et al., 2001; for a review see Shin, Proctor & Capaldi, 2010) combine ideas from associative learning (ASL) and action reproduction accounts. This school of thought dates back more than 100 years and is often exemplified with William James who famously argued that merely thinking about an action was sufficient to cause that action to occur (James, 1890). Following this notion, ideomotor models suggest that integrated goal-action representations – the anticipation of an action’s perceivable effects – are fundamental for the control of action. Accordingly, any voluntary action – from complex skills such as performing traditional dances to simple button presses in the lab – is controlled through imagining the action’s perceptual consequences (Lotze, 2006).

According to the ideomotor framework, this co-activation of both goal and motor components is possible because people learn – either from observation or when acting themselves – which body movements bring about which outcomes (in the environment or their own body) and associate both components, like in ASL (Heyes, 2012). In contrast, to ASL however, the assumption is that the resulting action representations are fundamentally hierarchical. They do not only encompass the lower-level (proximal)

consequences of an action, but the higher level (distal) ones as well. For example, one might learn that a certain motor command might cause the perception of one's finger being depressed, but also that this finger key press might help make a room brighter, when it is a light switch that is being depressed. As soon as such hierarchical links between motor programs and low-level and high-level perceptual outcomes are established, it suffices to mentally activate a representation of the outcome – the effects one wants to achieve – and this would trigger the associated bodily movements. As a consequence, merely thinking of an action's intended outcomes, can trigger its execution, like William James famously proposed, irrespective of whether one thinks of higher-level distal goals (the light coming on) or lower-level goals (a finger being depressed).

Evidence for this view comes from the well-known observation that in certain “magical” phenomena the mere thought of an outcome suffices to produce subtle movements. For example, in the Ouija board, the sitters' hands move towards the letters that are expected to be spelled out by a ghostly presence (Hyman, 2007), and in Chevreul's magic pendulum, people involuntarily produce the swings they imagine (Wegner, 1994). It is also reliably demonstrated in the lab, where presentation of an action's previously learned consequences suffices to bias motor output towards this action (e.g., Elsner & Hommel, 2001).

These ideomotor models can account for both the imitation of an action's kinematic features and its higher-level goals, explaining not only findings on automatic imitation (e.g., Wohlschläger, Gattis, & Bekkering, 2003), over-imitation in children (Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009), but also goal-directed imitation (Massen, & Prinz, 2009). Imitation of an action's kinematics comes about because

observation of these lower-level action components (e.g. seeing a finger being lifted) is similar to the observer's lower-level representation of their own actions that would achieve the finger lift (e.g., Brass et al., 2000, 2001, 2004). They can account for goal-directed imitation, and the flexible decision of what will be imitated: the actions higher-level or lower-level outcomes (see Elsner, 2007, for a review). When one observes an action, one can generate a hierarchical action representation, simply by associating the observed lower-level perceptual features (e.g. pressing down with the head, as in Csibra's study above) with its higher-level features (e.g. turning on the light). Depending on what is salient, and what is seen as relevant for one's own goal achievement, the child – or the adult – can then decide what to imitate. If the action's form seems important, the child just needs to re-activate the lower-level perceptual outcomes it has observed, and because they are linked to the motor commands that would achieve it, the action follows, closely matching the kinematics that were observed. However, if the goal is important, it could also think of the higher-level outcomes, leading to either the selection of the action one has just observed (pressing the light switch with one's head), or, an action from one's own repertoire that can achieve the same outcome more effectively (e.g. pressing the light switch with one's hand).

Ideomotor approaches can also account for both goal-directed and automatic imitation. They place the observable outcomes of an action – at both a high distal level and a lower kinematic level – at the centre stage of imitation. They can therefore naturally account for the outcome guidance of goal directed imitation observed in studies in children's goal directed imitation (for a review, see Elsner, 2007). As described above, children particularly imitate actions with salient and rewarding outcomes (Hauf, Elsner, and Aschersleben, 2004; Corriveau, Min, Chin & Doan, 2016; Huang, Heyes &

Charman, 2002), they distinguish between a model's intended and incidental outcomes and primarily imitate the former (Carpenter, Akhtar, & Tomasello, 1998; Bellagamba & Tomasello, 1999), and they correct observed unsuccessful actions during imitation and use an a more successful alternative (Meltzoff, 1995; Over & Gattis, 2010).

A striking prediction of these ideomotor approaches is that the same outcome-guidance should also exist for automatic imitation. When people merely observe an action of another, they could similarly create an integrated action representation that links the proximal body movements observed to the outcomes they generate. To the extent that automatic imitation is guided by hierarchical action representations, it should then also primarily be observed for actions with positive outcomes. However, this proposal has so far not been tested.

### **3. Thesis overview**

As the review above shows, automatic imitation and goal-directed imitation are often conceptualized differently and investigated on different populations (e.g. adults vs. children; humans vs. primates). Yet, at the same time, they share many similarities, such as a flexible focus on either the action's kinematic features or the higher-level goals that can be achieved with these actions. This thesis is an attempt to test whether automatic imitation can be described in the same framework as goal-directed imitation and whether it shows the same signature characteristics, specifically its outcome-dependence.

A core idea of ideomotor accounts of imitation is that, when observing another's action, people can establish a hierarchical action representation that links the observed body movements to the ultimate outcomes they produce in the environment. While it is clear that such representations are established during goal-directed imitation (see Elsner, 2007, for a review), it is not clear whether this also happens when people merely observe an action, without prior intention to imitate, so that it also determines automatic imitation. If this were the case, it would provide further evidence against bottom-up accounts that primarily link automatic imitation the observation of an action's proximal (kinematic, body related) characteristics (e.g. nativist accounts, ASL), and support accounts arguing for a higher-level, hierarchical control of automatic imitation (ideomotor and action reproduction accounts).

No prior studies have tested this proposal. Prior studies have only tested whether imitation is generally governed by top-down information, without addressing outcomes, and even these studies are not fully conclusive. For example, while several studies have manipulated the implied goals of observed action, and sometimes found that goal-directed actions are imitated more (Liepelt, 2010; Bach et al., 2011), others have challenged this proposal, finding stronger effects of actions without goals (e.g. a recent meta-analysis, Cracco et al. 2018). Moreover, goals, per definition, are not directly observable. Designs therefore need to make sure that enough contextual cues are provided *before* the action so that participants attribute such goals to others, making control of stimuli and the attentional focus of participants difficult. Whether automatic imitation is controlled through a top-down process generally, and through hierarchical action-outcome representations in particular, is therefore still debated.

This thesis is an attempt to answer this question and to demonstrate that automatic imitation is strongly outcome-dependent, in a similar way as is observed for goal-directed imitation. To do so, it will present a series of experiments on adult participants.

The experiments in Chapter 2 provide a first test of whether automatic imitation is outcome dependent. It involves a series of experiments in which participants observe a simple card-game scenario whilst evaluating the outcomes of the observed actions.

Participants were instructed to imagine that the observed hands represented their own hands and that they were actively taking part in the observed card-game. Responses required the same or different action as was observed in order to measure automatic imitation, as in prior studies described above. As predicted, facilitation of similar responses was only found for actions with positive (winning) outcomes, irrespective of whether participants evaluated the outcomes in terms of numerical magnitude or their value relative to another card, and irrespective of whether the actions were seen from a 1<sup>st</sup> person or 3<sup>rd</sup> person perspective. It was only required that the participant evaluated the outcome of the acting player (not of the passive opponent).

An open question is whether the effects in Chapter 2 indeed reflect imitation of the action's kinematic or spatial properties (i.e. that they reflect more general response compatibility effect). Chapter 3 therefore resolved whether the outcome-dependency affects specifically the imitation of the action's kinematic components, separating it from spatial compatibility. The experiments show actions with positive and negative outcomes – reaches towards and withdrawals from safe and unsafe objects – from the side. By varying the participants' response assignments on a joystick, it was possible to counterbalance for spatial and movement compatibility. This experiment demonstrated that facilitation of imitative responses reflected the actions' kinematics, not its spatial

properties, and that this facilitation was again determined by action outcomes. However, in a further iteration of the experiment the potential to imitate was removed by presenting non-biological stimuli: bubbles moving across the screen towards object that would let it safely pass or that would make it pop. This stimulus retained all the movement and directional information of the previous experiment but, in this case, this information was attributed to a simple bubble. Although this reduced the effect of automatic imitation overall, it also revealed that simply evaluating the action's appropriateness may be enough to induce its modulation through action outcomes.

Chapter 4 attempts to resolve the issue whether viewing actions with positive (relative to negative) outcomes is enough to modulate automatic imitation, even if these outcomes do not need to be actively evaluated. A simple interactive game was designed in which participants took turns to act on a touch screen making movements towards a target. Random variation of the outcome of this action (positive or negative) made it possible to test whether any differences in automatic imitation were directly linked to the outcome of the previously seen movement made by the interaction partner.

Together, therefore, this thesis provides considerable evidence that automatic imitation is, similar to goal-directed imitation. It is guided by the outcomes of the observed actions, with stronger automatic imitation effects found when observing actions with positive outcomes. This modulation happens both when participants view actions from the 1<sup>st</sup> or 3<sup>rd</sup> person perspective, but it is tied to some extent, to the active evaluation of the observed action outcomes, and partially observed if the valence of the outcomes is not explicitly evaluated by participants.

## Chapter 2

The experiments in Chapter 2 provide a first test of whether automatic imitation can be described in the same framework as goal-directed imitation, and specifically whether it shares the dependence on the observed action outcomes. Goal-directed imitation, or “imitation proper”, is mostly studied in human children and primates (e.g., Call., et al 2002; Gattis et al., 2002; Tomasello et al.,1993). As described in Chapter 1, it is typically seen as a top-down guided, “rational” process, in which the imitator links the seen body movements (the “means”) to the changes in the environment they produce (the “ends”) and uses this knowledge to achieve the same outcome (for a review, see Elsner, 2007).

From 12 months onwards, children learn actions in such a manner. They particularly imitate actions that produce salient outcomes (Hauf et al., 2004; Corriveau et al., 2016; Huang, Heyes & Charman, 2002), they learn new action-outcome relations from observation (Gergely et al., 2002; Meltzoff, 1988), and during imitation, they focus particularly on reproducing these outcomes and check whether they are indeed achieved (Carpenter et al., 2005; Carpenter et al., 1998; Elsner et al., 2003). Later on, they learn to distinguish between a model’s intended and incidental outcomes and primarily imitate the former (Carpenter et al., 1998; Bellagamba et al., 1999), they correct observed unsuccessful actions during imitation (Meltzoff, 1995; Over et al., 2010), and they readily use different body movements, should they allow them to achieve the outcome more effectively (Tomasello, 1996; Gergely et al., 2002; Buttelmann et al., 2007; but see Over et al., 2012, for evidence on over-imitation).

In sharp contrast, automatic imitation reflects the tendency to non-strategically and non-intentionally copy the gestures, body language, accent, posture and facial expressions of

one's interaction partners. It is observed in everyday interactions (Chartrand et al., 1999) and in the lab, where participants execute responses more quickly if they match an action they have just observed (e.g., Heyes, 2011; Brass et al., 2002; Bach et al., 2007; Bach et al., 2007; Catmur et al., 2011; Bertenthal et al., 2006). In contrast to goal-directed imitation, automatic imitation is assumed to be primarily bottom-up driven, resulting from a simple matching of observed body movements to participants' own motor programmes. It has been suggested that automatic imitation is mediated by a specifically evolved "mirror" system (Iacoboni, Woods, Brass, Bekkering, Mazziotta & Rizzolatti, 1999; Iacoboni, 2009) or by sensorimotor associations between correlated motoric and sensory action components (e.g., Heyes, 2011; Catmur et al., 2009; Hommel, Müsseler, Aschersleben & Prinz, 2001; Van der Wel, Knoblich & Sebanz, 2013). And while automatic imitation is modulated by liking and perceived similarity of the model (e.g., Wang & Hamilton, 2012; Leighton, Bird, Orsini & Heyes, 2010), it is widely assumed to occur automatically, without top-down control (Rizzolatti & Fogassi, 2014), even when attention is directed away from the observed action (Brass et al., 2000; but see Bach et al., 2008) and under both low and high perceptual load (Catmur, 2015; Ramsey, Darda & Downing, 2019). Theorists have therefore described it as "unintentional" (Richardson et al., 2007), "unconscious" or "non-conscious" (Belot et al., 2012; van Baren et al., 2003), or, indeed, "automatic" (Obhi et al., 2013; Heyes, 2011).

The experiments in this chapter are intended to provide a challenge to this view. They provide a first test of whether automatic imitation, as it is measured in response time tasks in the lab, is similarly outcome-driven as goal-directed imitation. This argument follows from ideomotor or hierarchical/predictive models of action (e.g., Hommel et al., 2001; Adams, Shipp & Friston, 2013; Grafton & Hamilton, 2007). These models argue

that the representations that humans use to control their own behaviour – and understand the behaviour of others – are inherently hierarchical. They are assumed to link an action’s lower-level body movements – the action’s more proximal components or “means” – to their ultimate effects: the action’s consequences, or “ends”, both within the environment and on one’s own body or affective responses. Goal-directed imitation, in such models, is possible, because whenever people observe an action, they establish such an integrated representation, associating the observed body movements to the observed outcomes (Wohlschläger et al., 2003; Hommel et al. 2001; Gergely & Csibra, 2003). From this point onwards, observers only need to activate the higher-level “outcome” components to trigger activation of the lower-level bodily components to imitate the behaviour and achieve the same outcome, and this should happen primarily when these outcomes are desirable (see Elsner, 2007, for review and extended argument). The crucial insight of these models is that automatic imitation could rely on the same representations (e.g., Hommel et al., 2001; Van der Wel, et al., 2013). Simply observing others’ actions could be enough to generate such hierarchical means-end representations. Own actions would then be executed more quickly not only when they match the seen action’s more proximal, kinematic components, but specifically when their observed outcomes are positive and match one’s own goals.

The review of the literature in the Introduction has shown that this proposal has so far not been directly tested. However, several recent studies provide more general evidence for top-down control also in automatic imitation (see Campbell & Cunnington, 2017, for a review). For example, Liepelt et al., (2008) reported that people imitate the inferred goal of an action (intending to lift a finger) rather than what is actually observed (finger held in place by a clamp). Similarly, studies in adults as well as children have shown that people imitate actions more quickly if they are directed

towards an object (i.e. a dot on a table) rather than to empty space (Wohlschläger et al., 2003), especially if these actions are appropriate for successful interaction with this object (e.g., Bach et al., 2008). While such findings are typically explained in terms of the object-centeredness of the human mirror network (e.g., Bach, Nicholson & Hudson, 2014; Wohlschläger & Bekkering, 2002), they could equally reflect the representation of observed or anticipated achievement of action outcomes (i.e. the successful reaching of the action targets).

The experiments in this chapter directly test whether automatic imitation is driven by the observed action outcomes. Four experiments independently manipulated (1) the observed action outcomes (positive vs negative) and (2) the match of the observed actions to the participants' own responses (matching vs mismatching). They were designed analogously to experiments in children in which they particularly imitate actions that are successful or have positive outcomes and, if anything, correct unsuccessful attempts towards more effective alternatives (e.g., Corriveau et al., 2016; Carpenter et al., 1998; Meltzoff, 1995; Over et al., 2010). In the studies in the current chapter, adult participants watched simple reaches with the left or right hand that either revealed winning or losing cards in a card game (relative to a previously displayed card on a table). They judged these actions – did the player win or lose? – by making a left/right response that therefore either matched or mismatched the observed actions. It was measured whether these responses would be executed more quickly if they matched the just observed actions, particularly when these actions had positive outcomes (wins in the card game), but not for negative outcomes (losses). Such results would reveal close links between automatic imitation and goal-directed imitation and would support hierarchical models of action control, in which action observation and execution are driven by action representation that link proximal action properties to their distal action

outcomes (e.g. Wohlschläger et al., 2003; Hommel et al. 2001; Gergely & Csibra, 2003).

### **Experiment 1a**

The aim of Experiment 1a was to provide a first test of whether automatic imitation is modulated by the outcome of the observed action. Participants observed simple actions in a game of cards. In each trial, an actor used their left or right hand to reach towards – and reveal – a left or right card on the table directly in front of them. The chosen card was then revealed to have either won or lost, depending on whether the card was higher or lower than a previously revealed opponent's card. Participants simply reported which type of outcome they observed (winning or losing) using a left or right key press, which therefore either matched the observed actor's left/right action or mismatched this action.

This design provides a first test (1) of whether automatic imitation is elicited in such a setting and (2) whether it depends on the observed action's outcome, that is, whether the observed action revealed a winning or losing card. We should then find automatic imitation – faster and more accurate responses that match the just seen action – specifically for observed actions with a positive outcome. Note that in this setup, the observed body movements are identical: the only aspect that differs is the outcome revealed by the action, which was not part of the action and statistically independent of which action was executed. Finding that automatic imitation depends on the action's outcome would therefore provide direct evidence that observers establish hierarchical

action-outcome representations whenever they see others' act and that they rely on these representations when planning their own actions.

## **Method**

### *Participants*

41 participants took part in the experiment (age range from 18 to 45, mean age = 27, 7 males, 5 left-handed). They were recruited by the Plymouth University, School of Psychology participation system, which includes (non-academic) staff, students and members of the public. Participants were given a cash reward of £4 or course credit for participation. They were given an information sheet, which explained the experiment and procedure, as well as their right to withdraw at any time, and gave informed written consent. No personally identifying information was collected or retained. Following the experiment, participants were fully debriefed in writing, and allowed the opportunity to ask questions as well as being given contact details for any further queries they may have. The experiment was approved by the Ethics Committee of Plymouth University.

Four participants were excluded from analysis for making more than 20% errors. Two additional participants were removed because they were current PhD students and not naïve to the purpose of the experiment. As these participants showed the predicted pattern to a stronger extent than usual, their removal did not affect the pattern of results. A sensitivity analysis with G\*Power showed that the final sample size of 35 provides .80 power to detect interaction effects with Cohen's  $d = .49$ . A typical example

of a similar study testing links between SRC and valance shows an interaction effect size of  $F(2, 42) = 26.07, p < .001, \text{Cohen's } d = .55$  (Xiaojun, Xuqun, Changxiu, Shuoqiu, & Chaoyi, 2014). Another example of the effect sizes expected taken from an automatic imitation SRC study, with similar trial numbers, shows an interaction effect size of  $F(1, 18) = 21.9, p < .001, \text{Cohen's } d = .54$  (Klapper, Ramsey, Wigboldus, & Cross, 2014) confirming that expected effect sizes are in this range.

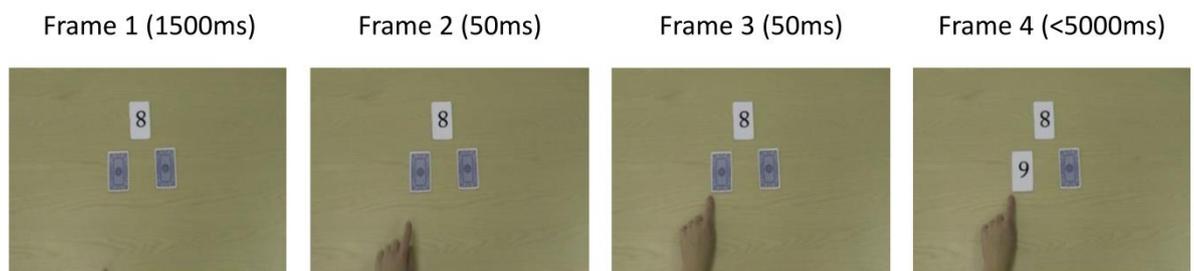
### *Apparatus and stimuli*

The experiment was conducted in a laboratory room with participants seated in separate sound proofed cubicles. The stimuli consisted of video clips presented on a 21 inch monitor positioned at approximately shoulder height, 60 cm away from participants, with a resolution of 1024 x 768 pixels. Stimulus presentation was controlled by Eprime 2.0. Participants responded to the stimuli using a keyboard by pressing either a button on the right with their right index finger or a button on the left with their left index finger. Buttons were colour coded (yellow and blue) rather than being assigned a left/right or numerical identifier.

The stimuli were recorded with a Sony DCR-TRV900E camcorder fixed to a tripod. The camcorder was arranged directly above the actor and pointed downwards over the actor's hands at a position that was as similar as possible to the actor's own visual perspective. Two five-frame action sequences were created in this way, showing either the left or right hand moving forward and pointing towards a left or right card on the table in front of it (see Figure 1). The pointing action was chosen because it was similar as possible to the participant's key press. The first frame, displayed for 750 ms, showed the actor's hands in resting state at the edge of the screen with the three cards above, the top (the opponent) card face up, showing one of eight possible numbers (2-9). The next

two frames, each presented for 50 ms, then showed the actor reaching forward and pointing, with either the left or right hand, towards one of the two cards, without obstructing their view. The last stage of the movement, frame 4, was seen for longer (up to 5000 ms. or the participant made a response) to make clear that the movement had stopped. It showed the card that the actor pointed towards face up, again revealing either one of eight numbers (1-10), selected so that the revealed number would in half of the cases be larger than the number of the first case and lower than the other half (see Table 1a).

Sixteen such action sequences were created for each hand, showing the different combinations of symbols on the player’s and opponent’s cards, such that either the player or the opponent was equally likely to win (see figure 1 for an example). No draws were shown (see table 1).



**Figure 1a:** An example of a stimulus sequence, showing a higher (“winning”) outcome.

Table 1a: Combinations of farthest card and revealed card

Farthest card number	2	3	4	5	6	7	8	9								
Left Hand Card Revealed	1	3	2	4	3	5	4	6	5	7	6	8	7	9	8	10
Right hand Card Revealed	1	3	2	4	3	5	4	6	5	7	6	8	7	9	8	10

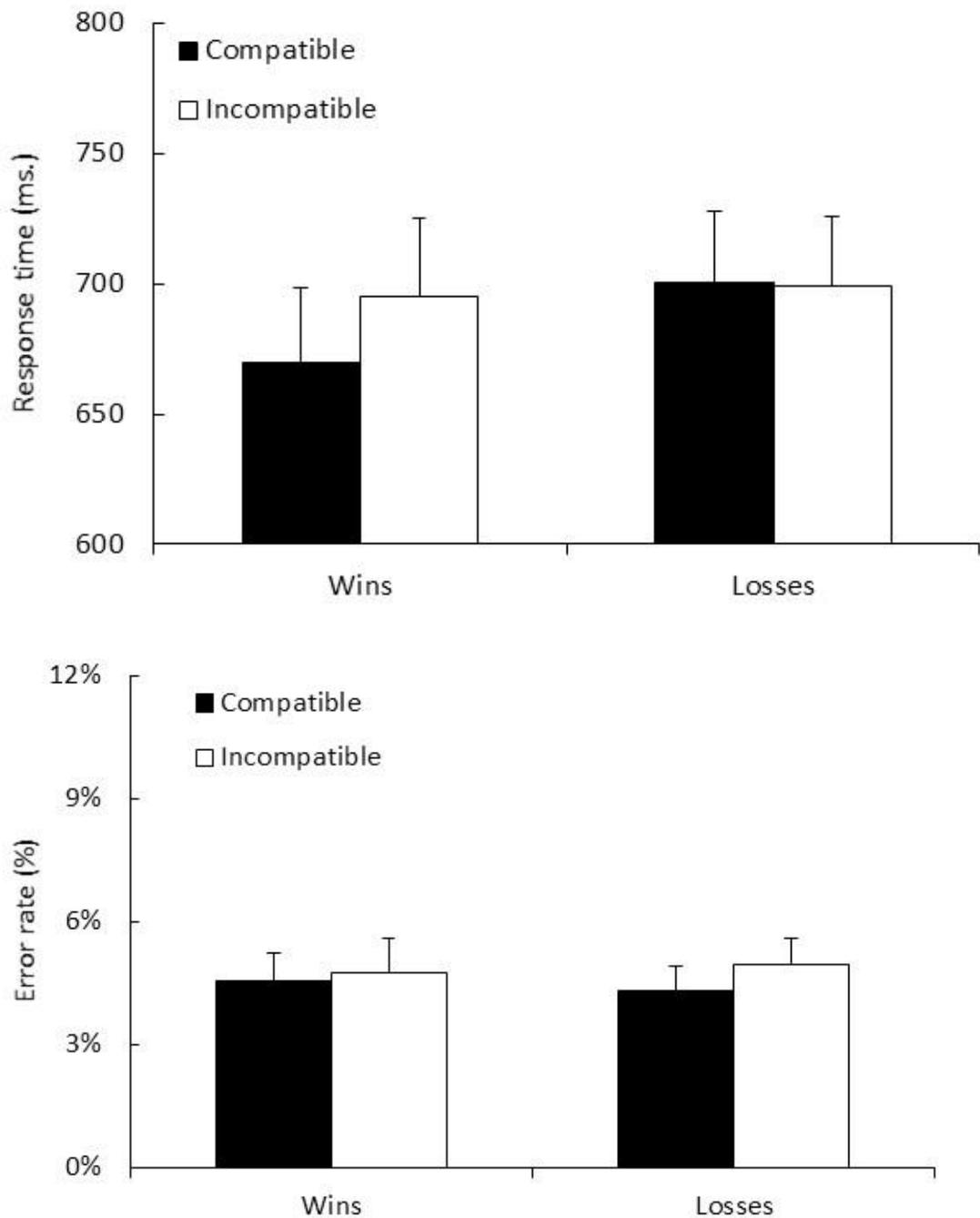
### *Procedure and Design*

Participants were asked to imagine that the stimulus hands were their own, and to judge, in each trial, whether they won or lost in a card game. Each trial started with a hand in resting position at the bottom of the screen, with three cards in front of it (Figure 1a). The farthest card was already revealed – showing one of the numbers 1-8 – and referred to as the opponent’s card. The hand then reached forward and revealed one of the two other cards – the player cards –, which would show either a number higher or one number lower than the ‘opponent’s’ card. Participants judged - through the press of one of two buttons with their left or right hand (counterbalanced between participants) – whether this card won (was higher) or lost (was lower) against the already revealed card.

Each participant completed two blocks. Odd-numbered participants completed the first block such that a left response indicated a loss and a right response a win, while this assignment was reversed for the second block. Even numbered participants completed the reverse assignments. There were 224 experimental trials per block (448 in total). Each trial was randomly selected (without replacement) from each of the 32 stimuli and repeated 7 times within each block. It was varied whether the reach of the actor would need to be imitated by the participant to make their response (e.g., both the actor and the participant used left hands) or not (e.g., the actor used their left hand and the participant used the right hand) and whether the observed action produced a positive or negative outcome (i.e. revealed a winning or losing card). Prior to the experiment, participants completed ten randomly selected practice trials.

### **Results**

Trials were excluded when RTs were faster than 100 ms. or slower than 5000 ms. and when beyond 3 standard deviations from the mean of their respective win/loss condition (2.2%). The remaining data were analysed with a 2x2 repeated measures ANOVA, with the factors Compatibility (whether the participants' action was compatible or incompatible with the just observed action) and Outcome (whether the observed action revealed a winning or losing card). The analysis of response times (Figure 2a) revealed a main effect of Outcome,  $F(1, 34) = 5.74, p = .022, \eta^2 = .144$ , with participants identifying wins faster than losses. There was no main effect of Compatibility  $F(1, 34) = 3.28, p = .079, \eta^2 = .088$ , but the analysis revealed the predicted interaction of Compatibility and Outcome,  $F(1, 34) = 10.42, p = .003, \eta^2 = .235$ . Paired-samples t-test showed, as predicted, that the RT advantage of compatible actions was only present for winning actions,  $t(34) = 3.650, p = .001$ , and numerically reversed for losing actions,  $t < 1$ . The same ANOVA on the Error rates did not reveal any main effects or interactions (for all,  $p > .196$ ).



**Figure 2a:** Response times (top) and Error Rates (bottom) in Experiment 1a. The left bars reflect responses in which the actor's reach revealed a winning (higher) card and the bars on the right reflect responses in which it revealed a losing (lower card). The black bars show response times for matching button presses (on the same side as the just observed action) and grey bars show response times for non-matching actions (on the opposite side as the just seen action). The error bars show the standard error of the mean.

## Discussion

This study provided a first test of whether the outcome of an observed action affects automatic imitation. Participants watched an actor whose actions revealed winning or losing cards in a card game and evaluated these outcomes with responses that either matched or mismatched the just observed actions. The results showed, first, that participants' responses were faster when they matched the observed action, confirming that this paradigm captures the expected automatic imitation effect (e.g., Heyes, 2011; Brass et al., 2002; Bach & Tipper, 2007; Bach, Peatfield & Tipper, 2007). In addition, and more importantly, we found that action observation facilitated similar responses only if the action had a positive outcome, in the present case, when it produced a win in a game. Observing a losing action elicited no such effect, and did, if anything, slow down participants' ability to produce a matching compared to a non-matching action.

This finding provides a first indication that automatic imitation – at least in our paradigm – cannot simply be attributed to a simple matching of observed actions to one's own action repertoires. Instead, outcome information must have been integrated into the action's representation and directly affected whether it would be imitated. This finding is striking because in our game the outcome is not part of the motor act itself; it is an incidental consequence of which card is revealed by this act. Moreover, outcomes were not statistically linked to which action was executed but were randomly selected (i.e. both outcomes occurred equally for both actions). The finding that action outcome nevertheless affected automatic imitation indicates that it is guided not only by motoric- or goal representations linked to a motor act itself. Instead, it must draw upon higher-level representations that integrate this motor act into a hierarchical representation that also includes the action's value in terms of the distal (not body-related) outcomes it

produced (e.g., Hommel et al., 2001; Adams, Shipp & Friston, 2013; Grafton & Hamilton, 2007).

One potential problem with Experiment 1a may be that the numerical value of the card might have influenced responses rather than the positive or negative outcomes.

Numerical representations might have a special status in cognitive processing (Cohen Kadosh, Lammertyn, & Izard, 2008), are given magnitude automatically (Girelli, Lucandeli, & Butterworth, 2000) and might produce compatibility effects themselves (for example: SNARC effect, Dehaene, Bossini, & Giraux, 1993; see Fischer, 2003).

Whilst the game depicted in the stimuli is an ecologically valid representation of a card game, it is therefore nevertheless possible that the effect observed may have occurred due to the presentation of number, particularly given that the task required participants to find a larger number than the opponent's, and positive outcomes went together with higher value cards than negative outcomes. The effect could therefore, at least in part, be due to the numerical values of the cards, not the outcomes themselves. Experiment 2a is an attempt to address this question.

## **Experiment 2a**

Experiment 2a attempted to disentangle the modulation of automatic imitation through outcome information from its modulation through card magnitude alone. In Experiment 2a, we therefore varied how higher or lower cards had to be interpreted by participants. In different groups, we varied whether participants were told that: (1) higher card numbers would win (as in Experiment 1a), that (2) higher cards would lose and that

lower numbers would win, or (3) to make no valence judgments, but to simply evaluate if the second card was numerically higher or lower than the previous one.

If the modulation of automatic imitation was driven by the magnitude of the numbers presented on the stimuli, rather than the actual outcome in terms of game wins or losses, then each of the three groups should produce the same pattern of results: automatic imitation should be found for cards that are of higher magnitude than the opponent card, irrespective of instruction. In contrast, if in the previous experiments, the modulation of automatic imitation was driven by the evaluation of action outcomes, then the pattern should differ across the three experimental groups. In other words, higher value cards should induce automatic imitation in the group in which higher cards, but not in the no-valence group. The group in which lower cards won should show the opposite pattern, with automatic imitation for lower value but not higher value cards.

## **Method**

### *Participants.*

84 participants took part in the experiment (age range from 18 to 38, mean age = 26, 7 males, 5 left-handed), recruited as in Experiment 1. The final sample of 75 (after exclusion, see below) was split into three equal-sized groups. Power was assessed using G\*Power. For the individual groups of 25 this provides .8 power to detect an effect size of Cohen's  $d = .51$  and differences between groups with  $d = .71$ .

### *Apparatus and stimuli*

Apparatus and stimuli were identical to Experiment 1, with the exception of the three sets of instructions provided for the participants.

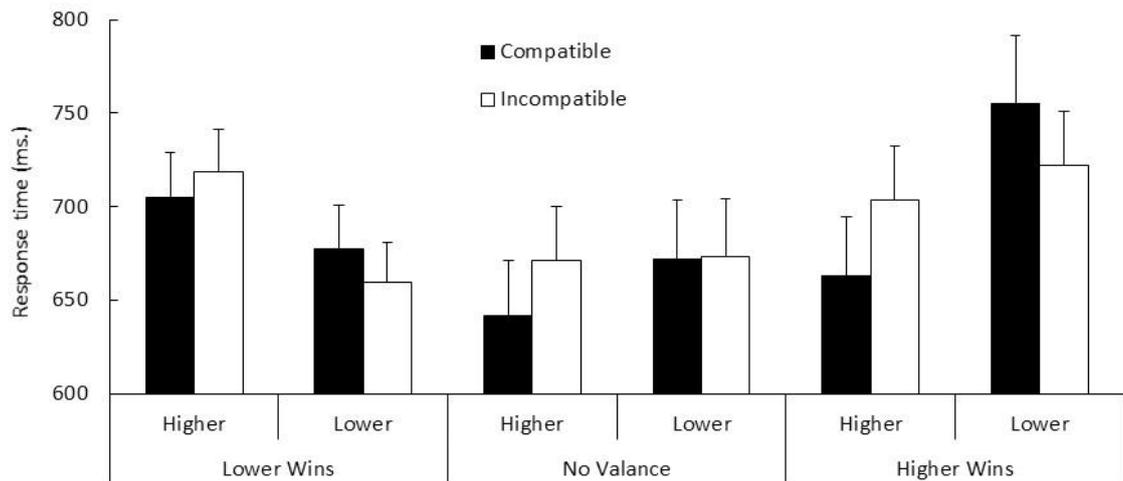
### *Procedure and design*

As before, participants were asked to imagine that the hands they observed were their own, and that they were playing a card game. Thus, the farthest card against which they would make a judgement was referred to as the “opponent’s” card. Participants were instructed to respond according to whether a player won or lost in two of the conditions using one of the pre-specified rules: (1) to *win*, your card must be higher than the opponent’s; (2) to *win* your card must be lower than the opponent’s card. In a third control condition, (3) participants were simply asked to respond as to whether their card was higher or lower than the opponent’s card. All other aspects of procedure and design were identical to Experiment 1.

## **Results**

Nine participants were removed from the analysis for failing to meet an accuracy threshold of 80%. Analysis was conducted on the 75 successful participant recordings. As in Experiment 1a, individual trials were discarded when RTs were faster than 100 ms. or slower than 5000 ms. and when beyond 3 standard deviations from the mean of their respective win/loss condition (2.43%).

The response time data (Figure 4, upper panel) was analysed with a three-factor analysis of variance (ANOVA) with the within-subjects' factors Compatibility (whether the required response matched the observed action or not), Magnitude (whether the revealed card was higher or lower than the opponent card), and the between factor of Instruction (higher wins, no valence, lower wins). The analysis revealed no main effects of Magnitude,  $F(1, 72) = .88, p = .35$ , and only a marginally significant main effect of Compatibility,  $F(1, 72) = 2.15, p = .09, \eta^2 = .04$ , reflecting the general automatic imitation effect. Compatibility and Magnitude interacted,  $F(1, 72) = 21.95, p < .001, \eta^2 = .23$ . Step-down analysis with paired samples t-tests revealed a general (i.e. across groups) RT advantage for responses that matched the observed actions, specifically when responding to higher value cards,  $t(74) = 2.19, p = .03$ , but not when responding to lower value cards,  $t(74) = 1.49, p = .14$ . There was no interaction of Magnitude, Imitation and Instruction,  $F(2, 72) = 1.948, p = .15, \eta^2 = .05$ . While the expected pattern was seen numerically (see Figure 3), with larger modulation of automatic imitation in the Higher-wins group than the No-valence and Lower-wins group, the pairwise differences between the groups were not significant ( $p > .28$ , for all), and the interaction of Magnitude and Compatibility was present in all three groups ( $p < .005$  for all).



**Figure 3a:** Response times in Experiment 2a, showing the data from the three participants groups from left to right (Lower Wins, No Valance, Higher Wins). Within each group, the left two bars reflect responses in which the actor's reach revealed a higher card and the bars on the right reflect responses in which it revealed a lower card than the opponent card. The black bars show response times for compatible button presses (on the same side as the just observed action) and grey bars show response times for incompatible button presses (on the opposite side as the just seen action). Error bars show the standard error of the mean.

The same ANOVA was conducted on the error rates (Figure 3, lower panel), but did not reveal any significant main effects or interactions ( $p > .34$ ).

## Discussion

The aim of Experiment 2a was to test whether numerical magnitude contributed to the modulation of automatic imitation times in Experiment 1a, and to disentangle this contribution from that of the outcome (win/lose) evaluations. The results in the participant group for whom higher cards won and lower cards lost replicated Experiment 1a in terms of automatic imitation being present only when higher cards were being played, but not when losing cards were played. Strikingly, however, while

this modulation was numerically larger in this group, it did not differ statistically in the other two groups of participants. Indeed, the modulation of automatic imitation through card values was present in both others participant groups. Higher value cards elicited stronger automatic imitation effects compared to lower value cards, even when no valence was assigned to card magnitude, and even if higher cards had to be interpreted as losing cards.

These data suggest that the outcome modulation observed in Experiment 1a could be due to, at least in part, the numerical values of the cards, which give rise to automatic imitation for high value cards and eliminate automatic imitation for low value cards. This is a surprising – and to my knowledge – novel finding, which implies that card value itself may be coded in a valenced way that evaluates higher-value cards more positively than lower-value cards, and that this cancels out any additional influence of the outcomes cognitive evaluation in terms of winning or losing. Of course, card magnitude is itself an action-external action outcome, so this finding does not undermine the general proposal of an outcome modulation of automatic imitation. Nevertheless, this potential influence is avoided in the following studies reported in this chapter, by exchanging the magnitude decisions for symbolic judgments based on the rules of the game rock-paper-scissors. In doing so the experiment directly tests whether automatic imitation depends on the conceptual representation of the observed action's outcome and will reveal any effect of top-down processing on automatic imitation.

### **Experiment 3a**

This experiment tested whether imitation is guided by the outcome of the observed action but does so using symbols that have no magnitude information. To do so, we used the same card game as in Experiments 1a and 2a, but replaced the numbers with the well-known symbols of Rock-Paper-Scissors. The initial “opponent” card revealed one of these symbols, and the “player” card revealed by the observed action showed another of these symbols, which could win or lose against the first card following the well-known rules of Rock-Paper-Scissors (paper beats rock, rock beats scissors, scissors beat paper). As in the previous experiments, participants were asked to identify whether they saw a winning or losing outcome by making a left or right key press, which either matched (using the same hand) or mismatched the action they just observed (using a different hand).

If Experiment 3a replicates that outcomes modulate automatic imitation, it would solve the problem of numerical magnitudes contaminating the results and automatically guiding automatic imitation. The symbols used do not hold intrinsic value. They cannot be assigned a numerical value, nor can a decision be made about whether a particular symbol is positive or negative when presented individually. The outcome of the action can only be resolved when the symbol on the player card is evaluated against the opponent card, providing a “pure” measure of action outcome, and whether it affects automatic imitation. If so, then the participants’ own responses should again be faster if they match the just seen action, specifically when this action revealed a winning card.

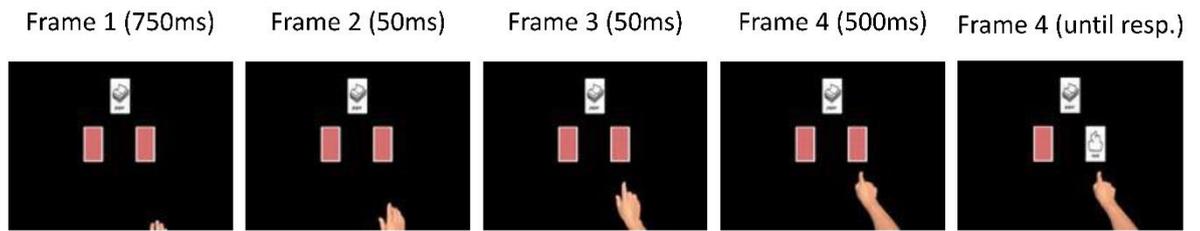
## Method

### *Participants*

35 participants (age range from 18 to 45, mean age = 28, 8 males, 2 left handed), all members of the public and recruited through the Plymouth University, School of Psychology participation system, took part in the experiment, in exchange for a cash reward of £4. Five of these participants were excluded for making more than 20% errors. Participants were fully briefed and debriefed and gave informed consent, in accordance with the ethical guidance of Plymouth University and the Declaration of Helsinki. The resulting total sample size of 30 provides .80 power to detect interaction effects with Cohen's  $d = .46$ .

### *Apparatus and stimuli*

Apparatus and stimuli were created in the same way as Experiment 1a and 2a with the exception that the background of the stimuli was removed and replaced with a black screen. Additionally, instead of numerical symbols, an image of rock, paper or scissors was presented in the centre of the card (Figure 4). To present a smoother action, the movement sequence was subdivided in three rather than four frames of 50 ms. Moreover, a small delay of 500 ms. was introduced between the finger reaching the target card and this card being revealed (see Figure 4).



**Figure 4a:** An example of an experimental stimulus set using a right hand, when the opponent’s card was ‘paper’ and the participant’s card was ‘rock’.

Six combinations of stimuli sets were created for each hand producing 12 in total; note that no draws were shown, outcomes were either positive or negative and none of the games showed a draw (Table 2).

<b>Table 2a: Combinations of farthest (opponent’s) card and revealed (participant’s) card</b>						
Opponent’s Card	<b>Rock</b>		<b>Paper</b>		<b>Scissors</b>	
Left Hand Card	Paper	Scissors	Scissors	Rock	Rock	Paper
Right Hand Card	Scissors	Paper	Rock	Scissors	Paper	Rock

*Procedure and Design.*

Participants were asked to imagine that the hands they observed in the stimuli were their own, and that they were playing a card game. The farthest card against which they would make a judgement was referred to as the “opponent’s” card. Participants were instructed to respond according to whether a player won or lost using the pre-specified rules – rock beats scissors, scissors beats paper and paper beats rock. They completed

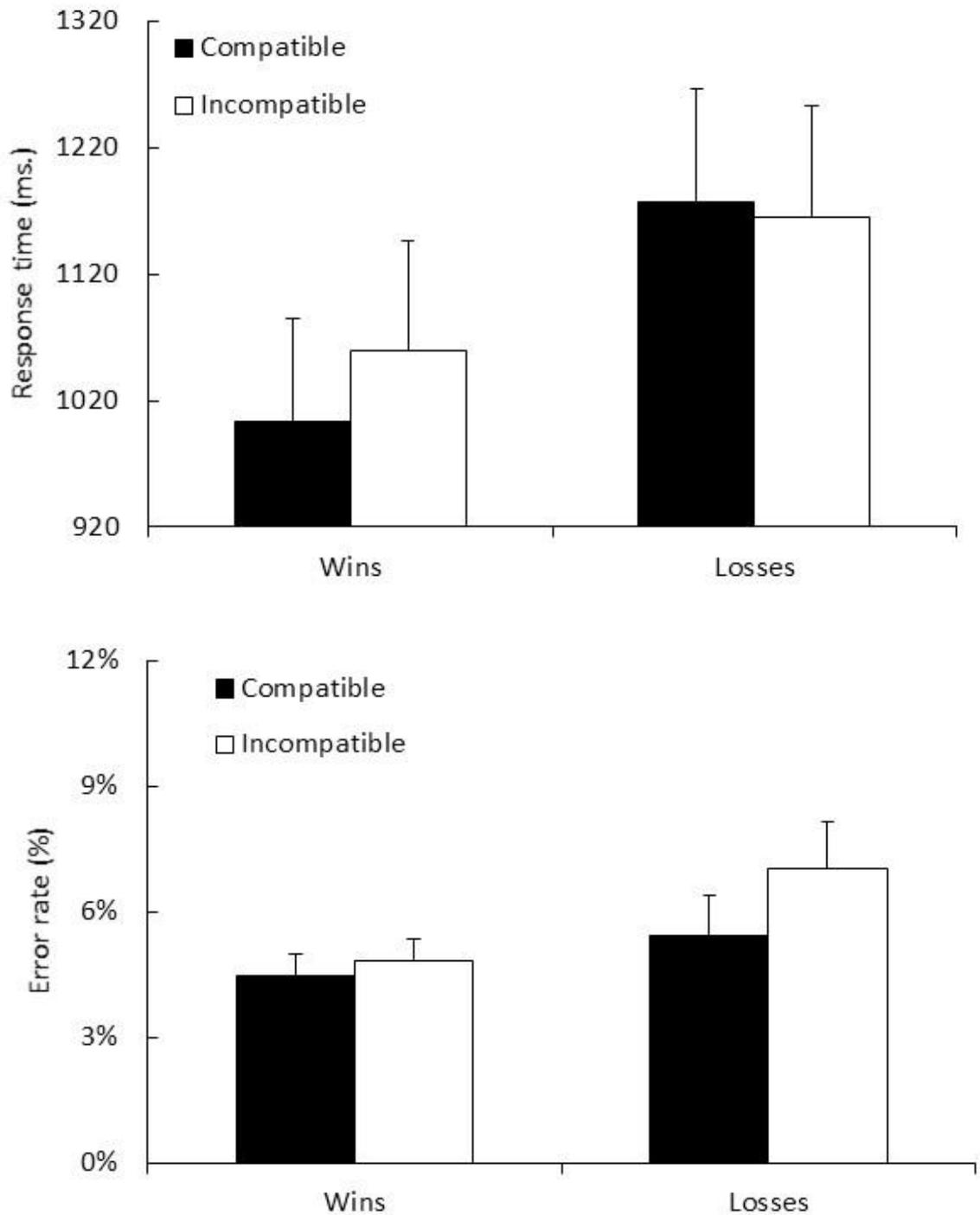
ten practice trials prior to the experiment, randomly selected from the experimental stimuli. The experiment was divided into two blocks. Odd numbered participants completed the experiment with right button for winning and left button for losing, whilst the even numbered participants completed the experiment with reverse hand mapping. Each block of trials consisted of random without replacement selection for each of the twelve stimuli which was repeated thirteen times within each block. This resulted in 156 experimental trials per block, with 312 in total for each participant. All other aspects of procedure and design as well as data recording and analysis were identical to Experiment 1.

## Results

Trials were excluded when RTs were faster than 100 ms. or slower than 5000 ms. and when beyond 3 standard deviations from the mean of the respective win/loss condition (3.0%). Response times were analysed with a 2x2 repeated measures ANOVA, with the factors Compatibility (whether the side of the participants' action matched or mismatched the observed action) and Outcome (whether the observed action revealed a winning or losing card). The analysis (Figure 2) revealed a main effect of Imitation,  $F(1, 29) = 9.22, p = .005, \eta^2 = .241$ , and of Outcome,  $F(1, 29) = 42.85, p < .001, \eta^2 = .596$ . Participants generally responded more rapidly to wins than to losses and when their responses matched the action they just observed, replicating the expected automatic imitation effect. Importantly, as in Experiment 1, Imitation and Outcome interacted,  $F(1, 29) = 13.57, p = .001, \eta^2 = .319$ . Follow up t-tests revealed that after observing winning actions, compatible responses were faster than incompatible

responses,  $t(29) = 4.66, p < .001$ , but no such effect was observed for losing actions,  $t(29) = 1.02, p = .316$ .

The same ANOVA run on the error rates only revealed theoretically uninteresting main effects of Outcome,  $F(1, 29) = 4.35, p = .046, \eta^2 = .130$ , and neither a main effect of Imitation,  $F(1, 29) = 3.93, p = .057, \eta^2 = .119$ , nor an interaction,  $F(1, 29) = 2.42, p = .130$ .



**Figure 5a:** Response times in Experiment 3a. The left bars reflect responses in which the actor's reach revealed a winning card and the bars on the right reflect responses in which it revealed a losing card. The black bars show response times for matching button presses (on the same side as the just observed action) and grey bars show response times for non-matching actions (on the opposite side as the just seen action). Error bars show the standard error of the mean.

## *Discussion*

Experiment 3a again replicated the automatic imitation effect (e.g., Heyes, 2011; Brass et al., 2002; Bach & Tipper, 2007; Bach, Peatfield & Tipper, 2007), with participants responding more quickly when their response was similar to the action they had just observed, compared to when their responses was more dissimilar to this action. In addition, and more importantly, Experiment 3a showed again that – as in the previous two experiments in this chapter – automatic imitation is modulated by the outcome of the observed action. The response time advantage for matching actions was only observed for actions with winning (positive) outcomes, not for losing actions (negative outcomes). This was the case even though the action outcomes were not established by comparisons of the cards' intrinsic (numerical) magnitudes, but through comparisons of the not-magnitude-related symbols on the player and opponent card, according to the rules of the game Paper-Scissors-Rock.

The results therefore confirm that the evaluation of the action outcome itself, as either positive or negative, can modulate automatic imitation, eliciting a tendency to perform the same action as the model when the observed outcome is positive, but not when negative. These findings are not consistent with idea that automatic imitation results from a simple kinematic matching of observed actions to ones' own motor repertoire (Heyes, 2011; Iacoboni et al., 1999; Iacoboni, 2009), for which such distal (non-action-related) outcomes would not matter. They favour hierarchical models of action observation and control, in which action observation establishes integrated representations that include not only the observed motor act but also the outcome it produces, which then guides overt behaviour, similarly to findings in goal-directed

imitation in children and primates (e.g., Elsner, 2007; Hommel et al., 2001; Call, et al., 2002; Gattis et al., 2002).

One aspect of the present design limits the conclusions that can be drawn from the present results. First, in all experiments so far, participants were asked to imagine that the hands in the scene were seen from a 1<sup>st</sup> person perspective. While previous studies have revealed little distinction between the imitation of 1<sup>st</sup> person and 3<sup>rd</sup> person actions (Cracco et al., 2018), this raises the question whether our effects indeed reflect automatic imitation, which reflects, by definition, the copying of an action of another person, or whether the egocentric viewpoint might have caused participants to encode the action's outcome to a stronger extent than they otherwise would have. If we are to truly investigate whether imitation is affected by outcome information, we also need to include an investigation that presents the actions from another, 3<sup>rd</sup> person perspective.

### **Experiment 4a**

Experiment 4a addressed two potential alternative explanations for the present results. First, in Experiments 1a to 3a, participants always saw the actions from a first-person perspective, as if the hands were their own. While previous studies have revealed that mimicry in everyday social interactions can be affected by perspective (Genschow, Florack, & Wänke, 2013), automatic imitation appears to reflect different processes (Genschow, et al., 2017) and there is indeed little distinction between automatic imitation of actions seen from 1st person and 3rd person perspectives (e.g., Bertenthal, Longo & Kosobud, 2006; Jackson, Meltzoff, & Decety, 2006), even when tested using meta-analytic measures (Cracco et al., 2018). Nevertheless, the stimulus presentation

from the 1st person perspective in the previous experiments raises the question whether the effects are perhaps better explained as spontaneous motor responses resulting from the body parts mapped to one's own body (e.g., Ramsey, Cumming, Eastough & Edwards, 2010). Experiment 1d therefore replicates Experiment 1c but varies, between participants to avoid carry-over effects, whether the actions are seen from a 1st person perspective or a 3rd person perspective. If the outcome-dependence seen in Experiment 1a and 3a indeed reflects automatic imitation, then it should be observed in both viewing perspectives.

A second question is whether the observed modulation of automatic imitation indeed reflects – as we hypothesized – the integration of (positive or negative) outcomes with the action that was observed, into a combined action representation. One way to test this is to decouple participants' outcome evaluation from the observed action. Orthogonal to the perspective manipulation, we therefore gave half of the participants the same task as before, judging whether the actor's actions caused them to win or lose. This group should replicate the effects of Experiment 1a and Experiment 3a. The other half, however, was instructed to take the perspective of the opponent, whose card was revealed from the outset, and to judge whether the action of the *other* player caused them to win or lose. This subtle shift in instruction keeps the type of response and the requirement for outcome evaluation identical as well as the presented stimuli.

Moreover, as before, this judgment requires attention towards the observed action and how the card it reveals relates to the previously revealed (own) card. The only difference is therefore that the to-be-evaluated action outcome was not linked to the actor that produced it, but to the other, non-acting player.

In Experiment 4a, there were therefore four groups of participants. They all performed the same general task but we varied orthogonally (1) whether the actions were seen

from a 1st person perspective or a 3rd person perspective, and (2) whether participants judged how the action's outcome affected the player that had produced this outcome or how it affected the other, passive player.

## **Method**

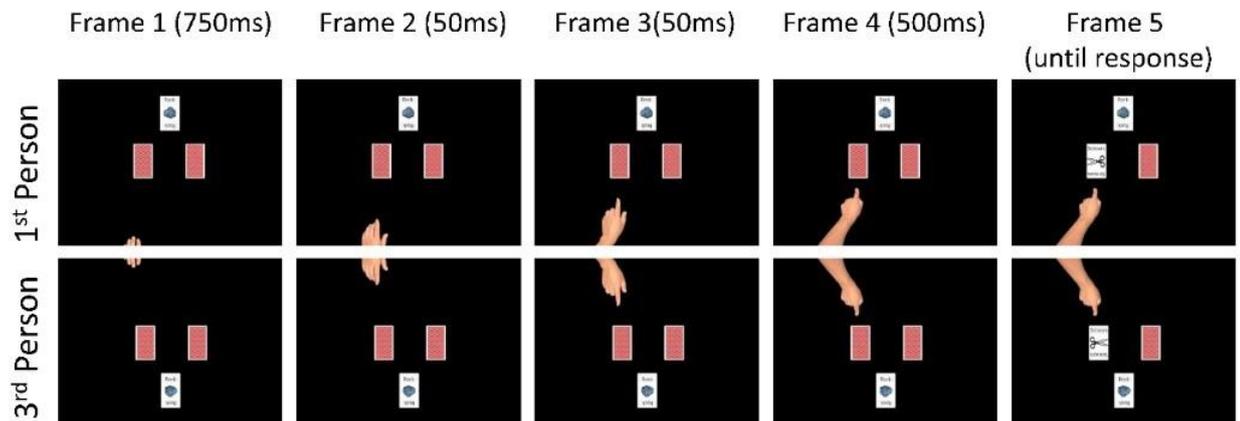
### *Participants*

120 participants took part (age range from 19 to 39, mean age = 24, 32 male, 10 left handed), selected as in the previous experiments. Ten participants were excluded because they made more than 20% errors. Six additional participants were not considered for analysis due to experimenter error. Analysis was conducted on the 104 remaining participants, with at least 25 participants in each of the four groups of participants (1st person player, 1st person opponent, 3rd person player, 3rd person opponent). Assuming that the between-group manipulation would eliminate or reverse the effect of previous study, the total sample size of 104 post exclusion provides .80 power to detect interaction effect sizes with Cohen's  $d = .28$ , and group differences of  $d = .57$  (based on split-half main effect and interaction contrasts).

### *Procedure and design*

The procedure was identical to Experiment 3a. However, now, half of the participants were shown the actions from a 1st person perspective, whilst the other half showed them in 3rd person perspective. Orthogonal to that manipulation, half of the participants were asked to imagine that the hands they observed were their own hands and judged whether "they" won or lost. The other half were asked to imagine that the moving hands

were the “opponent’s” hands, and they judged whether they themselves won or lost (for differences see table 3). All other aspects of the experiments were identical across conditions.



**Figure 6a.** Example stimulus sequences in Experiment 4, showing the same action seen from a 1st person perspective (upper panels) and 3rd person perspective (lower panels).

#### *Apparatus, Stimuli and Procedure*

Apparatus and stimuli were identical to previous experiments, with the exception that the action sequences were mirrored along the horizontal axis. In addition, labels and items on the cards were exchanged for ones that looked equal in both perspectives, ensuring that identification difficulty does not differ between perspectives (see Figure 6).

Participants had the same task as before. They first saw a revealed card and then a left or right reach towards one of two other cards, which caused this card to be revealed. They judged whether this newly revealed card caused them to win or lose the game, by either judging taking the perspective of the player or the opponent. In both conditions, judgments were therefore based on the second card that was revealed by the left or right action.

**Table a:** Instructions 1 given to half of the participants in 1<sup>st</sup> & 3<sup>rd</sup> person perspective condition and instructions 2 given to half the participants in 1<sup>st</sup> and 3<sup>rd</sup> person perspective conditions.

<b>Instruction 1: Imagine you are the actor</b>	<b>Instruction 2: Imagine the actor is an opponent</b>
You are playing a card game against an opponent.	You are playing a card game against an opponent.
You will see three cards on the table. One of them is face up.	You will see three cards on the table. One of them is face up.
This is the OPPONENT'S card	This is YOUR card
You will see a player point to and choose a card. This is YOUR card.	You will see the opponent point to and choose a card.
If you can, try to imagine that the hands are your own.	You have to decide if YOUR card beats their card or not.
You have to decide if YOUR card beats THEIR card or not.	

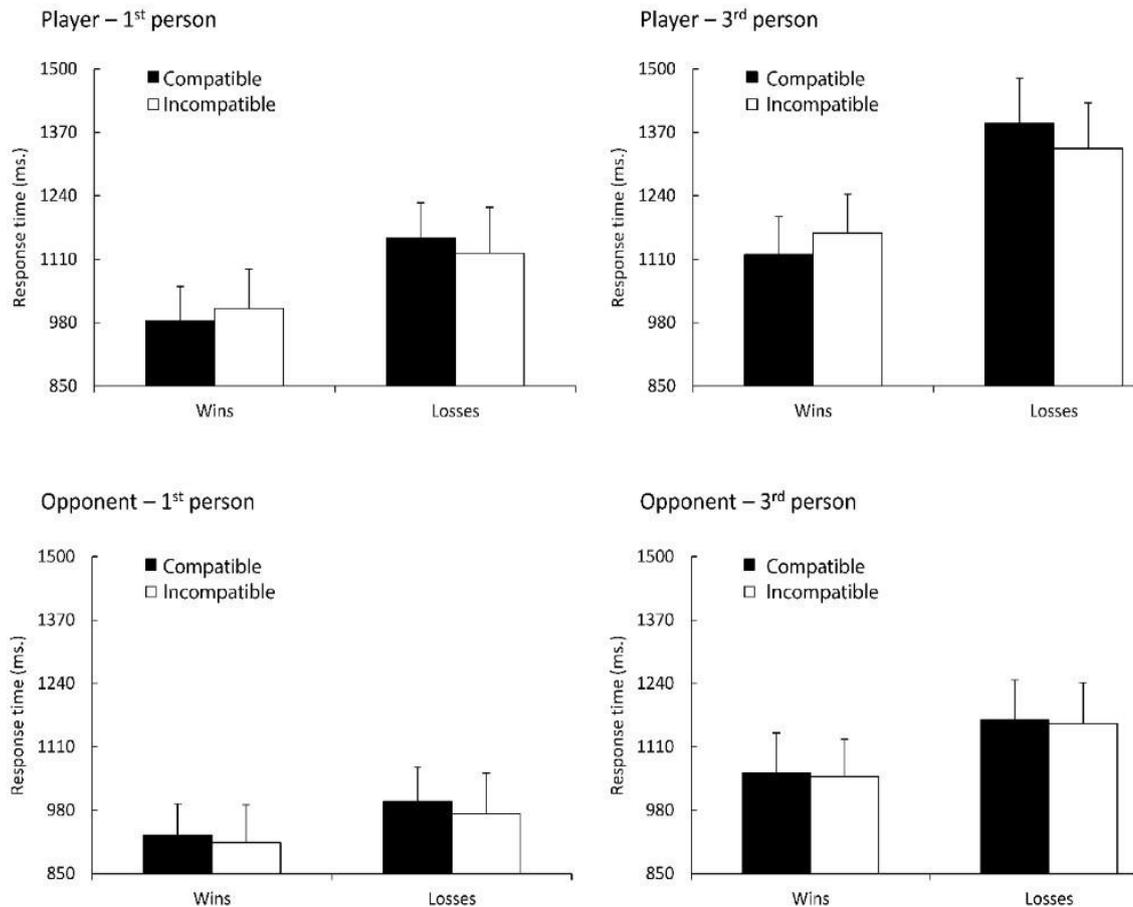
Each block of trials consisted of random without replacement selection for each of the twelve stimuli which was repeated thirteen times within each block. This resulted in 156 experimental trials per block, with 312 in total for each participant.

### ***Results***

As in all previous experiments, trials were excluded when they were faster than 100ms or slower than 5000 ms, and if they fell outside 3 standard deviations of the mean (3%). The remaining data (Figure 4) was analysed with a four factor ANOVA with the within-participant factors Compatibility (whether the response was compatible to the seen action or not) and Outcome (whether the observed action revealed a winning or losing card), and the between-participant factors Perspective (whether the actions were seen from a 1st or 3rd person perspective) and Target (whether participants judged the outcomes for the actor or the not-acting opponent). The analysis of response times

(Figure 4) revealed a main effect of Outcome,  $F(1, 100) = 143.48, p < .001, \eta^2 = .59$ , which interacted with Perspective,  $F(1, 100) = 7.78, p = .006, \eta^2 = .07$ , and Target,  $F(1, 100) = 18.12, p < .001, \eta^2 = .153$ . Participants identified wins faster than losses, specifically when seeing actions from the 1st person perspective and when taking the opponent's point of view. Replicating Experiment 1, there was only a marginal main effect of Compatibility,  $F(1, 100) = 2.90, p = .092, \eta^2 = .028$ , as well as the predicted interaction of Compatibility and Outcome,  $F(1, 100) = 11.73, p < .001, \eta^2 = .11$ . As before, the response time benefit for matching actions was seen for actions with positive outcomes (wins,  $t(103) = 1.74, p = .085$ ), and reversed for those with negative outcomes (losses,  $t(103) = 3.53, p = .001$ ). Importantly, the interaction of Compatibility and Outcome was qualified further by an interaction with Target,  $F(1, 100) = 9.22, p = .003, \eta^2 = .084$ , but not Perspective,  $F < 1$ . The outcome modulation of automatic imitation was present when participants judged action outcomes for the actor  $F(1, 100) = 18.07, p < .001, \eta^2 = .258$ , but absent when judging the outcomes for the opponent  $F < 1$ . Indeed, for participants judging outcomes for the actor, the relevant interaction of Outcome and Compatibility was present both when they saw the actions from a 1st person perspective,  $F(1, 25) = 5.11, p = .033, \eta^2 = .170$ , and when they saw them from a 3rd person perspective  $F(1, 27) = 14.09, p = .001, \eta^2 = .34$ . When judging the outcomes for the opponent, the interaction was absent in both perspectives (both,  $F < 1$ ).

The same ANOVA was conducted on the error rates (figure 5), but this did not reveal any theoretically interesting effects, other than a marginally significant interaction of Outcome and Compatibility,  $F(1, 25) = 3.44, p = .067, \eta^2 = .033$ . For winning actions, participants made more errors for matching rather than non-matching actions,  $t(103) = 2.27, p = .025$ , but this difference was absent for losing actions,  $t < 1$  (see figure 7).



**Figure 7a.** Response times in Experiment 2, depending on whether the participant evaluated the player’s actions (upper panels) or the opponent’s actions (lower panel) and on whether participants saw the actions from a 1st person perspective (left panels) or 3rd person perspective (right panels). In each panel, the left bars reflect responses in which the actor’s reach revealed a winning (higher) card and the bars on the right reflect responses in which it revealed a losing (lower) card. The black bars show response times for compatible button presses and white bars show response times for incompatible actions. The error bars show the standard error of the mean.

### Discussion

Experiment 4a replicated the outcome-dependency of automatic imitation first demonstrated in Experiments 1a and 3a. As before, the benefit of responding with a compatible response depended on the observed action’s outcome. While the response

time advantage of compatible responses was observed when viewing actions with positive outcomes (wins), it was reversed for actions with negative outcomes (losses). These data therefore confirm, first, that automatic imitation does not only reflect kinematic (“motor”) properties of the observed actions, but also the outcomes they produce, suggesting a hierarchical integration of action and outcome. Second, they show that the valence of these action outcomes – whether they are positive or negative – determines whether automatic imitation is elicited (for positive outcomes), or whether it is inhibited (for negative outcomes). The results therefore fully match the results in goal-directed imitation studies in children, in which imitation similarly occurs for actions with positive outcomes while those with negative outcomes are corrected towards a more efficient alternative (e.g., Corriveau et al., 2016; Carpenter et al., 1998; Meltzoff, 1995; Over & Gattis, 2010).

In addition, Experiment 4 helps to rule out two important alternative explanations for the observed effect. It revealed, first, that the outcome-dependency of automatic imitation was independent of viewing perspective: it was observed both when the actions were seen from a 1st person or 3rd person perspective. This confirms that the effects indeed reflect automatic imitation and are not restricted to actions attributed to one’s own body (for such an effect, see Bach, Fenton-Adams & Tipper, 2014). Second, Experiment 4 revealed that the outcome modulation only happens when participants judge the outcome of the actions for the actor. If they made the same judgements and saw exactly the same stimuli, but now treated the moving hand as belonging to another player, all such effects were eliminated.

Note that this difference between the player and opponent condition are unlikely to just reflect changes in attention, for example, if participants would focus on the left or right

action in the “player” condition and on the central card in the “opponent” condition. In both conditions, the central, non-lateralised card was available from the outset. Participants make their judgment directly after-action observation and judged whether the card revealed by the observed action caused a win or a loss. Indeed, response times in the opponent conditions are, if anything, faster than in the player condition, inconsistent with an attention-switch back to the original, centre card once the player card was revealed.

## **General Discussion**

Chapter 2 established, over four experiments, that automatic imitation in adults may be as outcome-driven as goal-directed imitation in children (e.g., Corriveau et al., 2016; Carpenter et al., 1998; Meltzoff, 1995). Participants watched actions that either had a positive or negative outcome, by revealing a winning or losing card in a game. They responded with an action that either matched the just seen action or mismatched it. All experiments replicated the well-known automatic imitation effect (e.g. Heyes, 2011; Brass et al., 2001; Bach et al., 2008), such that participants performed matching actions more quickly than mismatching ones. However, they also revealed, for the first time, that this automatic imitation effect depends on the observed action’s outcome. Even though the resulting outcomes were not part a proximal part of the observed action, and neither causally nor statistically related to them, the response time benefit of matching actions was only seen for actions that had a positive outcome and revealed a winning

card. For actions with negative outcomes – those revealing losing cards – the automatic imitation effect was eliminated and, numerically, reversed.

This outcome-dependency was observed both when wins and losses were decided based on the cards' symbolic meaning in the game of rock-paper-scissors, (Experiment 3) or their numerical value (Experiment 1 & 2), and both when participants saw the actions from either a 1<sup>st</sup> or 3<sup>rd</sup> person perspective (Experiment 4). What was required was, however, that the participants' judgements referred to the currently observed action. The outcome-dependency of automatic imitation was only observed for judgments of the current player's actions. When participants made the same judgments from the perspective of the not-acting opponent, all effects were eliminated, even though the stimuli and judgments were otherwise identical (Experiment 4).

Together, these findings reveal that automatic imitation is best conceptualised as a hierarchical process that is guided by the valence of the outcome, such that only those actions are imitated that have positive outcomes. The outcome-dependency of automatic imitation challenges the idea of a simple bottom-up matching of observed kinematic information to the observer's motor repertoire, mediated perhaps by a specifically evolved mirror system (e.g., Iacoboni et al., 2001; Iacoboni, 2009) or due to sensorimotor learning of correlated motor and perceptual action features (e.g., Heyes, 2001, 2011). In such a view, both negative and positive action outcomes should elicit automatic imitation equally, especially as both types of outcome were not part of the observed action, but one of their randomly following distal consequences. Instead, our data link automatic imitation to the top-down control in goal-directed imitation in children and primates (Call & Carpenter, 2002; Gattis et al., 2002; Elsner, 2007). Children similarly do not imitate all actions, but specifically those that produce

successful outcomes (for a review, see Elsner, 2007), and even correct unsuccessful or erroneous action to their more effective counterpart (e.g., Corriveau et al., 2016; Carpenter et al., 1998; Meltzoff, 1995; Over & Gattis, 2010), similar to what was observed here for losing cards (Experiment 2).

While previous studies have shown that automatic imitation is guided by higher-level information such as the actor's goals (Liepelt, von Cramon & Brass, 2008), their typical behaviour (Bach et al., 2006; Tipper & Bach, 2011) or the action's match to the objects in the environment (Bach et al., 2010), such an outcome dependency has not been reported. Our data therefore supports hierarchical models of action cognition (Hommel et al., 2001; Adams et al., 2013; Grafton et al., 2007), which argue that action control is based on integrated, hierarchical representations that links the body movements that are carried out to the outcomes they produce. While it has been previously suggested that such integrated action representations are generated when children watch others' actions and in order to imitate them later (e.g., Elsner, 2007), these experiments are the first to suggest that similar integrated representations may also underlie automatic imitation in adults. The finding that only outcome evaluations of the observed actor – not the opponent – affected automatic imitation particularly supports this interpretation. It ties modulation of automatic imitation directly to the evaluation of this particular action – and the resulting integrated action representation, but not evaluative processes in general.

One problem with the experiments in the present chapter may be that there is no separation of motoric and spatial compatibility. The cards were always presented on the left or the right of the centre of the screen, such that motorically matching responses were always also spatially matching. Ruling out that the automatic imitation effects

reflect spatial compatibility effects, such as the well-established Simon (1969) effect, requires a new paradigm that allows for a separation of spatial and motoric codes. Such an experiment is described in Chapter 3.

### Chapter 3

Automatic imitation reflects the facilitation of responses that topographically match a task-irrelevant observed action (for a review see Heyes, 2011). For example, in one of the original demonstrations participants opened and closed their hands to respond to a colour cue (task) which was overlaid on images of hands opening and closing (task-irrelevant stimulus). Responses were initiated faster when this task irrelevant stimulus (e.g. an opening hand) matched the response (opening a hand) and slower when these dimensions were mismatching (closing a hand) (Stürmer et al., 2000). This facilitation of matching responses and has been replicated for a range of actions with different effectors, such as mouth actions (Leighton & Heyes, 2010), finger actions (Catmur et al., 2011; Brass et al., 2001; Brass et al., 2000), arm actions (Gowen et al., 2008; Kilner et al., 2007; Kilner, Paulignan, & Blakemore, 2003), hand actions (Craighero et al., 2002; Craighero et al., 1996; Craighero et al., 1997) and foot actions (Gillmeister et al., 2008; Bach et al., 2007). This facilitation of matching responses is generally thought of as primarily bottom-up driven, guided by a specialised mirror neuron system that automatically maps others' actions onto one's own body, bypassing any need for intentional control (Iacoboni et al., 1999) or higher order cognition (Aczel, Kekecs, Bago, Szollosi, & Foldes, 2015). Indeed, several studies have now shown that directing attention away from observed actions does not eliminate automatic imitation (e.g., Brass et al., 2001; but see Bach et al., 2007). Moreover, automatic imitation is elicited even when cognitive resources are occupied (Catmur, 2015), and when imitation conflicts with the participants' own goals (Cook, Bird, Lünser, Huck, & Heyes, 2011). Together, these findings provide evidence that the mere observation of an action facilitates motoric reproduction of the same action in an automatic fashion (for review and meta-analysis, see Cracco, Bardi, Desmet, Genschow & Rigoni et al, 2018).

Despite the evidence that action stimuli induce automatic imitation, several objections against the above interpretation of an automatic matching of observed actions to own responses have been put forth. One important objection is that automatic imitation could represent a special kind of stimulus response compatibility (e.g., Boyer, Longo, & Bertenthal, 2012). In this view, automatic imitation would only be another version of the well-known spatial compatibility effects, which describe the phenomenon that responses are faster if they occur on the same side as a stimulus (Simon, 1969).

To distinguish spatial from motoric compatibility, Brass et al. (2000) compared symbolic cues to spatial cues in an imitative compatibility experiment. They first presented moving hand stimuli in which either the middle or the index finger was raised with the numbers 1 and 2 presented centrally as the response cue. Participants were required to raise the appropriate finger according to the number that was presented. They found that the moving hand stimuli facilitated matching versus mis-matching responses, as expected. They then tested whether an imperative spatial cue would produce the same effect, by asking participants to respond to an 'x' symbol presented *on* the relevant fingernail on the moving or non-moving fingers. Again, participant's responses were facilitated by matching compared to mis-matching trials. To test whether the task was truly accessing automatic imitation, Brass et al (2000) then asked participants to respond in a non-imitative fashion, where they observed the finger raises as described in the previous two experiments, but the response required from them was a tapping motion, such that their actions did not kinematically match the actions they observed. This third experiment revealed a decrease in the facilitation effect of the observed movement and the authors concluded that the motoric similarity between observation and execution was the cause of this effect, not the overlap of its spatial features. Nevertheless, matching imitative trials were also matching spatially due to the

nature of human stimuli (matching stimuli and response finger matched anatomically as well as being presented on the left or right), so that it was still possible that some parts of the effects were spatially (rather than motorically) mediated.

Other SRC paradigms have tried to tease kinematic and spatial components apart by independently varying whether stimuli and responses matched or mismatched spatially or motorically (i.e. spatially matching and motorically matching; spatially matching and motorically mismatching; spatially mis-matching and motorically matching; spatially mis-matching and motorically mismatching) (e.g. Catmur et al., 2011; Chong et al., 2009; Bertenthal et al., 2006; Heyes et al., 2005; Brass et al., 2001), or by controlling the spatial component in the stimuli. For example, the procedure used by Stürmer and colleagues (2000), as reported above, revealed the same imitation facilitation if the task-irrelevant action hand stimuli were presented orthogonally to response movements (up/down vs left/right movements), thereby eliminating spatial correspondences while keeping imitative relationships intact (Heyes et al., 2005). These experiments revealed that automatic imitation depends upon the topographical or configural aspects of the observed action stimuli rather than their spatial configuration in relation to its external position. Nevertheless, in almost all these studies controlling for spatial compatibility *reduced* the overall compatibility effect, but did not *eliminate* it, suggesting that spatial compatibility form part of the effects.

These considerations raise the possibility that the outcome-dependency we demonstrated for automatic imitation in Chapter 2 could also reflect such spatial compatibility instead of motoric compatibility effects. In the experiments of Chapter 2, the target cards that participants responded to with left and right finger key presses were always presented to the left or the right of the central card, and were reached to with hands on the left or right of the screen. Whilst the automatic imitation effect was

modulated by the outcome of the action, as predicted, it is therefore unclear whether it affects the motoric or spatial compatibility of observed actions and responses. Chapter 3 therefore developed another experimental paradigm in which participants again evaluated the valence of the outcomes of observed actions, but in which it could be varied independently whether the resulting responses matched the actions spatially and/or motorically. This made it possible to disentangle whether the outcome modulation observed in Chapter 2 reflects the spatial or motor similarity of observed actions and responses.

### **Experiment 1b**

Experiment 1b teased apart whether observed action outcomes affect the spatial or motoric components of automatic imitation. Participants observed a model hand from an allocentric perspective that was initially in a neutral position near an object and would then either grasp the object or withdraw from it. It was varied, between participants, whether the object was positioned on the left or the right of the screen such that reaches would move from the middle of the screen to the left or to the right, and vice versa for withdrawals (see Figure 2b). Half of the objects were safe to grasp (orange, wine glass) whilst the other half would cause pain if grasped (cactus, broken wine glass). Participants were asked to decide if the action was appropriate to the object and would produce a positive outcome (grasping a neutral object, avoiding a painful one) or inappropriate and produce a negative outcome (grasping a painful object, withdrawing from a neutral one).

Crucially, as in prior work (Longo & Bertenthal, 2009), this design independently manipulated whether the responses that participants had to make were motorically or spatially matching with the observed action, or both. Participants indicated their outcome judgments by themselves moving a joystick forwards and backwards in the same horizontal plane as the observed action, with the assignment of positive and negative judgments to these movements counterbalanced between participants (See Figure 1b). This forward or backwards movement therefore mapped onto the reach and withdrawals they observed (motoric congruency). Importantly, the joystick was positioned parallel to the screen so that these forward and backward movements also corresponded with movements to the left or right, such that the spatial locations matched or mismatched the observed movements to the left or right (spatial congruency). This created an experimental setup in which the outcome of an action was either positive or negative, and participants indicated this judgment with responses that could either spatially and or motorically match or mismatch the observed actions. It therefore made it possible to disentangle whether automatic imitation is outcome guided, and whether this outcome guidance specifically impacts the motoric, rather than spatial, compatibility of observed and executed actions.

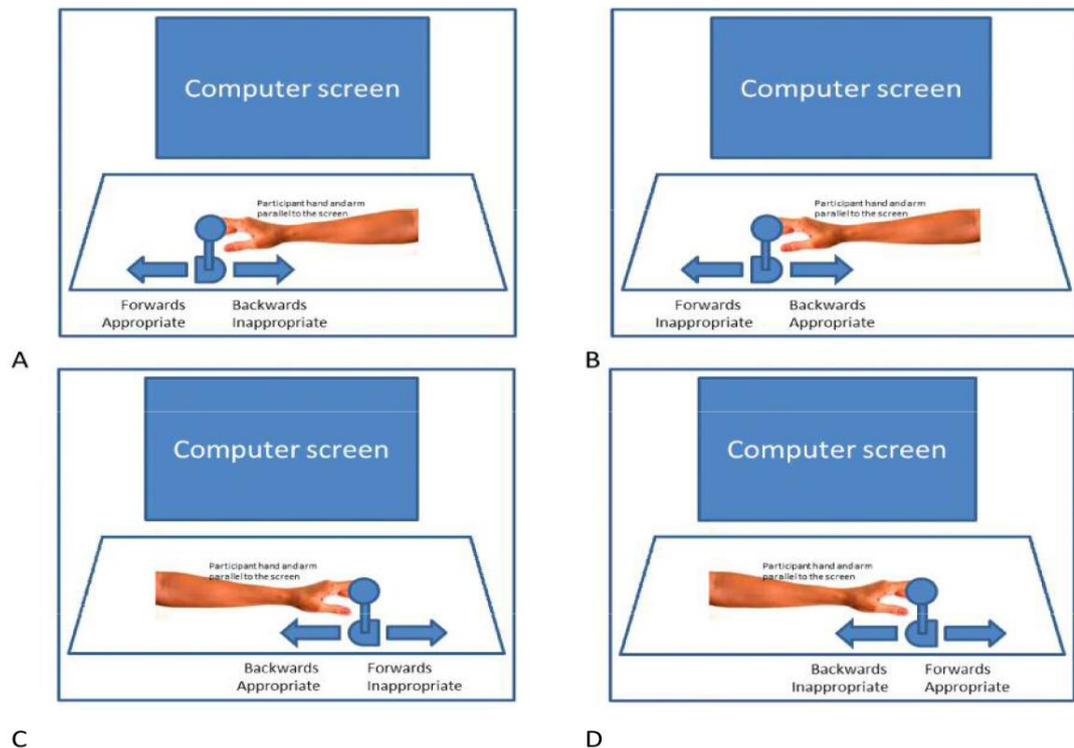
## **Method**

*Participants.* 70 participants took part in the experiment (age range from 18 to 45, mean age = 23, 17 males, 10 left-handed). They were recruited by the Plymouth University, School of Psychology participation system, which includes (non-academic) staff, students and members of the public. Participants were given a cash reward of £4 or course credit for participation. They were given an information sheet, which explained

the experiment and procedure, as well as their right to withdraw at any time, and gave informed written consent. No personally identifying information was collected. Following the experiment, participants were fully debriefed in writing, and allowed the opportunity to ask questions as well as being given contact details for any further queries they may have. The experiment was approved in accordance with the ethical guidance of Plymouth University and the Declaration of Helsinki. Eight participants were excluded from the analysis for making more than 20% of errors, leaving 62 data sets for analysis. This provides 80% power to detect effects of  $d > .36$ . The effect size of the relevant effect in the experiments in Chapter 2 ( $d = .45$ ) confirms effect sizes are likely larger.

*Apparatus and stimuli.* The experiment was conducted in a laboratory room with participants seated in separate sound proofed cubicles, so that they could complete the task without being disturbed. Participants filled out a paper questionnaire which contained the images of common household objects that they would later see in the experiment. They rated the extent to which they felt that the objects were either painful to touch or not on a 5-point Likert scale (Appendix A). These images included: an intact glass, a broken glass, a cactus and an orange. Participants were also asked to what extent the rating they gave was based on personal experience, again, on a 5-point Likert scale.

The experimental stimuli were presented on a 21-inch monitor with a resolution of 1024 x 768 pixels, which was arranged at approximately shoulder height of the participants, 60 cm away. Stimulus presentation was controlled by E prime 2.0. Participants responded to the stimuli using a joystick by either pushing it forwards or pulling it backwards (See figure 1b).

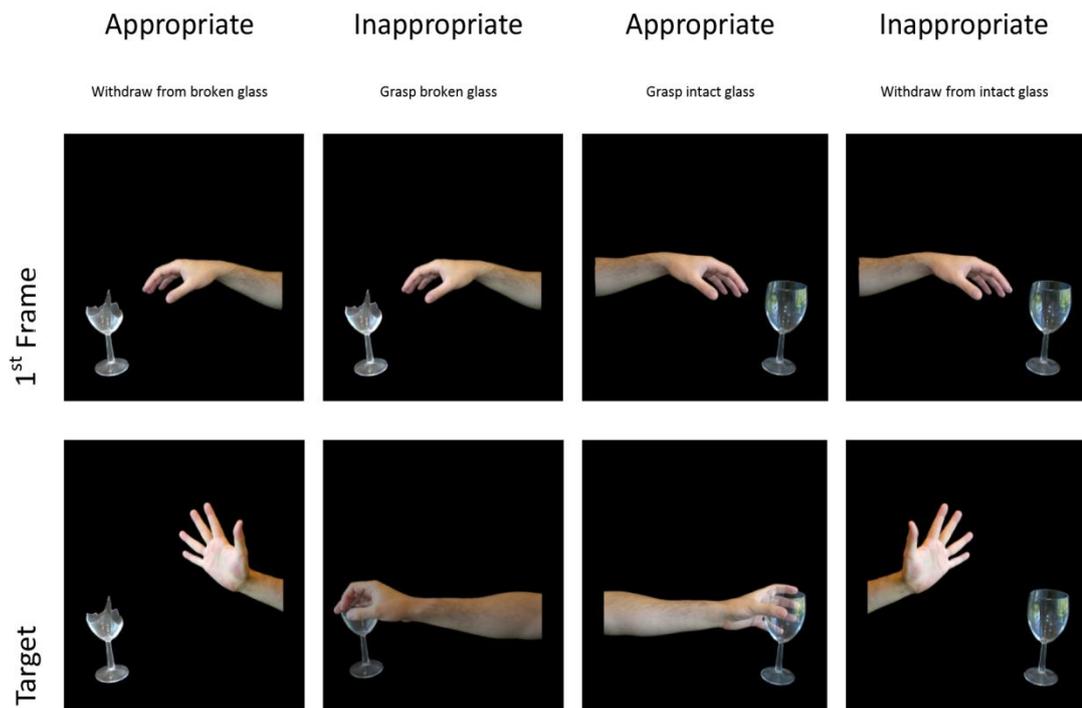


**Figure 1b:** Layout combinations of the experiment in each cubicle: A&B show participants using their right hand whilst C&D shows participants using their left hand; A&C show participants pushing the joystick towards the left for appropriate responses and towards the right for inappropriate responses whilst B&D show participants pushing the joystick towards the right for appropriate responses and pulling towards the left for inappropriate responses; A&D show participants pulling backwards for inappropriate actions and pushing the joystick forwards for appropriate actions whilst B&C show participants pulling backwards for appropriate actions and pushing the joystick forwards for inappropriate actions.

Participants evaluated the outcomes of observed actions with joystick movements. The joystick was attached to the table, so that it could not be moved and was positioned so that it would only move in the horizontal plane, parallel to the monitor. Forwards and backwards motions would therefore require a left or right movement across the body rather than towards or away from the computer screen. Printed arrow labels were always placed at either side of the joystick with the words 'Appropriate' and 'Inappropriate' in clear view of the participant to prevent confusion (counterbalanced between

participants). Participants were requested to keep their arm parallel to the screen during the experiment. Participants were randomly assigned to use a specific hand to respond. Counterbalancing of hand used and joystick movement required for positive/negative outcome evaluations resulted in four different response assignments that were varied between participants (A—right handed with a forwards response for “appropriate” actions, B—right handed with a backwards response for “appropriate” actions, C—left handed with a forwards response for “Inappropriate” actions, D—left handed with a backwards response for “Inappropriate” actions).

The stimulus consisted of sixteen two-frame action sequences. Each sequence started with an initial, neutral image that showed either a right or left hand ready to reach in the middle of the screen and a potential target object on the left or right. It then switched to the target image, without any SOA, which showed the hand either grasping the object, or withdrawing from it (see figure 2b). There were four objects, two of which (broken wine glass or cactus) were painful to grasp and two which (intact wine glass and orange) were safe to grasp.



**Figure 2b:** Examples of experimental stimuli for each combination of space, movement and appropriateness showing frame 1 above and the target frame below.

*Design & Procedure.* All participants had the task to report, by pressing the joystick forwards or backwards, whether an observed action was appropriate or inappropriate. Participants first completed ten practice trials selected at random from the experimental stimuli list, and then two experimental blocks. Each experimental block consisted of random without replacement selection of each of the sixteen stimuli. This repeated thirteen times within each block, resulting in 208 experimental trials per block (416 in total).

Each trial began with a blank screen presented for 800 ms. A fixation cross appeared for 300 ms which was then followed by another blank screen for 300 ms. The first (neutral) frame, depicting a hand in neutral position near an object, was presented for 500 ms followed by the target stimulus, showing the hand either reach or withdrawing from the

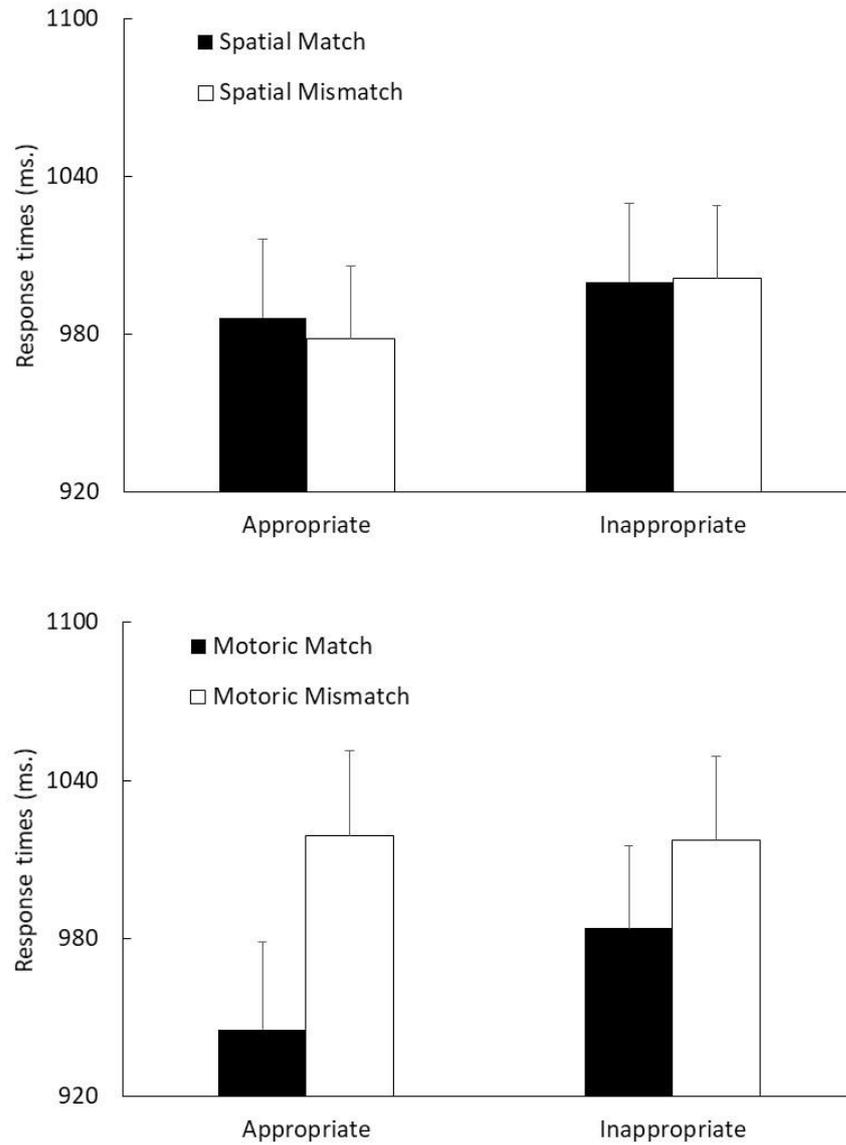
objects (see figure 2b for example). As neutral and target action image followed each other without any gap, this created the impression of apparent motion (Wertheimer, 1912). If the action shown in the target frame was appropriate, i.e. the hand withdrew from a painful object or grasped an object that would cause no pain, participants pushed the joystick in the designated direction (see figure 3b). If the action shown was inappropriate i.e. the hand grasped a painful object or withdrew from an object that would cause no pain, participants produced the opposite action with the joystick. to which participants were given infinite time to make a response. The next trial started after participants made their response.

## Results

The response time data (Figure 3b) was analysed using a three factor, repeated measures ANOVA with the factor Appropriateness (appropriate: withdrawing from a painful object or grasping a safe object; inappropriate: grasping a painful object or withdrawing from a safe object), Motor Compatibility (motorically matching: pushing a joystick forward when seeing a reach or backwards when seeing a withdrawal; motorically mismatching: pushing a joystick forward when seeing a withdrawal or backwards when seeing a reach forward) and Spatial Compatibility (spatially matching: pushing the joystick to the right when seeing an action towards the right or to the left when seeing an action to the left; spatially mismatching: pushing the joystick to the right when seeing an action towards the left or to pushing it to the left when seeing an action to the right).

The results of the ANOVA revealed no main effect of Spatial Compatibility,  $F(1, 58) = .281, p = .598$ , and no interaction of Spatial Compatibility with Appropriateness,  $F(1,$

58) = .445,  $p=.507$ . However, as predicted from the idea that automatic imitation captures the kinematic features of the observed action, the ANOVA revealed a main effect of Motor Compatibility  $F(1, 58) = 18.132$ ,  $p < .001$ ,  $\eta^2 = .24$ . Participants were faster to produce a motorically matching response ( $M=950$  ms) than a motorically mismatching response ( $M=1012$  ms). Moreover, as in Chapter 2, this effect was further qualified by an interaction of Motor Compatibility and Appropriateness,  $F(1,58)= 5.53$ ,  $p=.02$ ,  $\eta^2 =.08$ . As can be seen in Figure 3b, the speed up of matching actions was only present for actions with positive outcomes (i.e. reaches to safe objects and withdrawals from painful objects) but not those with negative outcomes, fully replicating the experiments in Chapter 2.

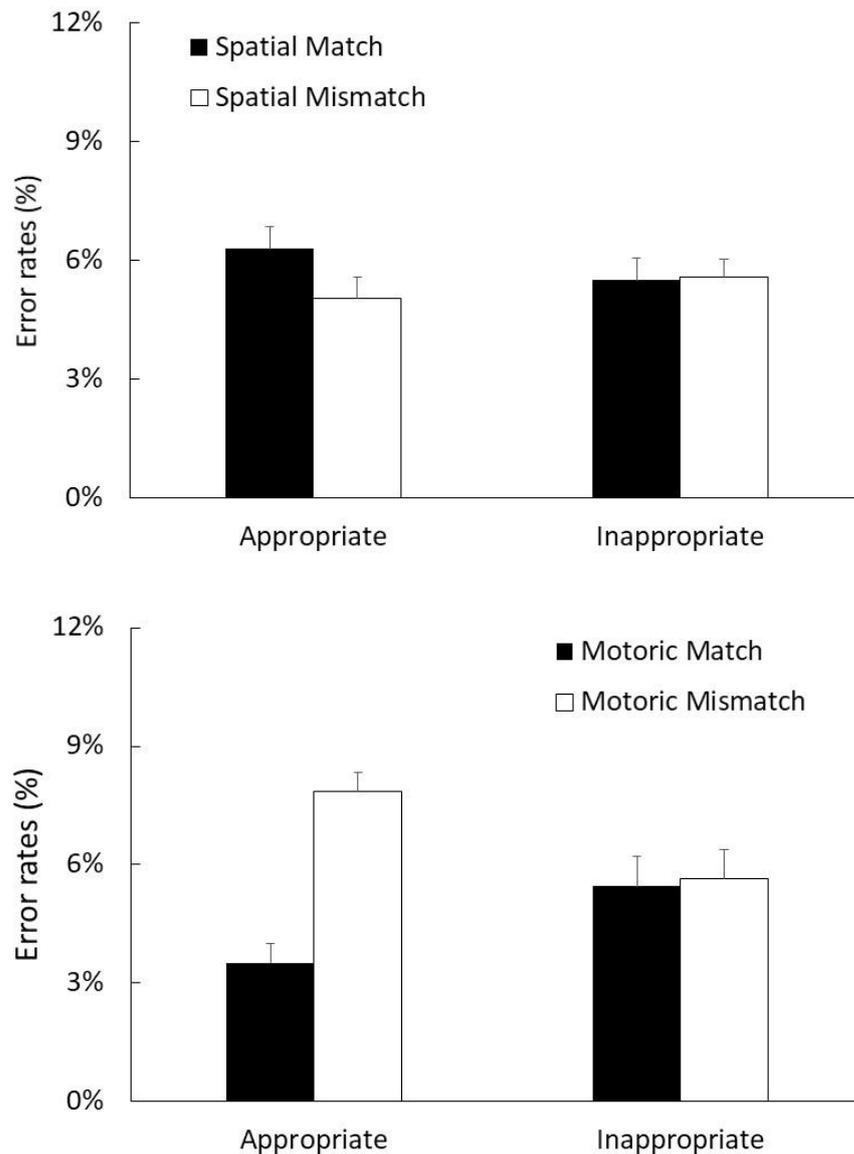


**Figure 3b:** Reaction times in Experiment 1b: The top panel shows spatial compatibility effects and the bottom panel shows motoric compatibility effects. In each panel, the left two bars show responses made after observing an inappropriate action that was appropriate and the right bars show responses after observing an inappropriate action. The black and white bars show responses that either matched or mismatched the spatial (left panel) or motor (right panel) features of the stimuli. Error bars show the standard error of the mean.

None of the other, unpredicted effects reached significance, especially when it is considered that unpredicted effects in an ANOVA are subject to alpha inflation and therefore must be interpreted against a more stringent (Bonferroni-corrected) threshold (e.g. Cramer, 2016). In particular, there was no effect of Appropriateness,  $F(1, 58) =$

3.367,  $p = .07$ , no interaction of Spatial Compatibility and Motor Compatibility,  $F(1, 58) = 3.478$ ,  $p = .067$ , and no three-way interaction,  $F(1, 58) = .026$ ,  $p = .872$ .

Analysis of the error rates with the same ANOVA revealed a similar pattern as the analysis of the response times. A main effect was found for Motor Compatibility,  $F(1, 58) = 15.479$ ,  $p < .000$ ,  $\eta^2 = .211$ , which again interacted with Appropriateness,  $F(1, 58) = 10.292$ ,  $p = .002$ ,  $\eta^2 = .151$ . Participants made fewer errors during motorically matching responses than motorically mismatching responses, and this difference was larger for actions with positive outcomes (See Figure 3b). While the error analysis also revealed a main effect of Spatial Compatibility,  $F(1, 58) = 4.11$ ,  $p = .047$ ,  $\eta^2 = .066$ , which interacted with Appropriateness  $F(1, 58) = 4.67$ ,  $p = .035$ ,  $\eta^2 = .075$ , it should be interpreted with caution before being replicated, as it only just passed the alpha of .05 and was in the opposite direction than predicted. Participants made *fewer* error for responses that were spatially mismatching with the observed action, again specifically for actions with positive outcomes. There were no further main effects or interactions (Appropriateness,  $F(1, 58) = .067$ ,  $p = .79$ ; Spatial Compatibility by Motor Compatibility,  $F(1, 58) = .093$ ,  $p = .88$ ; Appropriateness, Spatial compatibility by Motor Compatibility,  $F(1, 58) = 2.128$ ,  $p = .15$ ).



**Figure 4b:** Proportion of errors Experiment 1b: The top panel shows spatial compatibility effects and the bottom panel shows motoric compatibility effects. In each panel, the left two bars show responses made after observing an inappropriate action that was appropriate and the right bars show responses after observing an inappropriate action. The black and white bars show responses that either matched or mismatched the spatial (left panel) or motor (right panel) features of the stimuli. Error bars show the standard error of the mean.

## Discussion

Experiment 1b shows, like the studies in Chapter 2, that observed action outcomes modulate automatic imitation. These data reveal that higher-level representations of the value of an action's outcomes affect automatic imitation, such that only those actions with positive outcomes produce a tendency to respond similarly. Importantly, the current study independently manipulated the spatial and motoric compatibility of observed actions and responses. The results showed that the above interaction reflected specifically the kinematic – but not the spatial – features of the observed action. Thus, after viewing an action with a positive outcome, participants found it easier to move their own hand forwards or backwards when they had just seen the hand on the screen perform a similar forward/backward movement. In contrast, the analysis revealed no such effect for the spatial matching of observed actions and responses. If anything, observing an appropriate action induced a negative spatial compatibility effect such that participants found it easier to move their hand in the opposite to the action they observed.

These data show, first, as suggested by others (Longo et al., 2009; Wohlschläger et al., 2003; Liepelt et al., 2010), that automatic imitation cannot just be explained in terms of the spatial features of the observed actions but draws upon motoric or kinematic features. Second, it shows that the outcome dependency observed in Chapter 2 is a replicable phenomenon that extends to the type of reaching actions seen here. Third, and most importantly, it shows that the outcome modulation observed in Chapter 2 specifically affects the similarity of one's own responses with the motoric components of the observed action, not its spatial features.

An open question is on what level the action's kinematic features are encoded. It is possible that the facilitation for matching (versus mis-matching) appropriate actions may

not reflect the encoding of the action's motoric features (Kornblum, Hasbroucq & Osman, 1990), such as an arm moving forwards or backwards, but more abstract spatial codes that reflect the hands' movement towards or away from the goal object, that is, more general representations of the action as approach and avoid. Indeed, several studies suggest that automatic imitation sometimes occurs in such an object-centred reference frame (Aicken, Wilson, Williams, & Mon-Williams, 2007). Viewing lifting or tapping fingers produces the same compatibility effects than when viewing the same actions using a pen, and participants responded similarly when viewing an opening or closing hand or dots moving away or toward each other (Jansson, Wilson, Williams & Mon-Williams, 2007). The implication is that automatic imitation is not unique to the observation of biological motion but could reflect the encoding of such abstract changes in a spatial reference frame.

To tease apart how the kinematic features of the actions are encoded in the current experiment, a second experiment was devised which replaced the human stimuli with an inanimate object, but which required exactly the same judgments and responses of the participants.

### **Experiment 2b**

In Experiment 2b, participants were tested using the same paradigm as in Experiment 1b but the hand was replaced with an image of a bubble, which approached or withdrew from the same household objects. Participants' were told that the bubble moved through an obstacle course, and that half of the objects were safe for the bubble to touch (orange, wine glass) whilst half would cause it to burst (cactus, broken wine glass). Participants were

again asked to decide if the bubble moved appropriately (bubble touches a neutral object, avoids a dangerous one) or an inappropriately (the bubble touches a dangerous object or avoids neutral one) for its safety relative to the given object. To make these judgments, participants moved their hands in the same or different spatial direction to that produced by the bubble by moving a joystick left and right, and these movements either matched the bubble's forwards or backwards movement in the given reference frame.

If participants encoded the actions kinematically in Experiment 1b, motoric compatibility effects should now be reduced, and not modulated by outcome. Instead, results may now reveal a 3<sup>rd</sup>-person spatial encoding of the observed movements. In contrast, if people encoded the movements as more abstract approaches or avoidance of obstacle, then the same effects as in Experiment 1b should be observed.

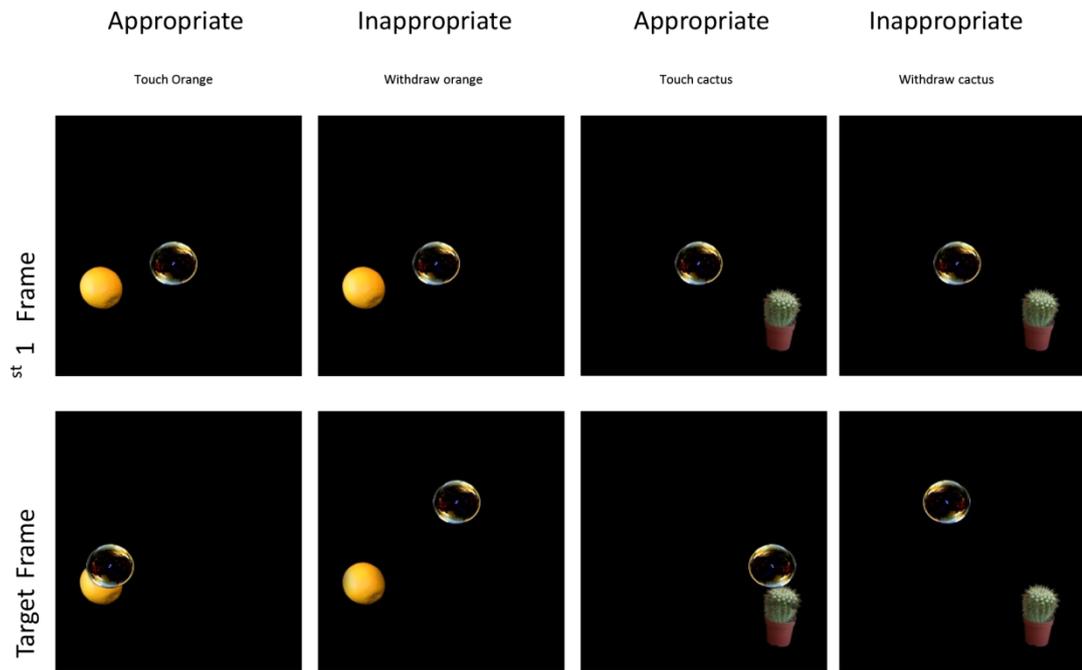
## Method

*Participants.* 69 participants were tested for the experiment, (age range from 18 to 45, mean age = 23, 5 males, 7 left-handed). They were recruited in the same way as in Experiment 1b. Five participants were not considered for analysis because they made more than 30% of errors. The final sample size of 64 provides 80% power to detect effect sizes larger than  $d = .31$ . Previous experiments suggested that effect sizes are likely larger.

*Apparatus, stimuli and procedure.* Participants completed the same paper questionnaire as in Experiment 1b. They rated the extent to which they felt that the objects used in the experiment were either painful to touch or not on a 5-point Likert scale (Appendix A).

Apparatus and stimuli were identical to Experiment 1, but the images of the reaching hands were replaced with bubbles (Figure 5b). Thus, eight sets of two images were produced for each bubble (right and left to the goal object in the neutral frame). The initial image was of a bubble in neutral position near one of four objects of Experiment 1b. The target image was of the bubble either touching the object, or moving away from it, in the same position as the hand was in in Experiment 1b. Combining both images without temporal gap created the impression of the bubble's apparent motion (Wertheimer, 1912) towards or away from objects.

During the instructions phase of the experiment, participants were told that they were inspecting special fans in a 'bubble making factory'. The bubbles needed to travel from one end of the factory to the other in the safest way, and in the quickest time possible. The participants were advised that two of the objects (broken wine glass or cactus) were dangerous to the bubble, making it burst. The other two objects (intact wine glass and orange) were safe for the bubble to touch and it would just bounce off. If the action shown in the scene was appropriate and produced a positive outcome, i.e. the bubble withdrew from or avoided a dangerous object or touched an object that would not cause it to burst, participants pushed the joystick in the designated direction (again forward or backward in the horizontal plane before the monitor). If the action shown was inappropriate i.e. the bubble touched a dangerous object or withdrew from or avoided an object that would not cause it to burst, participants responded with the opposite movement of the joystick. Importantly, the bubble in the stimuli was positioned so that it was in exactly the same place as the contact point of the hand in Experiment 1b (see figure 5b for examples). This meant that the movement and distance travelled would match exactly for both experiments. The timings for presentation of stimuli exactly matched Experiment 1b.

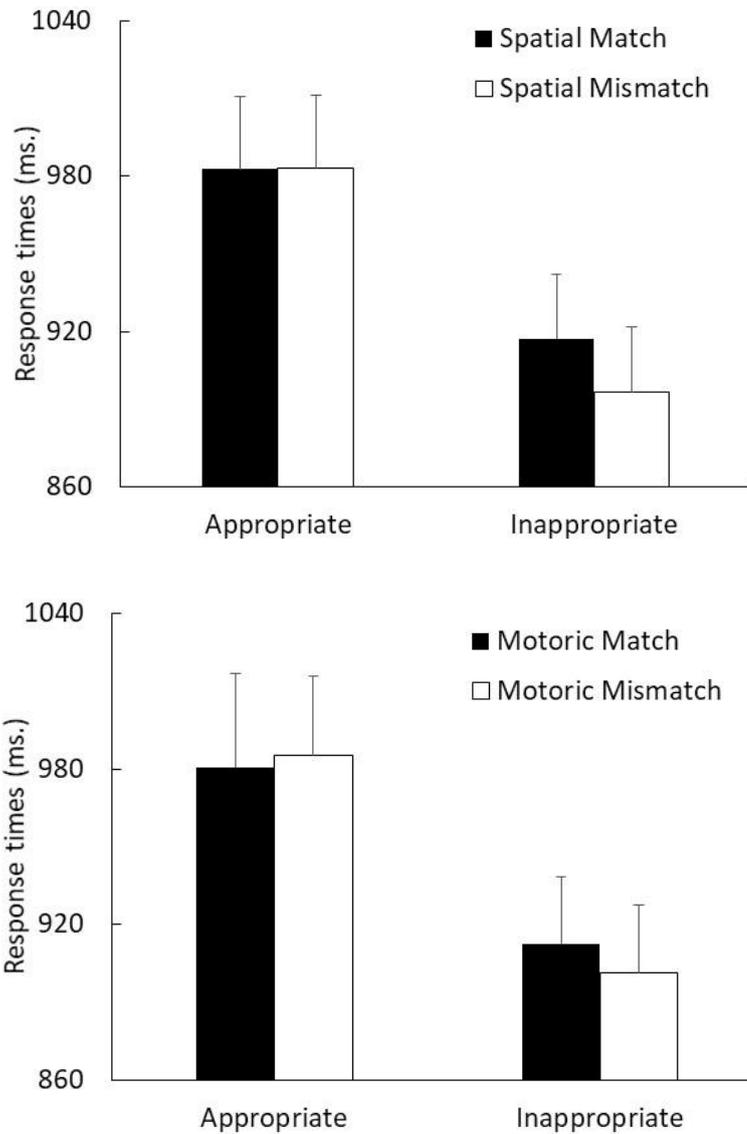


**Figure 5b:** Examples of experimental stimuli for each combination of space, movement and appropriateness showing frame 1 above and the target frame below.

## Results

As in Experiment 1b, the Response times (Figure 6b) was analysed using a three factor, repeated measures ANOVA with the factor Appropriateness (appropriate: moving away from a painful object or grasping a safe object; inappropriate: moving towards a painful object or withdrawing from a safe object), Motor Compatibility (motorically matching: pushing a joystick forward when seeing a movement towards an object or backwards when seeing a movement away from an object; motorically mismatching: pushing a

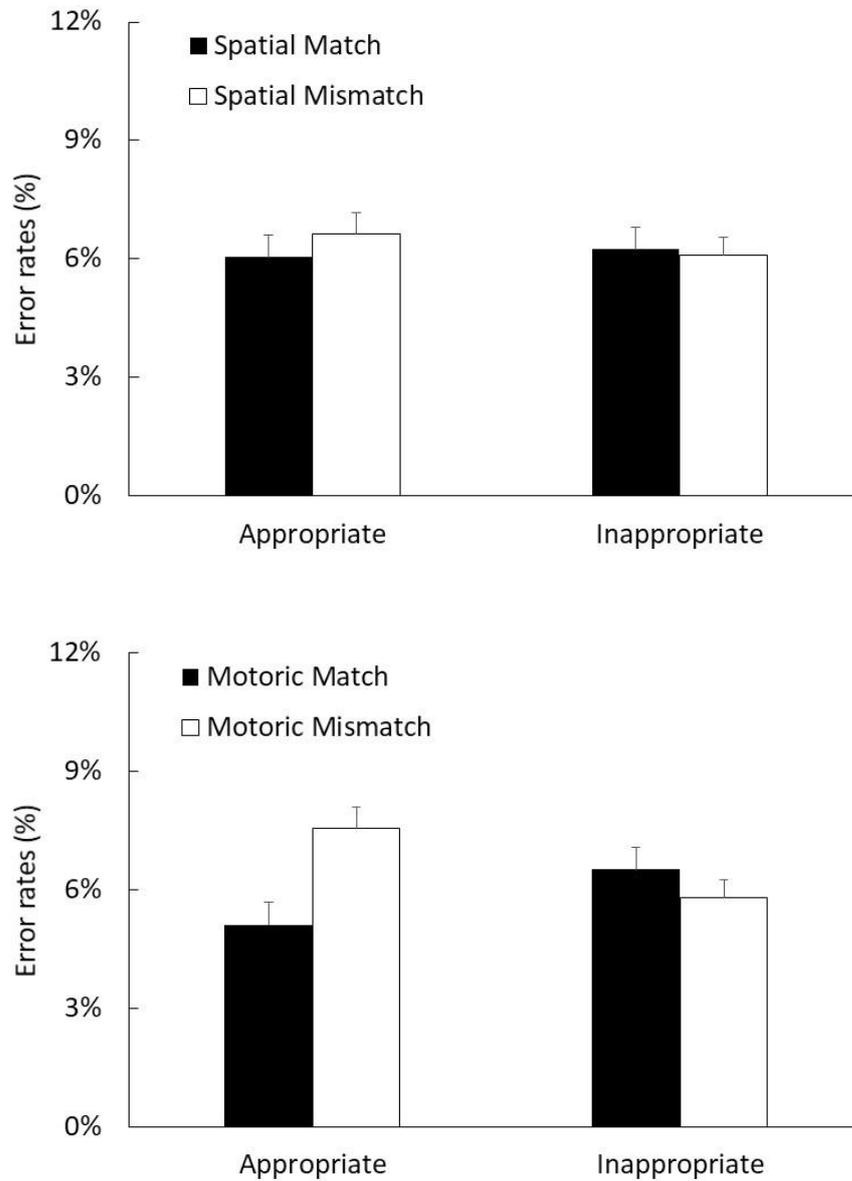
joystick forward when seeing a movement away from an object or backwards when seeing a movement towards an object) and Spatial Compatibility (spatially matching: pushing the joystick to the right when seeing a movement towards the right or to the left when seeing an movement to the left; spatially mismatching: pushing the joystick to the right when seeing a movements towards the left or to pushing it to the left when seeing a movement to the right).



**Figure 6b:** Reaction times in Experiment 2b: The top panel shows spatial compatibility effects and the bottom panel shows motoric compatibility. In each panel, the left two bars show responses made after observing an action that was appropriate. The right two bars show responses made after observing an action that was inappropriate. The black and white bars show responses that either matched or mismatched the spatial (left panel) or motoric aspects of the stimuli (right panel). Error bars represent standard error of the mean.

The ANOVA revealed a main effect of Appropriateness  $F(1, 60) = 101.465, p < .001, \eta^2 = .628$ , with participants making appropriate judgements more slowly than inappropriate judgments. It revealed no main effect of Spatial compatibility  $F(1, 60) = 2.247, p = .139$  or Motor Compatibility  $F(1, 60) = .107, p = .745$ . Appropriateness did neither interact with Spatial Compatibility  $F(1, 60) = 2.627, p = .11, \eta^2 = .042$ , nor with Motor Compatibility  $F(1, 60) = .544, p = .464$ .

The analysis of the error rates (Figure 7b) revealed no main effects of Spatial Compatibility  $F(1, 60) = .325, p = .571$ , Motor Compatibility  $F(1, 60) = 2.364, p = .129$  or Appropriateness,  $F(1, 60) = .074, p = .786$ . Appropriateness did not interact with spatial compatibility  $F(1, 60) = 1.008, p = .32$ . As in Experiment 1b, however, there was an interaction between Appropriateness and Motor Compatibility  $F(1, 60) = 7.984, p = .006, \eta^2 = .117$ . When viewing a bubble movement with positive outcome, participants made more errors when making a movement that motorically mismatched this movement than when it matched. This difference was, if anything, reversed when viewing bubble movements with negative outcomes. Spatial Compatibility did not interact with Motor Compatibility  $F(1, 60) = .822, p = .368$ . No three-way interaction was observed,  $F(1, 60) = .000, p = .983$ .



**Figure 7b:** Proportion of errors: Proportion of errors Experiment 2b: The left panel shows spatial compatibility effects and the right panel shows motoric compatibility effects. In each panel, the left two bars show responses made after observing an action that was appropriate. The right two bars show responses made after observing an action that was inappropriate. The black bars show responses that matched either the spatial (left panel) or motor aspects of the stimuli (right panel). The white bars show responses that did not match either the spatial (left panel) or motor aspects of the stimuli (right panel).

A crucial question is whether the spatial or motoric compatibility effects differ between experiments. We therefore compared the main effects of Spatial and Motor Compatibility, as well as their interactions with Appropriateness, with a combined ANOVA that also included the between-experiments factor Experiment.

For brevity, only the interactions of theoretical interest are reported. Analysis of response times revealed no interaction of Spatial Compatibility and Experiment,  $F(1, 118) = .435, p = .511$ , and neither a three-way interaction of Appropriateness, Spatial Compatibility and Experiment  $F(1, 118) = 2.412, p = .123$ . However, it revealed the predicted interaction of Motor Compatibility and Experiment,  $F(1, 118) = 11.102, p = .001, \eta^2 = .086$ , showing that, overall, motoric compatibility effects were larger when participants judged the movements of (animate) hands compared to (inanimate) bubbles. There was no three-way interaction of Appropriateness, Motoric Compatibility, and Experiment  $F(1, 118) = .539, p = .464$ .

The analysis of error rates revealed the predicted interactions between Spatial compatibility and Experiment,  $F(1, 118) = 2.751, p = .10, \eta^2 = .023$ , and between Appropriateness, Spatial Compatibility and Experiment,  $F(1, 118) = 4.685, p = .033, \eta^2 = .038$ . Thus, while viewing hand movements induced negative spatial compatibility effects, facilitating movements in the opposite direction, specifically after positive outcomes, this effect was abolished when the same movements were performed by inanimate bubbles.

There also was a marginally significant interaction of Motor Compatibility and Experiment,  $F(1, 118) = 2.865, p = .093, \eta^2 = .024$ , which was, however, not qualified by a three-way interaction of Appropriateness, Motor Compatibility and Experiment,  $F(1, 118) = .306, p = .581$ . Thus, as in the response time analysis, while the amount of Spatial

Compatibility and its modulation by Appropriateness *increased* in the bubbles experiment, there was an overall decrease in motoric compatibility effects.

## **Discussion**

Experiment 2b tested whether the automatic imitation effects of Experiment 1b – and the observed modulation through action outcomes – could also be replicated when participants observed the movements of an inanimate object. The results were mixed. On the one hand, overall measures of automatic imitation of the action's kinematic features were consistently reduced when participants observed bubble, as opposed to hand movements. Viewing bubbles move forward or backwards towards or away from an object did not generally speed up similar forward or backward joystick movements. This reduced effect is similar to previous investigations showing that automatic imitation is generally reduced for computer generated hands as opposed to photographic human hand actions (Shea, 2009), and for movements seen to be unintentional compared to intentional, even if the stimuli themselves are identical (Longo et al., 2008). It therefore confirms that automatic imitation, in this paradigm, reflects an encoding of the action's kinematic features, rather than just an abstract representation of approach or avoiding objects.

Strikingly, however, at least in the error rates, the outcome modulation of automatic imitation was still observed, even if automatic imitation effects themselves were reduced. This suggests that outcome evaluation itself – whether seeing a movement produces a positive or negative outcome for the agent – can induce a goal directed mode

of processing, and, perhaps, cause the seen movements to be evaluated teleologically: as moving towards and away from obstacles. Our data suggest that as soon as this teleological encoding of observed movements is present even for inanimate objects, then the outcomes these movements produce either induce a stronger tendency to imitate (in the case of positive outcomes) or to not imitate the movement (in the case of negative outcomes).

## **General Discussion**

This chapter described two experiments that tested whether automatic imitation is outcome dependent (e.g. Wohlschläger et al., 2003), whether it can be separated from spatial compatibility (e.g. Simon., 1969) and whether it specifically reflects the kinematics of human movements, compared to that of inanimate objects.

The data confirm, first, that automatic imitation is outcome dependent. Participants observed actions which either had positive or negative outcomes (by way of an interaction between a hand and a safe or painful object). Participants responded with a movement that either motorically or spatially matched or mismatched the observed action and to stimuli which showed the actions of a person (Experiment 1) or of a non-human object (Experiment 2). In both experiments, the actions' outcome modulated automatic imitation, such that actions with positive outcomes (approaching a safe object, withdrawing from a dangerous one) produced stronger automatic imitation effects than actions with negative outcomes (withdrawing from a safe object, approaching a dangerous object). The present experiments therefore replicate the results

of Chapter 2 in a new paradigm and with new stimuli. They add to the growing consensus that automatic imitation can be thought of as goal directed, similarly to children's goal directed imitation (e.g. Elsner et al., 2003; Nielsen et al., 2011; Southgate et al., 2009).

Second, these experiments allowed effects of kinematic versus spatial compatibility to be disentangled. In the previous experiments (Chapter 2), whilst automatic imitation was also affected by outcome information, this effect could not be separated from other forms of stimulus-response compatibility. The results of the present experiments show that the outcome modulation affected specifically the kinematic encoding of the observed actions as forward and backwards towards or away from objects (from the actor's perspective), rather than as left and right (from the participants' perspective). In Experiment 1b, if anything, outcome modulated spatial compatibility effects in the opposite manner: for actions with positive outcomes, participants responded more quickly with spatially mismatching rather than matching responses. Thus, at least in the experiments presented here, action outcomes specifically modulated the imitation of the action's kinematic (forward/backwards) components, rather than its spatial (left/right) organisation. It is therefore different from Simon-based (Simon, 1969) spatial compatibility and tied to representing the action from the actor's point of view as forward/backwards movement.

Finally, the experiments showed that automatic imitation in general, specifically the imitation of the action's kinematic components, is tied to the observation of human (animate) motions. Automatic imitation effects were generally reduced for the observation of movements of inanimate bubbles, even though the experiments went to great lengths to make sure both the task and stimuli matched as closely as possible. For example, the bubbles in Experiment 2b were presented in the same coordinates and

travelled the same distances as the hands in Experiment 1, and we gave participants an elaborate back story so that they were able to view the movements of the bubble in an as meaningful way as the movements of the hand. These results therefore add to previous reports that automatic imitation is stronger when observing biological, intentional actions (e.g., Kilner et al., 2003) compared to unintentional ones, even if this difference is just implied by the instruction while stimuli were identical (Longo et al., 2009). However, in contrast to the current experiments, these prior studies were not able to link these modulations specifically to the imitation of the action's kinematic rather than spatial components.

What was striking that while viewing bubbles (as opposed to hands) reduced overall automatic imitation, it seemed to leave its modulation by outcome relatively unaffected. The analysis of the error rates showed that even if participants judged the outcome of bubble movements, they were more prepared to make a similar forward/backward movement in, if the seen bubble movement had a positive outcome, compared to a negative one. This suggests that evaluating movements as goal directed can, by itself, induce a kinematic action coding, and its evaluation by outcome. In other words, these data suggest that even when viewing inanimate objects people can “embody” their movements, as long as these movements are evaluated in an outcome-based manner.

These findings link the present automatic imitation task to findings in biological motion perception in children. Even very young children can see inanimate object movements as goal directed, if these movements show features of intentional movement, such as avoidance of obstacles or a speed up towards a goal (e.g. Gao, McCarthy, & Scholl, 2010)). They also link to findings in adults showing that participants embody (i.e. take the perspective) of inanimate objects in Heider and Simmel-like displays (Heider & Simmel, 1944), if they consistently behave in a meaningful way and follow intentional

movement patterns (Zwicker & Mueller, 2010). We speculate that our (top-down) instructions to be “bubble safety officers” and evaluate the bubbles in a positive or negative way may have induced a similar “intentional stance” (Dennett, 1989) and induced a tendency to copy their positive but not their negative actions.

In more general terms, the outcome dependency of automatic imitation observed here provides a challenge to models which describe it in terms of a bottom-up matching of the kinematic information during observation with own action possibilities of the observer. Neither theories embracing associative learning of contingencies between vision and action (Heyes, 2010) nor direct-matching by way of specialist mirror function can account for the top-down influences observed in these experiments (Rizzolatti et al., 2008). In these views, both positive and negative action outcomes should have facilitated compatible responses equally. Instead, this data could be better explained by accounts that integrate top-down control in goal-directed imitation (e.g., Elsner, 2007). In such views, automatic imitation can be described similarly to goal-directed imitation in children and primates which show similar positive outcome-dependence. For example, children only imitate actions which produce successful outcomes and will even correct errors in action observations, producing the intended successful outcome rather than that which was observed (Hauf et al., 2004; Carpenter et al., 2005; Carpenter et al., 1998). Thus, either actions that are positive inspire the observer to imitate the actor, or actions that are negative cause inhibition of the observed action in the participant.

One problem of the current studies may be that we asked participants to actively evaluate the outcomes of the observed movements. The data from Experiment 2 in particular suggests that such an instruction can, by itself, induce a teleological encoding of actions, in terms of moving towards or away from objects, thereby inducing

automatic imitation. The experiments in Chapter 4 address this problem and will attempt to replicate the outcome guidance of automatic imitation in a task in which outcomes did not have to be explicitly evaluated.

## Chapter 4

The experiments in Chapters 2 and 3 tested whether the outcome of an observed action affects automatic imitation. Observing an action facilitated imitative responses only when the outcome of the action was positive. When the outcome was negative no such facilitation was observed. These studies therefore show that imitation cannot merely be attributed to a simple bottom-up matching of observed actions to one's own action repertoires. Instead, automatic imitation seems to be dynamically guided by higher-level representations of the value or consequence of a given action, which is integrated into the representation of the observed action and directly affects whether participants imitated or not. Importantly, this happened even though outcome information was not part of the action's kinematic properties nor was it causally related to the actions that were observed.

These findings provide a challenge for approaches that conceptualize automatic imitation as an unintentional matching of the proximal properties of observed actions to the observer's own physical capabilities. Models have been suggested that include automatic bottom-up mediation via specific mechanisms such as the mirror neuron system (e.g. Iacoboni, 2009) or as a result of sensorimotor learning of compounded perceptual and motor components of movement (e.g. Heyes, 2010). In either of these cases the positive and negative aspect of the action outcome should not induce a difference in automatic imitation. Instead, the data in this thesis favours hierarchical models of action and action observation (e.g. Hommel, Müsseler, Aschersleben, & Prinz., 2001; Hamilton, Joyce, Flanagan, Frith, & Wolpert., 2007; Bekkering, Wohlschläger, & Gattis., 2000; Csibra, & Gergely., 2009), in which simple motor acts are embedded in a hierarchy of intended outcomes (the goals) and ways in which they

can be achieved (the means). In such views, automatic imitation happens not because people simply copy each other's motor behaviour, but because they evaluate the goals or outcomes that the observed actor wants to achieve with it (Bouquet, Shipley, Capa, & Marshall, 2011; see Campbell & Cunnington, 2017).

Such a top-down guidance is clearly present in early so-called "goal directed" imitation in children and non-human primates (e.g., Call & Carpenter, 2002; Gattis, Bekkering & Wohlschläger, 2002; Tomasello, Kruger & Ratner, 1993; Hauf, Elsner, and Aschersleben, 2004; Corriveau, Min, Chin & Doan, 2016; Huang, Heyes & Charman, 2002; for a review, see Elsner, 2007). Children's imitation involves copying others' observed body movements to attain the same (positive) outcomes. They specifically imitate actions with salient desirable outcomes, and the specific body movements are only copied when children do not already have more effective means at their disposal (i.e. "emulation", Tomasello, 1996; Gergely, Bekkering, & Király, 2002; Meltzoff, 1988; Meltzoff, 1995; Over & Gattis, 2010), or for creating/maintaining social bonds (e.g. Over & Carpenter, 2012).

The studies in Chapter 2 and 3 resolve several problems that have plagued previous attempts to demonstrate similar top-down guidance in adult automatic imitation. In a seminal study, for example, Liepelt and colleagues (2008) reported that people imitate the inferred goal of an observed action (e.g., to lift a finger) rather than what is actually carried out (finger held in place by a clamp). Similarly, people imitate actions more if they appear to be purposeful and are directed towards a valid goal object (e.g., Bach, Bayliss & Tipper, 2011). These findings do suggest that people do not simply map observed actions onto their motor system, but – like in children's imitation – that what is imitated is the outcome that the model was trying to achieve: the action's goal.

However, such findings can be well explained in bottom-up views if one simply assumes that (1) motoric matching does not need to rely on directly observed actions but can also emerge from actions that are merely imaged or predicted, and that (2) knowing another person's goal elicits such predictions of most likely actions. Indeed, several studies have recently shown that attributing goals to others causes such anticipations of their forthcoming actions, which are realised in a perceptual format and can therefor drive automatic imitation, as if directly observed (e.g., Hudson et al., 2016<sup>ab</sup>; 2017; Joyce, Schenke, Bayliss & Bach., 2014). In such views, therefore, top-down guidance only affects imagery and prediction processes, while automatic imitation reflects a bottom-up “motoric matching” processes that simply act on the resulting perceptual representations. For the experiments in Chapter 2 and 3 such an interpretation is unlikely, because the outcome was presented after the action was observed, making it less likely to induce imagery-like processes that could guide automatic imitation.

Another problem addressed by the experiments in Chapter 2 is that many tasks that are assumed to measure automatic imitation may not do so, or not do so exclusively, also capturing the observed action's spatial properties in the same way as of non-social stimuli, such as the body part's location in space, its direction, or its speed. For example, when viewing a left finger being depressed one might not respond faster with ones' own left finger due to a tendency to imitate, but simply because stimuli on the left side are generally responded to more quickly with a left-sided response, and vice versa for stimuli on the right (i.e. the well-known Simon effect, 1969). Indeed, when Longo & Bertenthal (2009) attempted to disentangle spatial and motoric components during automatic imitation, they found evidence for two independent influences, with a larger contribution of the spatial congruency (but see Gracco et al., 2018 for a recent meta-

analysis that comes to the opposite conclusion). If this is the case, then many of the above-reviewed top-down effects could simply reflect top-down changes to how the observed actions were spatially represented, again undermining any strong link to automatic imitation. While this problem exists for the experiments in Chapter 2, it is fully ruled out in Chapter 3, where automatic imitation reflected a copying of the kinematic – not spatial – action features.

One problem that remains unaddressed in the present experiments is that in many of the tasks that found top-down effects in automatic imitation, as in the studies in Chapters 2 and 3, participants were explicitly instructed to evaluate the outcomes of the observed actions, such that the participant's responses actions (presses/push & pull) often did not only differ in terms of whether they imitated an action with a positive or negative outcome, but also in their response meaning, for example, whether they signaled a positive or negative evaluation or a "yes" vs. "no" response, with large differences in response times. Especially if one accepts the fundamental difference in how yes and no responses are encoded in the brain (Merten & Nieder, 2012) or that they require different (i.e. exhaustive vs. matching) search processes (Van Zandt & Townsend, 1993), it may perhaps not be that surprising that one is found to be more susceptible to imitation than the other.

The experiments in Chapter 4 were designed to provide the first test of the top-down control of automatic imitation in face to face interactions, while staying clear of all three caveats described above. As before, it rests on the notion that if automatic imitation is as goal-directed as imitation in children, then it should be similarly affected by action outcomes, with imitation being stronger – or restricted to – actions with positive outcomes, and that this should be the case even if these outcomes did not have to be

evaluated by participants. In contrast, if it just reflects a bottom-up matching of observed action kinematics to the own motor responses, then the outcomes of an action – that happen after the action is completed – should not affect the responses.

To test this idea, a novel task was developed. In the task, two participants sat opposite each other across a touch screen and took turns drawing trajectories from a home area directly in front of them towards targets appearing on the left and right. It was inspired by previous tasks designed to measure inhibitory processes in imitation. The social inhibition of return effect (Skarratt, et al., 2016) describes the well-established finding that people generally carry out actions more quickly to the object towards which the partner had *not* just reached to, because it is difficult to re-orient attention towards an object one has just attended to when watching the partner's action (Skarratt, Cole & Kingston., 2010). Here, we use this type of paradigm to measure not this attention-orienting effect, but whether the kinematics of the movements reflect the automatic imitation the other partner's specific movement trajectory, and whether it is affected by the partner's action outcome.

The experiments in Chapter 4 followed a two-step strategy. In a first experiment, it was established that automatic imitation can generally be observed in this task and that it captures motoric/kinematic matching. To this end, participants interacted with a confederate, who sometimes would make either straight reaches towards the target, curved reaches that were signalled by an obstacle in their way that they had to circumvent, or curved reaches that were made in the absence of any visual cue. This allowed us to test whether participants would automatically copy this curvature, even if there was no obstacle for them to avoid. By comparing whether they copy these curvatures both for motivated (through an obstacle) curved reaches and unmotivated

ones, allows us to confirm that imitation indeed proceeds on the basis of a kinematic matching rather than based on seeing a reach around an obstacle.

Once automatic imitation of action kinematics is established, we then ran a second study in which two participants interacted in the same task, to test whether kinematic imitation depends on the outcomes of the observed action. We therefore randomly varied, after each successful reach of the target of each player, the outcome of the action, playing either a sound that signalled a positive outcome (that the experiment would terminate one trial earlier) or a negative outcome (that the experiment would not terminate earlier). We again measured if curved reaches would be imitated by the next actor and be reflected in their trajectory even if no obstacle was present. Crucially, such an effect should only be present for actions with positive outcomes, and not negative ones. It would establish the outcome guidance of automatic imitation, like it is seen in goal-directed imitation in children, while staying clear of the caveats and confounds outlined above. Specifically, such a finding would allow us to (a) link effects to the kinematic imitation of trajectories rather than an action's spatial components, (b) in a task of real face to face interaction, in which (c) participants did not have to actively evaluate outcomes and their responses did not differ between both outcomes, and (d) without a possibility to account for the effects in terms of imagery or prediction of the alternative action.

## Experiment 1c

Experiment 1c provided a first test as to whether automatic imitation of action kinematics can be measured in our alternating reaching task. Participants interacted with the experimenter who sat on the opposite side of a touch screen. Participants and experimenter would take turns reaching, on this touch screen, from a home area directly in front of them towards targets that appear to the left and right. To measure imitation of action kinematics, both participant and experimenter would, in some trials, reach straight to the target. In other trials, however, an obstacle would appear together with the target as soon as they put their fingers into the start position, and participant and experimenter were instructed to reach around it (see Figure 1c). If people imitate observed action kinematics, participants should make a higher reach after just having observed the experimenter make a higher reach around an obstacle. To ensure that any such effect indeed reflects kinematics (rather than imitation of a higher-level goal of object avoidance), we asked the experimenter to make, from time to time, curved reaches towards the target *even if no obstacle was present*. To ensure random distribution of these trials, such curved reaches were cued to the experimenter through “beep” sounds played through the headphones they were wearing, unbeknownst to the participant. If participants automatically copy the kinematic of the observed reach, then their own reach should be more curved whenever they have just seen a curved reach, irrespective of this seen reach was curved around an obstacle or around empty space.

## Method

### *Participants*

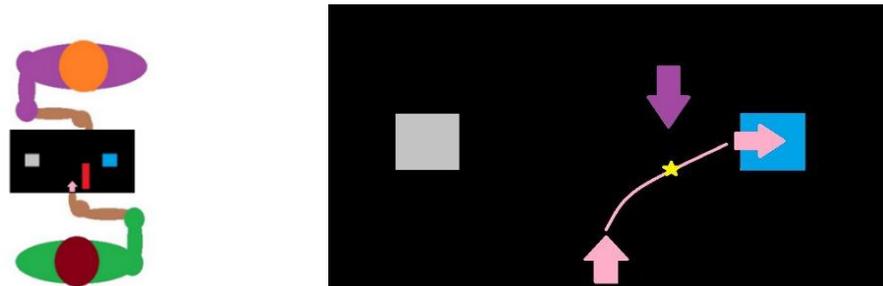
Thirty six participants (age range from 18 to 35, mean age = 20.6, 6 males, 6 left handed), all members of the public and recruited through the Plymouth University, School of Psychology participation system, took part in the experiment, in exchange for course credits or a cash reward of £4. Participants were excluded when making more than 20% errors in total (zero participants excluded). One participant was excluded for not performing the task correctly as indicated by an average Y-coordinate outside the range of goal and start locations. Participants were fully briefed and debriefed and gave informed consent, in accordance with the ethical guidance of Plymouth University and the Declaration of Helsinki.

Generally, a sample size of 35 provides .80 power to detect interaction effects with Cohen's  $d = .487$ . A prior pilot experiment established the predicted effect and suggested that effect sizes are likely higher (Cohen's  $d = .76$ ).

### *Apparatus and stimuli*

The experiment was conducted in a laboratory room with participants sitting opposite each other at a table, with a touch screen laid flatly on top of it. The touch screen was a 16:9, with a resolution of 1920 x 1080. Stimuli on the touch screen consisted of a grey rectangle in front of each player, designated as the start position (size 200 pixels by 200 pixels) located centrally on the screen nearer the participant 400 pixels from the centre. Blue squares (size 200 pixels by 200 pixels) served as the target areas, and could appear to the left or right of the participant (600 pixels from the centre of the screen), directly

on the midline between participant and opponent. The obstacles that could appear were red upright rectangles (100 pixels by 500 pixels) that were placed between the starting area and the target area, with their lower boundary located at the current players screen end. See Figure 1c for a schematic.



**Figure 1c:** Left image shows a visual representation of experimental set up. Right image represents a potential movement made during a trial. Star represents point at which movement would pass an obstacle or not.

Y coordinates of the participants' reaches were continuously sampled during each trajectory, and then, for data reduction purposes, binned in 6 bins of 100 pixels width along the X axis, reaching from the first bin at the start position, to the 6<sup>th</sup> bin at the target area position in the left or right. The obstacle location corresponded to bin 2 and 3. As reaches to the left and right were symmetrical, the data from reaches to the left were "flipped" along the Y axis and collapsed onto reaches to the right.

#### *Procedure and Design*

Participants completed 512 trials, consisting of 8 mini-blocks. Each mini-block consisted of 64 trials, 32 for each player. Trials alternated whether it was the participants turn or the confederates turn, indicated by the appearance of the start area at

the bottom of that player's side of the screen, and whether the target appeared to the left or right (from the viewpoint of the participants). Trials of the confederate varied in whether the target was simply presented, whether it was presented together with an obstacle between start and target area, or whether it was presented with no obstacle, but with a sound played through the confederate's headphones that signalled to them to make a curved reach as if an obstacle was indeed present. Trials of the participant varied only in whether the target was simply presented, or whether it was presented together with an obstacle between start and target area.

Each trial started with the start area appearing on the bottom middle of the current player's screen side. As soon as they placed a finger in this area, the target area appeared to this player's left or right, potentially with an obstacle on the straight path between them. If the current player was the confederate, a tone could additionally play, which signalled to them to make a curved reach as if an obstacle was indeed present. The target area remained present until it was entered by the player's finger and then disappeared. This triggered the start of the next trial for the other player.

## ***Results***

Trials were excluded when RTs were slower than 1500 ms. Erroneous trials of the participants and trials after a confederate error (reaching for the incorrect target) were excluded.

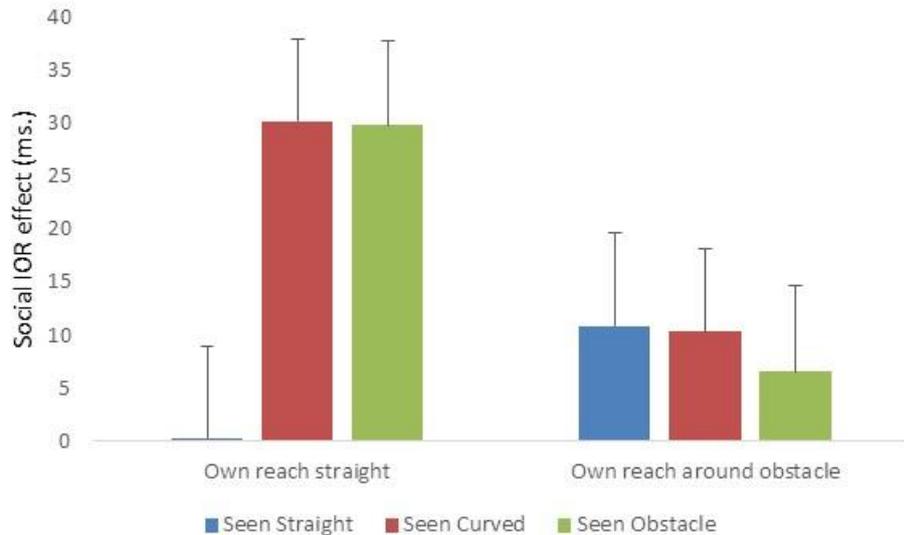
### *Social IOR*

We first verified that Social Inhibition of Return (sIOR, Skarratt et al., 2010) was present. Accordingly, participants should be slower in directing their finger to the same target as the previous' player's action, potentially reflecting difficulties of re-directing attention to the position one had attended during observation and then disengaged from (Skarratt et al., 2010). We therefore compared, with a repeated measures t-test, whether total movement times – from stimulus onset to the participant reaching the goal location – were faster when reaching to different target as the previous person than to the same target as the previous person. This was the case,  $t(34)=4.906$ ,  $p<.001$ ,  $d=.829$ . Participants took on average 692 ms. (SD=83) to reach the same target as the confederate but only 678 ms. (SD=86) to reach the other target.

*Does Social IOR depend on the similarity of own and others' reaches?*

We also checked whether sIOR only reflects directing/withdrawing attention to the same/different goal object or whether it depends on the similarity of own and others action. To this end, the social IOR effect – calculated as the difference between reaches to the same minus a different target as the previous person – was entered into a 2 X 3 repeated-measures ANOVA with the factors Own Action (straight, curved) and Seen Action (straight, curved without obstacle, curved with obstacle). If sIOR is sensitive action-related information, then it should differ depending on whether own and others' actions are similar or dissimilar (e.g. making a curved reach after just having seen a straight or another curved reach). This predicted interaction will be evaluated against the standard alpha of  $p < .05$ . The two other potential main effects are not theoretically predicted and will therefore be evaluated against the Bonferroni-corrected alpha of

$p < .025$  to safeguard against multiple comparison in a multi-factor ANOVA (Cramer, 2016).



**Figure 2c.** sIOR effects depending on whether participants reached straight towards the target or around an obstacle and depending on whether they had just seen a straight reach, a curved reach without obstacle, or a curved reach around an obstacle. Error bars show the standard error of the mean.

This ANOVA revealed no main effects of Own Action,  $F=3.504$ ,  $p=.070$ ,  $\eta^2=.093$ , or Seen Action,  $F=3.309$ ,  $p=.043$ ,  $\eta^2=.089$  that would surpass the Bonferroni-corrected alpha for incidental findings. However, it did reveal the predicted interaction of both factors,  $F=3.478$ ,  $p=.036$ ,  $\eta^2=.093$ . As can be seen in Figure 2c, the social IOR effect was generally larger when participants had produced a different curvature as the previous action. For straight reaches, sIOR was larger after having observed a curved reach or a reach around an obstacle compared to having observed a straight reach (both  $p < .019$ ). In contrast, for curved reaches, sIOR was largest after having seen a straight reach and numerically reduced for curved reaches and reaches around an obstacle. This

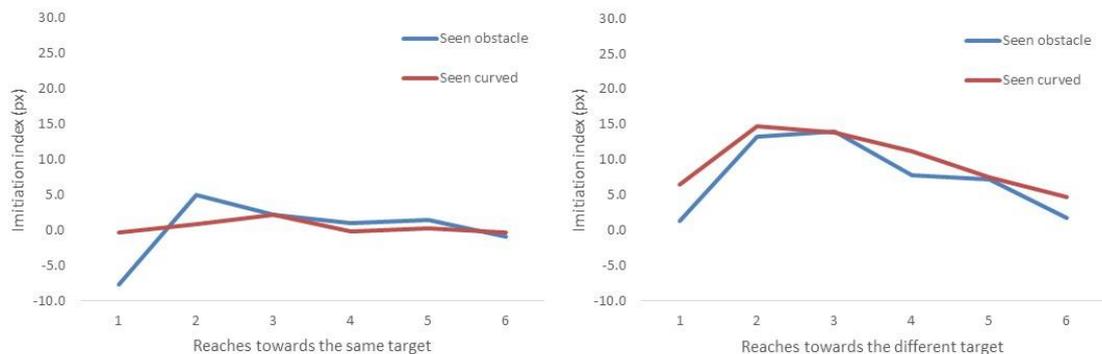
is consistent with the hypothesis that the sIOR effect is not just an effect of returning attention towards a just attended target but depends on the action with which it was reached. Note however that the relevant interaction just passed the significance threshold of  $p < .05$  and therefore needs to be confirmed in a separate study.

*Do own kinematics capture the kinematics of the seen reaches?*

Our central prediction was that participants' own reaches should be higher after having seen a curved reach of the confederate, irrespective if they themselves have to reach around an obstacle or not. To test this, we calculated an *imitation index* that describes how much higher the participants' reach was in each of the six bins after having just seen a curved reach compared to having just seen a (baseline) straight reach. To do so, we subtracted the Y coordinate of their reach in each bin after having seen a straight reach from the same coordinate when having seen (a) a curved reach without obstacle, and (b) having seen a curved reach with obstacle. This therefore derives two separate imitation indices for each bin, one for deviation induced by seeing a curved reach around an obstacle, and one for the deviations induced by seeing a curved reach even though there was no obstacle. Positive values on the imitation index indicate higher reaches when participants' saw a curved reach, either around an obstacle or through empty space, compared to a straight reach.

The data were analysed with a repeated measures ANOVA with the factors Bin (from 1 to 6), Own Action (straight, curved) and Seen Action (curved reach with obstacle, curved reach without obstacle) and Target (same target as previous action, different target). We predicted the following three main effects and interactions, which will be evaluated against the usual alpha of  $p < .05$ . First, a main effect of Bin would reveal the predicted reach deviations compared to having just seen a straight "baseline" reach,

which should occur mostly for the intermediate bins, not for the start and end bins (start position and target). Second, a main effect of Seen Action, or its interaction with Bin, will reveal to what extent deviations differ for seeing curved with and without obstacle. Third, a main effect of Target, or its interactions with Bin, will reveal to what extent participants imitate seen reaches depending on whether they go to the same or different target as the previous reaches. As no other effects were predicted, and because ANOVAs are subject to alpha inflation due to multiple testing (Cramer, 2016), all other findings will be treated as incidental unless they pass the Bonferroni-corrected threshold of  $p < .005$ .



**Figure 3c.** Deviations induced by seeing curved reaches with or without an obstacle, when reaches are directed the same target (left panel) or the other target (right panel) as the just seen reach of the confederate. In each panel, deviations induced by seen curved reaches are plotted in red and deviations induced by seen reaches around an obstacle are plotted in blue.

The ANOVA revealed the predicted main effect of Bin,  $F=3.851$ ,  $p=.002$ ,  $\eta^2=.102$ , showing that seeing curved reaches generally induced higher reaches after just having seen a curved reach of the other person, with deviations being the largest in bins 2 and

3, which correspond to the approximate obstacle location (i.e. automatic imitation of seen reach kinematics). The ANOVA also revealed a main effect of Target,  $F=11.712$ ,  $p=.002$ ,  $\eta^2=.256$ , showing that deviations after having seen one of the curved relative to the straight reaches were generally larger when participants reached to a different compared to the same target as the experimenter. There were no other significant differences. In particular, there was no main effect of Seen Action,  $F < 1$ , revealing no overall differences in the size of deviations induced by seeing curved reaches with or without obstacles. Seen Action did not interact with any of the other experimental factor, all  $F < 1$  for all, with the exception of a interaction of Seen Action and Bin that just failed to reach significance,  $F=2.007$ ,  $p=.080$ ,  $\eta^2=.056$ . As this interaction did not meet conventional thresholds of significance it needs to be verified in further studies. As seen in Figure 3c, it may indicate, however, that deviations after seeing reaches around an obstacle were most pronounced at the obstacle locations (Bins 2 and 3) while deviations after curved reaches without an obstacle were more evenly distributed across bins.

To further explore this potential interaction, we also analysed the imitation index across bins, separately for curved reaches and reaches around an obstacle, with a repeated measures ANOVA with the factors Bin (from 1 to 6), Own Action (straight, curved) and Target (same target as previous action, different target). For curved reaches around obstacles, the analysis replicated both the main effect of Bin,  $F=6.593$ ,  $p<.001$ ,  $\eta^2=.162$ , showing more pronounced deviations at the middle bins, and the main effect of Target,  $F=5.160$ ,  $p=.030$ ,  $\eta^2=.132$ , showing larger deviations for reaches towards the different target than the other actor. For curved reaches without obstacles, the analysis replicated the main effect of Target,  $F=13.696$ ,  $p<.001$ ,  $\eta^2=.287$ , but not the main effect of Bin,  $F=1.272$ ,  $p<.278$ ,  $\eta^2=.036$ . No other main effects or interactions that would pass the

Bonferroni-adjusted threshold for incidental findings in an ANOVA of  $p < .005$ . Thus, as indicated in the main ANOVA, deviations induced by seeing curved reaches or reaches around obstacles were roughly equal in size, but more pronounced for reaches towards a different compared to the same target. However, the deviations for curved reaches around an obstacle were evenly distributed around the trajectory but focussed on the obstacle location when a reach around an obstacle was observed.

### *Discussion*

Experiment 1c confirmed, first, the well-known Social IOR effect, such that reaches were generally faster towards the target that the other player had *not* reached to. In contrast to previous research, we found some tentative evidence that this effect depended on the match of the kinematics one needs to produce oneself and the kinematics one had just observed. The Social IOR effect was generally larger for reaches with a different kinematic than the one that was just observed being executed by the other player (the confederate). If substantiated in further experiments, this would imply that sIOR does not just reflect difficulties in re-orienting attention towards a target one had just disengaged from. Instead, it might reflect action-related processes, for example the inhibition of a previously observed reach trajectory if one needs to make a reach towards the same trajectory (e.g. Doneva, Atkinson, Skarratt & Cole., 2017).

The crucial question was whether participants' own reach kinematics would capture the kinematics they had just observed, and whether this again depends on whether the same

or a different target was reached. We found that participants generally imitated the observed curvatures, both when having observed curved reaches around empty space and curved reaches around an obstacle. Thus, participants own reaches were generally higher after having just observed a curved reach with or without an obstacle, compared to having observed a straight reach. This dovetails with prior research by Hamilton and colleagues (2007) showing that people imitate kinematically even for actions whose kinematics seem to be unrelated to environmental constraints (e.g. obstacles). It provides direct evidence that imitation, in the present paradigm, is driven by the kinematic features of the observed reaches (i.e. their curvature) rather than conceptual factors, such as the presence or absence of obstacles.

There was some tentative (marginally significant) evidence that induced deviations were more pronounced around the location of the obstacle after having observed reaches around an obstacle than after having observed a curved reach without an obstacle. Especially if one assumes that people imitate action kinematics such a difference would not be surprising. Even though not instructed, the experimenter's own reaches around obstacles showed more pronounced curvatures at the object locations than for her reaches in which she was merely instructed to make a curved reach through empty space but where the kinematics were not constrained by visually available obstacle information.

Importantly, we observed that this capturing of observed reach kinematics depended, like the Social IOR effect, on whether the participants' reach was directed to the same or a different target as the just seen action of the experimenter. After having seen a curved reach, participants' own reaches showed a higher curvature whenever they had to reach to a different target, compared to the same target. This finding is entirely

consistent with the proposed interpretation of the social IOR effect above. When reaching to the same target, the previously seen trajectory is inhibited or “over-written”. This slows down responses and generates the sIOR effect, but at the same time decontaminates one’s own reaches from the influence of the just observed kinematic features.

### **Experiment 2c**

Having demonstrated that participants automatically imitate kinematic parameters of observed actions, we set out to test whether this form of kinematic imitation is sensitive to observed action outcomes, as in our previous studies. In this experiment, two participants interacted with each other rather than a confederate. Participants performed the same task as before, as quickly as possible reaching from their start area to one of the two targets, while avoiding obstacles in half the trials. In contrast to Experiment 1c, there were no trials in which one of the players was instructed to make a curved reach in the absence of an obstacle. As in Experiment 1c, we measured whether participants would imitate the previous reach parameters of their partner, that is, that they would show a more curved reach after viewing a curved reach of their partner (compared to viewing a straight reach). The important manipulation was the varied outcome of each action. As soon as the reach of each player entered the target area we played one of two sounds: a “ker-ching” sound, previously designated as signalling a positive outcome (that this trial would take participants further towards experiment completion) or beep sound that was explained as a negative outcome (that this trial would be repeated later). This allows us to assess whether automatic imitation of observed kinematics is outcome

dependent. If so, then participants should particularly copy the kinematics of seen actions with positive outcomes, but not – or less so – of negative outcomes. If reaches towards the same target are, like in Experiment 1c, subject to social IOR, and inhibition of the just seen kinematics, we would expect that the effect of outcomes on kinematic imitation is most pronounced for reaches towards a different target.

## **Method**

### *Participants*

Sixty-seven participants took part (age range from 18 to 37, mean age = 20.3, 20 males, 16 left-handed), selected as in Experiment 1c and the initial study in which we established the effect. Two participants were excluded because they made more than 20% errors. The final sample size of 65 gives us 80% power to detect effects of  $d > .352$ . On the basis of Experiment 1c, effect sizes - based on mean and standard deviation in the interaction contrast - are likely larger, Cohen's  $d = 0.494$ .

### *Apparatus and stimuli*

Apparatus and stimuli were identical to Experiment 1c, with the exception of two additional sound stimuli. One was a “ker-ching” sound to indicate the positive outcome and other a low beep indicating a negative outcome.

### *Procedure and design*

The procedure was identical to Experiment 1c, with the following exceptions. First, participants did not interact with an experimenter but a confederate, who alternated producing the reaches as in Experiment 1c. There were no reaches in which either participant had to produce curved reaches in the absence of an obstacle. In addition, one of the two sounds was randomly selected to be played after each participants' action: a "positive" ker-ching sound, indicating speedier completion of the experiment, and a "negative" low beep, indicating that the trial would be completed and the experiment would take longer.

### *Analysis*

Analysis proceeded as in Experiment 1c. We first tested whether the experiment would again reveal the well-established social IOR effect but tested now whether it was affected by action outcome as well as kinematic change or repetition. We will therefore report total response times for participants reaches towards the target, depending on whether the other player had just reached to the same target, whether the action used the same kinematics, and whether the previous action was followed by positive or negative outcome.

As before, we were mainly interested in the imitation of the kinematic properties of the participants' actions. As before, we simply compared the vertical position of participant's reach at the horizontal position at which the obstacle would appear, both for when it was indeed present and when it was not, depending on whether the outcome of the previous action was positive or negative and depending on whether it was directed at the same or a different target.

## Results

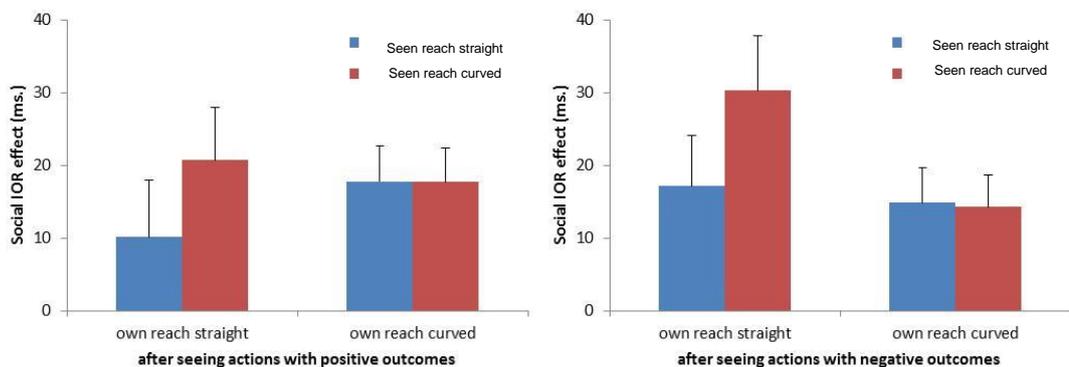
### *Social IOR*

As before, we first established that the expected Social Inhibition of Return (sIOR) effect was present (Skarratt et al., 2010), reflected in slower total response times for responses to the same target as the previous actor than to a different target. As in Experiment 1c, a repeated measures t-test revealed the expected difference,  $t(63)=7.143$ ,  $p<.001$ ,  $d=.893$ , with highly similar effect size. Participants took, on average, 639 ms. (SD=71) to reach the same target as the confederate but only 621 ms. (SD=71) to reach the other target.

### *Does Social IOR depend on the similarity of own and others' reaches?*

As before, we then tested whether sIOR depends on the similarity of one's own and the other's action. We entered the social IOR effect – calculated as the difference between reaches to the same minus a different target as the previous person – into a 2 x 2 x 2 repeated-measures ANOVA with the factors Outcome (positive, negative), Current Action (straight, obstacle, curved with obstacle) and Seen Action (straight, curved). As before, the 2-way interaction of Current Action X Seen Action tests whether the sIOR effect differs depending on whether people have to make the same or a different trajectory, and the 3-way interaction of Current Action X Seen Action X Outcome tests whether this difference in sIOR itself depends on the (positive or negative) outcome of the just seen action. However, the ANOVA did not reveal the interaction of Current Action X Seen Action,  $F=1.776$ ,  $p=.187$ ,  $\eta^2=.027$ , that was seen in Experiment 1c, even

though the data showed the same numerical pattern, with generally less sIOR when the current and seen action were congruent. Neither was there a three-way interaction of Current Action, Seen Action and Outcome,  $F < 1$ . None of the other main effects or interactions were significant,  $F < 1.591$ ,  $p > .212$ ,  $\eta^2 > .025$ , for all. Thus, despite an identical numerical pattern as in Experiment 1c, there was not statistically robust evidence for a modulation of sIOR by any of the experimental variables of interest.



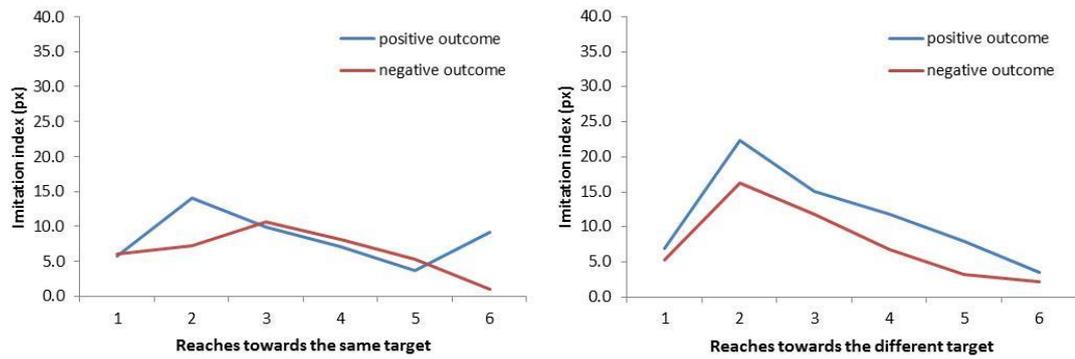
**Figure 4c.** The left panel shows sIOR effects after having seen actions with positive outcomes and the right panel shows sIOR effects when having seen actions with negative outcomes. In each panel, sIOR effects are plotted depending on whether participants reached straight towards the target (left bars) or around an obstacle (right bars) and depending on whether they had just seen a straight reach (blue bars) or a curved reach around an obstacle (red bars). Error bars show the standard error of the mean.

*Do own kinematics mirror observed kinematics for actions with positive outcomes?*

As in Experiment 1c, participants' reach heights along their trajectory were split into six bins of equal size along the X axis, with the data from reaches to the left collapsed onto reaches to the right, so that the first bin always indexes the location of the start area and last bin indexes the area of the target object. For each bin, we then calculated an *imitation index* that describes how much participants' reach deviated after having just

seen a curved reach from the baseline of just having seen a straight reach, by subtracting the Y coordinate in each bin after having seen a straight reach from the same coordinate when having seen a curved reach. Positive values on the imitation index indicate higher reaches of the participants when having seen a curved reach relative to a straight reach. The data were analysed with a repeated measures ANOVA with the factors Bin (0 to 5), Own Action (straight, curved), Target (same target as previous action, different target) and Outcome (positive, negative).

We predicted the following three main effects and interactions, which will be evaluated against the usual alpha of  $p < .05$ . First, as in Experiment 1c, a main effect of Bin will indicate the predicted reach deviations from baseline (having seen a straight reach), which should occur mostly for the intermediate bins, not for the start and end bins. Second, interactions of Bin and Target will reveal to what extent participants imitate seen reaches depending on whether they go to the same or different target as the previous reaches. Finally, interactions of Bin and Outcome will reveal to what extent action kinematics are mirrored specifically when actions with positive outcomes were observed. As no other effects were predicted, and because ANOVAs are subject to alpha inflation due to multiple testing (Cramer, 2016), all other findings will be treated as incidental unless they pass the Bonferroni-corrected threshold of  $p < .004$ .



**Figure 5c.** Imitation index. Deviations induced by seeing curved reaches relative to straight (baseline) reaches, when reaches are directed to the same target (left panel) or the other target (right panel) as the just seen reach of the confederate, and when the seen reaches achieved positive outcomes (blue lines) or negative outcomes (red lines).

The ANOVA revealed the predicted main effect of Bin,  $F=12.646$ ,  $p<.001$ ,  $\eta^2=.167$ , showing that reaches are generally more curved after just having seen a curved reach of the other person, especially in the bins that correspond to the approximate obstacle location. There was an interaction of Bin and Target,  $F=2.877$ ,  $p=.015$ ,  $\eta^2=.044$ , showing again that kinematic imitation is stronger for movements to the different target object. Of theoretical relevance, there was an interaction of Target, Outcome and Bin that just failed to reach significance,  $F=3.537$ ,  $p=.065$ ,  $\eta^2=.053$ . As can be seen in Figure 4c, deviations after seen curved reaches (relative to straight reaches) were stronger for reaches towards a different compared to the same target, and this difference was itself (marginally) larger for actions that produced positive compared to negative outcomes. No other effects passed the Bonferroni-corrected significance threshold of  $p < .004$ .

## Discussion

Experiment 2c confirmed, again, the Social IOR effect, such that reaches were generally faster towards the target that the other player had *not* reached to. In contrast to Experiment 1c, we did not find statistically robust evidence that this effect depended on the match of the kinematics one needs to produce oneself and the kinematics one had just observed, even though the pattern numerically supported this hypothesis. Together with Experiment, 1c, it may therefore provide tentative evidence for a role of sIOR beyond indexing difficulties in re-orienting attention towards a target one had just disengaged from, towards a role in inhibiting observed action features if reaching to the same target as one's predecessor.

Experiment 2c also confirmed that one's own reach kinematics capture the kinematics one had just observed, such that own kinematics were generally more curved after just having observed a curved reach around an obstacle. Importantly, as in Experiment 2c, we found that this kinematic imitation specifically happened for reaches towards the target that the other person had *not* just reached to. After having seen a curved reach, participants' own reaches showed a higher curvature whenever they had to reach to a different target, compared to the same target. As before, it suggests that, when reaching to the same target, the previously seen trajectory is inhibited or "over-written", slowing down overall action speed, but reducing the effect of just seen action kinematics.

The central question of Experiment 2c was, however, whether kinematic imitation depended not only on the target the reach was directed at, but also on the action outcome. We have found in previous studies that action outcome information determined whether actions were imitated, with automatic imitation generally restricted to actions with positive outcomes (e.g. wins but not losses in a game). The present data

provided similar results, but the results just failed to reach significance. We found that the increased curvature after seeing reaches around an obstacle was increased after seeing actions with positive compared to negative outcomes, specifically for reaches towards a different target. While this effect needs to be confirmed in further studies, it provides first tentative evidence that (a) the kinematics of an action are automatically imitated, specifically when the action produced positive outcomes, and (b) if the specific reach trajectory was not inhibited – causing sIOR – because one reached to the same target as the model.

## **General Discussion**

The tendency to imitate was previously deemed to arise from bottom-up processes which directly map observed actions onto the observers own motor system (Iacoboni et al., 1999; Heyes, 2012; Rizzolatti & Sinigaglia, 2010). Other studies have challenged this view suggesting that automatic imitation occurs on the basis of action goals rather than the motor level (Bouquet et al., 2011; Campbell et al., 2017). Investigations into top-down guidance of automatic imitation have however been hampered by several difficulties, making it difficult to rule out contributions of spatial relationships between stimuli and responses, as well as the role of explicit need to evaluate observed actions and respond accordingly (e.g. “yes” there was a match, “no” there was not a match). Here we have provided a novel solution to these problems that allows one to directly measure automatic imitation of action kinematics, rather than mere reaction times or error rates, ruling out spatial confounds, and without participants’ need to evaluate the actions, in a paradigm that uses truly social face to face interaction.

In two experiments, the participants' own action kinematics were measured in an alternating reaching task, in which the (confederate) partner produced straight movements, obstacle avoidance movements and curved movements without obstacles (Experiment 1c only). Both experiments replicated, first, the well-known sIOR effect such that participants were slower to reach to the same target as the previous player. In contrast to other studies on this effect (Skarratt, et al., 2010; Cole., 2017), there was tentative evidence that the effect depended upon whether the kinematics required to produce the response bore a similarity to the kinematics of the action one has just observed. Particularly in Experiment 1c, the sIOR effect was larger for movements made using differing kinematics suggesting that sIOR may include action components such as the inhibition of the trajectory of a previously observed movement, when one has to produce a different movement oneself. Because this effect was only present numerically in Experiment 2c, it would need to be replicated in further studies, before strong conclusions can be drawn.

In addition, we established that automatic imitation in this task captures the observed kinematics of the partner's movements. We found that participants generally imitated the observed curvatures regardless of necessity of the partner's curved reach. Compared to a straight reach trajectory, participants' reaches were higher when they had just observed a reach trajectory around an object as well as when they observed a similar reach trajectory around empty space. This is an important finding as it links imitation with the kinematic features of movements rather than environmental conceptual information such as the presence or absence of obstacles to avoid. An interesting finding in both experiments was that this automatic imitation depended whether the one's own movement was directed to the same or different target as the just observed action, much like the sIOR effect described above. Compared to movements made to

the same target, reaches to different targets were affected more strongly by the observed curvature, suggesting that when reaching to the same target the previously observed movements trajectory is inhibited, slowing down the overall action speed as measured by the sIOR effect (see above).

The main goal of Experiment 2c was to establish whether outcome information affected this automatic mirroring of observed reach curvatures. The actions in this experiment were therefore followed by a positive tone (indicating that the experiment would end earlier) or a neutral tone (the experiment would not end earlier). The results revealed an interaction that just failed to reach significance. The increase of curvature mirroring was stronger after positive outcome trials compared to negative outcome trials. Whilst this effect requires confirmation in other studies, it may provide the first tentative evidence that action kinematics are automatically imitated when the observed action had a positive outcome, even if participants are not instructed to evaluate the outcomes of the observed action, and the actions they make were independent of these outcomes, in contrast to all experiments in the previous chapters. It may therefore provide direct evidence that automatic imitation – like goal directed imitation in children – is driven not by bottom-up kinematic features of the observed action only, but that it reflects hierarchical, top-down guided processes in which these kinematics are always linked to the action outcomes they achieve.

## **Chapter 5: Discussion**

### **4.0 Summary of results**

Imitation is a pervasive social phenomenon. Research distinguishes the purposeful imitation of higher level features such as an action's goals and intended outcomes (Byrne, 1993; Byrne., 2003; Meltzoff & Moore., 2008; Chartrand & Dalton., 2009; Wang & Hamilton., 2012) and the automatic imitation of relatively low-level movement-based characteristics, such as the movements kinematics or the body parts used (Brass et al., 2000; Genschow et al., 2013; Genschow & Florack., 2014; Genschow & Schindler., 2016). However, most of the research thus far has mostly focussed on either one or the other type of imitation but has not considered how the two phenomena relate to each other. This thesis, in contrast, tested whether automatic imitation is similarly affected by the outcome of the observed action as it is the case for goal-directed imitation in children and primates, so that both phenomena can be described in a similar theoretical framework.

### **4.1 Summary of results: Chapter 2**

The first experiment in Chapter 2 (Experiment 1a) tested whether information about whether an observed action had led to a positive or negative outcome would affect automatic imitation. Participants observed a player in a card game reach for one of two upside-down cards on a table. When the card was revealed, the participant had to assess whether the outcome of the event was positive or negative by comparing the chosen card with an opponent's card: a higher number would beat the opponent card and a lower number loses to the opponent's card. Participants made these win/lose judgments

with actions that either matched or did not match the observed action. It was found that motorically matching actions were facilitated only when the outcome of the observed action was positive. This provided the first indication that automatic imitation is driven by outcome information, similarly as known for goal-directed imitation in children and primates.

However, an unexpected confound delayed this conclusion. The numerical value of the cards may have impacted the results as all of the positive outcomes were associated with higher value cards and negative outcomes with lower value cards. It may therefore be that card magnitude itself – rather than the action's outcome as win or loss – may have induced the observed differences. The second experiment (Experiment 2b) therefore used the same stimuli but varied the participants' instructions, such that, for some participants, higher cards were winning cards, lower cards for the other. For a third group, all valence was removed. Rather than asking participants to state whether the outcome was winning or losing, they simply identified whether the card which was revealed was higher or lower than the opponent's card. The results revealed that card magnitude indeed drove the automatic imitation effects. All conditions produced identical results. Actions that revealed higher value cards induced an automatic imitation effect, irrespective of whether these higher-value cards had to be interpreted as win/losses or not evaluated at all.

While card magnitude itself is a relevant action outcome, it was important to show that more arbitrary outcome evaluations induce the same modulation of automatic imitation. The third experiment (Experiment 3a) therefore used the well-known symbols of rock-paper-scissors on the card faces instead of numbers. Importantly, in this game, the symbol on the card face had no intrinsic value when presented alone. No one symbol was better or worse than the others and a judgement on the outcome of a game could

only be made by comparison of two of the symbols together (rocks beats scissors but loses to paper, scissors beat paper but loses to rock, paper beats rock but loses to scissors). This experiment therefore isolated the effect of positive and negative outcomes and eliminated additional influences of inherent card magnitude. The results revealed, as predicted, that automatic imitation was induced only by winning actions, showing that higher-level representations of positive and negative outcomes directly affected participant's tendency to imitate. Strikingly, observing a losing action produced the opposite pattern: participants were faster to respond with the action that they had *not* just observed, similar to the correction of unsuccessful actions during goal directed imitation in children (Meltzoff, 1995).

Another concern was that the egocentric nature of the stimuli used in the experiments may have allowed participants to encode the information about the actions more strongly than they might otherwise have done, for example, because they encoded the seen actions as their own, rather than actions of a model (Bach, Fenton-Adams, Tipper., 2013; Rizzolatti & Sinigaglia, 2016). Indeed, first person actions have been shown to be produced faster and with greater subjective ease (Nishizawa, Kimura, & Goh: 2015). In addition, it is possible that automatic imitation in the negative outcome condition could have been eliminated because participants made a negative evaluation in general (i.e. responding yes/no), even if this evaluation was not linked to the action at all. The final experiment (Experiment 4a) therefore also varied, between participants, whether the actions were seen in the 1<sup>st</sup> and 3<sup>rd</sup> person perspective, and whether participants judged the outcome of the action that they just observed or evaluated how this action affected the outcome for the other, passive player that did not act. If previous effects of outcome sensitivity indeed reflect processes in imitation (rather than 1<sup>st</sup> person imagery for example), then it should be observed when actions from both perspectives are observed.

If it is crucial that the positive/negative outcome refer to the observed action, outcome sensitivity should be seen only when participants make judgements for the acting person but be eliminated or reduced when they make judgements for the other player. These predictions are precisely what was observed. Automatic imitation was found for positive outcomes in both viewing perspectives, but this modulation only occurred when participants evaluated the outcomes from the perspective of the acting player, not the opponent.

Together, therefore, Chapter 2 showed that imitative responses were faster than non-imitative responses replicating the well-known automatic imitation effect (e.g., Heyes, 2011; Brass et al., 2001). However, this speeding-up of matching actions was only found when observing actions for which the outcome was positive, revealing that automatic imitation does not rely on only kinematic movement properties but is based on an hierarchical integration of these movements and the outcomes they achieve. This effect was independent of viewing perspective and tied to the (positive or negative) evaluation of the action that was currently observed.

#### **4.2 Summary of results: Chapter 3**

The experiments in Chapter 3 resolved another issue of the experiments in Chapter 2. It tested whether the observed automatic imitation effects reflected general spatial compatibility (Simon, 1969) or whether they indeed reflect a specific effect of imitating the motoric features of another's actions. Moreover, to increase the ecological validity of our conclusions, the experiments in Chapter 3 did not use the card game scenario. Instead, participants observed instances of a model's hand reaching towards or withdrawing from an object that was either safe to grasp (e.g. an orange) or painful to

grasp (e.g., a cactus) (Experiment 1b). As before, they had to evaluate the valence of the outcome, by making a response that either matched or mismatched the action they observed. By counterbalancing whether reaches were directed to the left and withdrawals to the right, or vice versa, and whether participants indicated positive outcomes with a leftward responses or negative ones with a rightwards one, or vice versa, it was possible to fully separate spatial and kinematic imitation effects. The data revealed that participants responded faster when their actions matched the kinematics of the previously observed action, regardless of spatial compatibility. Again, this facilitation occurred specifically for actions with positive outcomes. This experiment therefore replicated the findings of Chapter 2, showing that the outcome-dependency of automatic imitation is a replicable phenomenon across paradigms and stimulus sets.

In order to ensure that this effect was specific to biological intentional motion, a further investigation (Experiment 2b) was conducted in which people viewed movements of inanimate “bubbles” that travelled the same paths as the hands in the previous experiment (Experiment 2b). Although participants made exactly the same judgements as the previous experiments, the data revealed that action kinematics – movements towards or away from the objects – were generally imitated less. However, although the effect of outcome guidance of automatic imitation was eliminated in the reaction time data, it was still present in the error rates. The data therefore suggested that the outcome modulation of automatic imitation is a cognitively controlled process that, triggered by the instruction to evaluate these outcomes, can be applied to even inanimate objects.

### 4.3 Summary of results: Chapter 4

One problem of the current studies may be that participants were actively evaluating the outcomes during observation of movements. The data from Chapter 3, in particular, suggested that such an instruction can, by itself, induce a teleological encoding of actions, thereby inducing automatic imitation. Further investigation was needed to test the outcome sensitivity of automatic imitation in a task in which participants were not explicitly instructed to evaluate observed action outcomes.

We developed a new task that integrates all components of the prior studies – capturing kinematic properties rather than spatial ones, and positive versus negative outcomes – but put them in a context in which people interacted with a real person and in which they were not explicitly asked to make judgments about the action's outcomes. A first experiment (Experiment 1c) validated the task and assessed whether it indeed measures kinematic imitation. Participants sat opposite an experimenter with a touch screen laid flat between them. They took turns placing their finger on the screen in a home area directly in front of them and then moving their finger across the screen to a target area which appeared to the left or right. There were three conditions. Either the experimenter moved straight from the home screen to the target area (efficient movement), the experimenter made a curved reach to the target to avoid an object (necessary movement) or the experimenter made a curved movement to the target area when no obstacle was present (unnecessary movement). Next to finding the usual Social IOR effects that are present in such task (slower responses towards objects another had just acted on), the data revealed automatic imitation of kinematic action features: observing curved reaches, regardless of whether there was an obstacle present or not, produced more curvature in participants' responses. In other words, participants imitated the observed movement trajectory, and did not just simply respond to obstacle presence.

This established the validity of the experimental paradigm for measuring imitation of kinematic action features.

In a second experiment (Experiment 3c) we then used a simplified version of the task, in which there were only two conditions – seeing someone reach around an obstacle or straight towards the goal – and manipulated again the outcome of these actions. We played a random tone after each action, which indicated either a positive outcome (the experiment would finish one trial earlier than expected) or a negative outcome (the experiment would not end one trial earlier). The results showed again that people imitate the kinematics of observed movements. Participant's movements were generally more curved after observing a curved reach, and there was tentative evidence that these effects are stronger for actions that are made immediately following an action with a positive outcome compared to negative ones. This provided the first evidence for the proposal that the outcome modulation of automatic imitation can even be observed when the outcomes are not explicitly judged and for actions that do not, in contrast to the previous experiments, are tied to the outcome evaluation itself.

#### **4.4 Main findings**

This thesis provided five main findings. First, all experiments in the thesis confirmed that people have a general tendency to imitate the actions of others (e.g., Cracco & Brass., 2019; Scott, Emerson, Dixon, Tayler, & Eaves., 2019; Heyes, 2011; Bien et al., 2009). In Chapter 2, people were faster to respond with the same hand in the card games than they did with the opposite hand across number-related outcomes, symbol-related outcomes and in first and third person perspectives. In Chapter 3, people responded faster with forwards movements after observing a forward movement and to backwards

movements after observing a backwards movement. In Chapter 4, participants reliably imitated the kinematics of the other participants' actions, making more curved reaches after just having observed a partner make the same curved reach, and straighter reaches after having the partner seen make a straight reach. Thus, automatic imitation was found in all of the studies and was observed even though the similarity of own and others' movements was completely task irrelevant.

Second, the experiments in Chapter 3 and 4 showed that the effect of automatic imitation reflects the kinematics of the observed movement and can be dissociated from similar facilitation effects induced by spatial compatibility (for similar findings, see Boyer et al., 2012). In Chapter 3 (Experiments 1b & 2b), spatial compatibility and movement compatibility were separated, revealing that motorically compatible movements, regardless of direction of movement were responded to faster than incompatible movements. In Chapter 4, we found that people copied the kinematics of the observed movement, such that their own trajectory became more curved both when just having observed the other person make a curved reach around an obstacle or empty space (Experiments 1c & 2c). Thus, automatic imitation reflects not only spatial components of the seen actions (e.g. the location of goal objects and fingers within the body schema), but also the observed action kinematics.

Third, automatic imitation effects were generally larger when the outcomes of the observed actions were positive. In Chapter 2, this tendency to respond imitatively only for actions with positive outcomes was revealed when using numerical cards values (when the revealed card was larger than the opponent card (Experiment 1a)), and when symbols were used to replace these for winning trials opposed to losing trials (Experiments 3a & 4a). In Chapter 3, this was also the case when observed reaches and withdrawals were judged to be appropriate as opposed to inappropriate, relative to a

painful or safe goal object (Experiment 2). Additionally, in Chapter 4, where participants did not actively make a judgement on the outcome of a trial, they nevertheless showed a tendency for stronger imitation of the kinematics of the movement observed in the previous trial if the outcome of that previous action was positive (Experiment 2c). For that reason, we can conclude that automatic imitation effects are facilitated for positive outcomes and absent or reversed for negative outcomes, similar to research on goal directed imitation in children (Wilks, Collier-Baker, & Nielsen, 2015).

Fourth, the facilitation effect for positive outcomes was observed even when the outcome was not related to the observed movement. While in Chapter 3 the action outcomes were arguable closely linked to the specific action that participants observed (e.g. grasping or withdrawing from a painful object (Experiment 1b)), in Chapter 2, all movements observed were identical and only the outcome of the trial differed randomly, in a manner that was statistically independent of the actions observed (Experiments 1a, 3a & 4a). The same was true for Chapter 4 (Experiments 1c & 2c). The outcome was presented randomly after each action and was not related to the previous movement in any way. Thus, the tendency to imitate observed actions with positive outcomes arises even though the outcomes themselves are not proximal parts of the action, but their distal effects, even if these effects are not causally linked to the actions.

Fifth, automatic imitation – but not its outcome modulation – seemed to be driven by bottom-up perceptual information about the intentionality of the observed movements. In Chapter 3, general automatic imitation effects were extinguished when participants were presented with non-biological stimuli (i.e. a bubble traversing the same trajectories as the hands (Experiment 2b)). Whilst outcome guidance remained, the overall facilitation effect for imitative actions was substantially reduced. Ergo, the general

automatic imitation effect seems to be at least partially bottom-up driven and decreases when seeing non-biological stimuli. The observed outcome modulation, however, seemed to be at least partially tied to the explicit evaluation of the observed actions. The effect was more robust when participants had to explicitly evaluate action outcomes (Chapters 2 and 3) than when outcomes were incidentally varied (Chapter 4). In addition, the outcome modulation of automatic imitation was present even when participants observed – evaluated – the movements of inanimate bubbles. The outcome guidance of automatic imitation therefore seems to be at least partially under top-down control, driven by tasks to evaluate the observed movements in a teleological manner.

### **5.1. Relation to prior studies, captured by a recent meta-analysis**

A recent meta-analysis reviewed important questions about automatic imitation that neatly capture current debates in the literature (Cracco et al., 2018). They first asked which of three processes had the most influence on automatic imitation: spatial compatibility, effector compatibility or movement compatibility. The investigation found that automatic imitation could be influenced by - but not reduced - by controlling for spatial compatibility and that effector compatibility had more of an influence on automatic imitation than movement compatibility. While we did not manipulate effector compatibility (e.g. Bach, Peatfield & Tipper, 2007), we could rule out an effect of spatial compatibility. When spatial compatibility was controlled in Experiments 1b & 2b, we found automatic imitation still persisted. This is clear evidence that automatic imitation captures action kinematics, as suggested by the meta-analysis (Cracco et al., 2018) and other studies (e.g., Hayes, Roberts, Elliott, & Bennett., 2014).

Second, the meta-analysis found that automatic imitation could be influenced by periods of incompatible sensory motor training, for example, when participants are instructed to respond to hand stimuli with foot presses and vice versa (Cracco et al., 2018). Although this weakened the effect of the compatible relationships, they found that there was no increase in automatic imitation when participants were given compatible sensory motor training. They concluded that automatic imitation was a result of overlearned perception-action associations, which must be acquired through associative learning and used this for evidence to support ASL theory (Heyes., 2012; Brass & Heyes., 2005). In all of our experiments, especially in Chapter 2 and 4, we found evidence that outcome information, which was not related to the action itself, had an effect on automatic imitation. Whilst automatic imitation may be flexible in terms of stimulus-response learning, our data suggest that it is also affected by social top-down influences, and not just pre-established associative connections between motor responses and visual stimuli (Cook et al., 2010). It is likely that this effect emerges due to sensory predictions of the consequences of the observed action (Blakemore, & Decety., 2001).

Third, the authors concluded that automatic imitation is indeed largely automatic and driven by bottom-up stimulus information, relatively unaffected by top-down control. The meta-analysis found that automatic imitation is very fast, and that it is measured best at stimulus onset asynchronies between 80-150 ms between movement observation and response target. Moreover, if attention is directed away from the observed action a reduction in the effect is observed but the effect is not eliminated. Finally, when perceptual load tasks are applied, rather than eliminate the automatic imitation, it appears to reverse the effect (Catmur, 2016). In contrast, in all of our experiments, we see an influence of higher-level outcome information on automatic imitation.

Specifically, we found that automatic imitation is facilitated by actions with positive

outcomes and absent or reversed with actions that have negative outcomes, despite the consequence of the action being an entirely distal component of the action, and statistically unrelated to it. Here we must argue that whilst automatic imitation may indeed be automatic, it is flexibly deployed depending on observed outcomes, providing direct evidence for top-down control.

Fourth, the meta-analysis revealed that automatic imitation is greater for goal-less actions, or, in other words, bottom-up observations of movements, rather than object-directed or communicative actions which require top-down processing, and which imply clear goals (e.g. reaching for an object, thumbs-up or Okay hand gestures). They therefore suggest that any automatic imitation effects reflect movement parameters instead of goal information. But, as the authors recognise, this could be a result of movement characteristics being themselves coded as the action goal, when no other goals are apparent (Cracco et al., 2018). The present studies did not manipulate the goal-directedness of the actions, but showed that automatic imitation can be reliably observed for such actions and that it is, in such circumstances, reliably affected by the outcomes of the observed actions, that is, whether they achieve or fail to achieve their intended goal (e.g. win in a card game, safely pick up an object, proceed through the trials in the experiment).

## **5.2. Relation to studies in children's goal directed imitation**

The findings from the automatic imitation experiments reported in this thesis map closely onto work in children's goal-directed imitation, for which outcome guidance is

well-established. As reviewed in the introduction, children's goal-directed imitation is seen as a top-down guided, "rational" process, in which the imitator links the seen body movements (the "means") to the changes in the environment they produce (the "ends") and uses this knowledge to achieve the same outcome. For example, in one experiment children observed an adult act out a set of actions on objects which made something interesting happen (e.g. a wooden box with a wheel and a handle that opened to reveal a toy). During half of these observations the adult model verbally communicated that the action was either purposeful ("There") or accidental ("Whoops"). After each observation children were allowed the opportunity to interact with the object to try to complete the same action. Imitation was twice as likely to occur after the child observed an adult perform an action intentionally than if they observed an accidental action (Carpenter et al., 1998).

As children age, their imitation allows for more flexibility but remains firmly outcome-guided. For example, they learn to distinguish between intentional and error-full movements and correct movements so that they achieve the outcomes the model failed to achieve (Wohlschläger et al., 2003). If they observe an inefficient action (e.g. using one's head to turn on a light), they will readily use different bodily effectors should this allow them to complete tasks more effectively (Gergely et al., 2002).

The results reported in this thesis provided very similar findings for automatic imitation. In this thesis, we have established that responses that match a just-observed action are facilitated particularly when these actions had positive outcomes, but not when they had negative outcomes. This was the case when automatic imitation was tested when viewing actions in a card game (Chapter 2), when viewing people reaching to or withdrawing from painful or safe objects (Chapter 3), and, tentatively, when making reaches towards or around obstacles in a two-person social interaction (Chapter 4). Note

that these results cannot be explained simply by assuming that observers copy the goal of an observed action, rather than the outcome. In all experiments in this thesis, the goals were the same for all observed actions; the only component that influenced automatic imitation was whether the outcome actually achieved that goal. The findings therefore show a very similar outcome guidance of automatic imitation as is present for the goal directed imitation in children.

A specific finding in children's literature on automatic imitation is that children, after having seen a model not achieve their intended goal, correct the observed action towards a more appropriate one (e.g., Carpenter et al., 1998; Olineck & Poulin-Dubois, 2005). While we did not specifically test whether automatic imitation mirrors these findings, several experiments provided evidence that viewing actions with negative outcomes produced negative compatibility effects (e.g. Experiments 1a, 3a, 4a, 1b), facilitating the alternative action that was not observed. While this has to be confirmed by further studies, this may be taken as evidence that adult participants, in the same way as described in the children's literature, attempt to correct observed actions towards the alternative or more desirable outcome and that this correction directly affects automatic imitation.

Finally, a striking finding was that while, in the experiments in Chapter 3, observing an inanimate object generally reduced automatic imitation, the outcome dependency was *not* reduced in the same manner (Experiment 2b). While this may be surprising from theories assuming that automatic imitation is reduced or absent when inanimate objects – or objects believed to be inanimate – are observed (Gelman, Durgin, & Kaufman., 1995; Opfer, & Gelman., 2011), the findings reveal a link to biological motion perception studies with children. Young children are able to attribute goals to inanimate objects if they move in a way that appears intentional and they consistently behave in a

meaningful way. The results indicate that the delivery of instructions to evaluate the bubble's movement teleologically (in terms of whether they achieved the outcome) allowed participants to attribute an intention to the objects and again facilitated the copying of positive but not negative movements.

### **5.3 Theoretical implications**

The results in this thesis have important theoretical implications. Goal-directed and automatic imitation are usually described by different theories, which differ in whether they account for imitation of the actions' forms as such (e.g. the bodily movements) or the higher-level goals of the action. Simulation theories, for example, claim that imitation is possible due to the internal recreation of observed actions in the motor system of the observer (Rizzolatti et al., 2010; Gallese, & Goldman, 1998; Arbib, Billard, Iacoboni, & Oztop, 2000). This is computed by the observer using mirror neurons, which are assumed to "directly match" the action's kinematic features to an action in the observer's motor repertoire (Rizzolatti et al., 2014; Rizzolatti et al., 2011; Sebanz et al., 2003) and therefore 'mirror' others' behaviours as if the observer were performing the observed action. This internal simulation of the action allows the observer access to its meaning or goals. Automatic imitation, in such models, reflects this bottom-up matching of observed actions to a similar action in the repertoire of the observed (Iacoboni., 2009).

The findings of this thesis are not compatible with such an account. Across all experiments, the data suggests that automatic imitation is not just guided by bottom-up visual input about the action's kinematics, but by knowledge about the consequences of actions: whether they produced positive or negative outcomes. The prior knowledge of felt consequences of acting upon painful or safe objects (Chapter 3), the understanding

whether cards won or lost (Chapter 2), or, tentatively, whether the action sped up the experiment (Chapter 4) affected people's tendency to imitate. It is not possible to explain these results using a simple bottom-up mechanism. At the very least, one therefore needs to argue that simulation proceeds top-down, driven by viewing an action with positive outcomes (all experiment in this thesis), or by an attempt to mentally correct an observed unsuccessful action towards a more appropriate alternative (Experiments 1c & 2c).

Other theories, such as ASL argue that automatic imitation (and mirror neurons as its neuronal substrate) are an artefact of associative, domain-general learning mechanisms (Brass & Heyes, 2005; Heyes 2010; Heyes., 2012). The theory states that associations between visual representations of actions and their motor representations are initially unconnected but develop gradually whenever there is contingent motor output and sensory activation (e.g. when we watch our own actions or our facial expressions as baby are mirrored by our parent). With enough time this leads to bidirectional connections between representations for the perception and the execution of actions. While this provides a powerful account of automatic imitation, it does not seem to be able to explain the present results. All experiments revealed that the response time benefit for imitative actions was only seen for action with positive outcomes – those which were winning as opposed to losing (Chapter 2), appropriate as opposed to inappropriate to an object (Chapter 3) and those which were deemed to benefit the participant as opposed to those which did not (Chapter 4). In ASL, like in simulation theories, automatic imitation simply emerges from bottom-up stimulus-response links. Both negative and positive action outcomes would therefore elicit automatic imitation equally, especially as both types of outcome were not part of the observed action, but one of their randomly following distal consequences, and therefore equally associated

with both action possibilities (i.e., the left and right reaches). At the very least, one would therefore need to argue again that these automatic sensory-to-motor associations between observed actions and actions one can produce are modulated by top-down factors. However, such top-down factors are outside the scope of ASL theories and they could not account for the negative compatibility effects that were observed in some of our experiments (e.g., Chapter 2, 3 & 4), and which might mirror the automatic correction of an unsuccessful action towards its more appropriate counterpart, as sometimes seen in children's goal directed imitation (Wohlschläger et al., 2003).

While the differences are more subtle, the present data are also not consistent with approaches that argue that imitation reflects the goals attributed to an action (e.g., Liepelt et al., 2008; Bertenthal et al., 2003). For example, Csibra argues that automatic imitation emerges because the observer's motor system searches for an action with which it could achieve the same action goal as that attributed to the model (Schwier, Van Maanen, Carpenter, & Tomasello, 2006), irrespective of whether this movement corresponds to the action that was actually observed. For example, children sometime do not imitate the observed body movements (e.g. pressing a light switch with the head, Gergely et al., 2002), but use actions that achieve the same action more efficiently (pressing the light with their hands). However, the goals are identical in all experiments in this thesis, so the action that the motor system "emulates" should be identical as well. The only way these models could account for the present outcome guidance would be to propose that observed successful outcomes prompts the search towards the observed action, but unsuccessful ones bias it towards an alternative, perhaps more successful action. However, so far, these models do not include such a post-hoc, corrective processing step.

The one class of theories that fully accounts for both the findings in goal-directed imitation in children and the present results seem to be ideomotor theories of action and action observation (Camus, Hommel, Brunel, & Brouillet, 2018; Naber, Eijgermans, Herman, Bergman, & Hommel, 2016; Hommel, 2015; Hommel et al, 2001). These models argue that human action learning is fundamentally hierarchical. When we carry out actions ourselves, ideomotor theories propose that we form action representations that connect proximal action features (e.g. extending a finger to press a button) to the distal effects they produce in the environment (e.g., turning on a light). Once these representations are established, observers can use these hierarchical action representations to control their own behaviours. They only need to think if the distal effect they want to achieve, and – via the now established associations – the relevant motor behaviour to execute becomes activated.

Our data suggest that automatic imitation is best described in such a framework. Thus, when people observe an action, hierarchical action representations are established that link the observed actions' proximal features (e.g. using a left or right arm or making a reach or withdrawal) to the outcomes they produce (e.g. winning in the card game, safely grasping an object). As long as these hierarchical representations are coded in terms of actions and outcomes one can produce oneself (e.g., Hommel, 2015; di Pellegrino et al., 1992), they can then be used to guide both goal-directed and automatic imitation. Thus, when intentionally reproducing an action, observers just need to re-activate the positive outcome they want to also activate the just observed motor behaviours, enabling goal-directed imitation. Similarly, if these outcomes are positive and are therefore congruent with the observer's own goals, they would automatically induce automatic imitation, as these outcomes automatically also activate the proximal motor behaviours that have just achieved them.

Together, therefore, this thesis points to set of theoretical approaches that are useful not only to describe the current set of data but can also account for the patterns observed in the literature. They imply the presence of hierarchical action representations whenever we watch the actions of others, which causally link the observed action outcomes to the means with how they were achieved and can then guide both automatic and goal directed imitation.

#### **5.4 Future directions**

The present findings open up several further avenues for research. One important question that could not be fully resolved in this thesis is whether outcome guidance of automatic imitation is even present when not directly evaluated by participants. All experiments have shown that automatic imitation shows a similar outcome-dependence as goal-directed imitation, particularly when participants were explicitly asked to evaluate the observed actions' outcomes. It was less clear whether the same is true when these outcomes were not explicitly evaluated in Chapter 4, Experiment 2, where the effect just failed to reach the threshold for significance (but pointed in the direction of outcome-guidedness).

Several factors might have contributed to this lack of a reliable difference. Visual search studies have revealed that allocation of attention is based on the 'learned value' and requires it to be motivationally salient and rewarding (Failing, Nissens, Pearson, Le Pelley, & Theeuwes, 2015). Anecdotally, however, participants reported losing count of outcomes very quickly from the onset of the game, for positive outcomes in particular. This is consistent with the observation that people tend to orient attention towards negative stimuli more quickly than to positive or neutral stimuli (Kaspar, Gameiro &

König, 2015). However, such a shift would be particularly problematic because learning is widely known to be driven primarily by positive outcomes (rewards providing greater retention O'Doherty, Cockburn, & Pauli, 2017) and the same was true for automatic imitation in the present task. To remedy this problem, one could offer a greater reward for achieving positive outcomes or draw attention towards them by displaying a record of some sort such as a counter. This would allow participants to see what they had achieved so far and focus attention on the relevant positive aspect.

Should such improvements prove to be effective, this task would provide an ideal platform for further investigations on outcome guidance in automatic imitation, allowing one to trace, for example, the development of outcome-based imitation during children's development. It has been argued that children go through periods of change in their imitation habits, moving through intentional imitation, over-imitation (see Hoehl, Keupp, Schleihauf, McGuigan, Buttelmann & Whiten., 2019 for a review; Keupp, Behne, Zachow, Kasbohm, & Rakoczy., 2015) and automatic imitation (McGuigan et al., 2011). However, establishing this sequence has been difficult as there has been no useful task to measure automatic imitation in young children. The task in Chapter 4 provides a simple game on a touch screen, with very easy-to-follow instructions and actions that children of all age groups can carry out. It would, therefore, provide a powerful tool to test when outcome-guided automatic imitation emerges and whether it – like ideomotor theories suggest – is linked to the intentional ability to form hierarchical representations of others' actions, and therefore follows directly the use of these representations during goal-directed imitation.

More broadly, such a task could also disentangle to what extent such the observed sensitivity to others' outcomes depends on the participants' relationship to one another. In the real world, we work closely *with* others to achieve joint goals but also compete

*against* them to satisfy personal goals. Future studies could incorporate differential goals for participants. It would be important to establish, for example, whether participants still imitated the action leading to a positive outcome of another, even if having a different – perhaps even opposing – goal themselves. Consider a task like that in Chapter 4 in which different tones represent different outcomes for the two participants, with one indicating a rewarding outcome for participant 1, and another indicating a rewarding outcome for participant 2, and third neutral tone where neither is rewarded. It would then be possible to compare automatic imitation that is elicited when participants observe their peer make an action that has a positive outcome for themselves, or an outcome that provides a positive outcome for the other participant (compared against a baseline of neutral outcomes for both). If automatic imitation indeed reflects the integration of action outcomes into a hierarchical action representation, one may predict that participants imitate another’s action even if it was positive for this other participant, not themselves (but see the data from Chapter 2, Experiment 4a, in which actions were automatically imitated only when evaluating the outcome for this player, not the opponent).

Such a task could also manipulate participants’ affiliation or group membership. Participants could be introduced to each other as competitors, each attempting to be the first to achieve a finite number of rewarding outcomes based on the three tones as described above, or as collaborators, who have to achieve a number of positive outcomes together (even if each “collects” different tones to achieve this). It is likely (e.g., Bhattacharya, Devinney, & Pillutla, 1998) that imitation would be larger for the observation of others’ positive outcomes in the joint-goal condition, compared to the competing-goals condition. In this way, the tasks developed here could be extended to investigating joint-action, and therefore have implications on how people coordinate

with each other to achieve outcomes far beyond individual capabilities, as seen in the biggest human achievements to date (from building cities to the moon-landing).

## **6. Conclusions**

The experiments in this thesis have confirmed that people have a general tendency to imitate the actions of others and that this imitation reflects the kinematic properties of the observed movements, as argued before. The novel finding of this thesis was the stronger imitation when the modelled action resulted in a positive (or appropriate) action outcome, which was found across two different experimental paradigms (and potentially a third). This persistent outcome-dependency challenges models that explain automatic imitation through a simple bottom-up matching of observed kinematic information to the observers own repertoire, either through a precisely evolved mirror system (e.g., Iacoboni, Koski, Brass, Bekkering, Woods, Dubeau, & Rizzolatti, 2001; Iacoboni, 2009) or due to sensorimotor-learning of motor commands and their perceptual consequences (e.g., Heyes, 2001, 2011). In such models, both negative and positive action outcomes should have elicited automatic imitation equally. That these experiments do in fact elicit such a modulation is especially poignant, as both types of outcome were never part of the observed action, but a randomly following distal consequence, and therefore equally associated with both action possibilities (for example, left and right movements towards targets).

The experiment series in this thesis therefore links automatic imitation in adults to the top-down control in goal-directed imitation in children and primates (Call et al., 2002; Gattis et al., 2002; Elsner, 2007). Much like the data observed here, children generally do not imitate all actions, but specifically those that produce positive or successful

outcomes (for a review, see Elsner, 2007). Moreover, they focus on the actions' outcome and use the same body movements only if these body movements appear critical for action success (e.g., Corriveau et al., 2016; Carpenter et al., 1998; Meltzoff, 1995; Over et al., 2010) and more efficient actions are not available to them (e.g., Tomasello, 1996; Gergely et al., 2002; Buttelmann et al., 2007). The finding that outcome modulation was observed even when movement of inanimate bubbles were evaluated does not challenge this link. Even very young children can see inanimate object movements as goal directed, if these movements show features of intentional movement, such as avoidance of obstacles or a speed up towards a goal (e.g. Gao, McCarthy, & Scholl, 2010). They also link to findings in adults showing that participants embody (i.e. take the perspective) of inanimate objects in Heider and Simmel-like displays (Heider & Simmel, 1944), if they follow intentional movement patterns and consistently behave in a meaningful way (Zwikel & Mueller, 2010). The task to evaluate action outcomes may therefore induce a similar, flexible deployment of teleological evaluation of the observed movements, even if carried out by inanimate agents.

Together, therefore, our data argue that both forms of imitation – automatic and goal-directed imitation – may be guided by similar hierarchical representations that are established when watching other people and which combine both the seen body movements and the outcomes they achieve in the environment. If one follows such a model, the difference between automatic and goal-directed imitation may not lie in top-down versus bottom-up control, but simply in the mode of activation of these hierarchical means-end relationships: while goal-directed imitation requires their voluntary activation (or formation during observation), they are created spontaneously when watching the actions of others during automatic imitation.

## References

- Aczel, B., Kekecs, Z., Bago, B., Szollosi, A., & Foldes, A. (2015). An empirical analysis of the methodology of automatic imitation research in a strategic context. *Journal of Experimental Psychology: Human Perception and Performance*, 41(4), 1049-1062.
- Acharya, S., & Shukla, S. (2012). Mirror neurons: Enigma of the metaphysical modular brain. *Journal of natural science, biology, and medicine*, 3(2), 118.
- Adams, R. A., Shipp, S., & Friston, K. J. (2013). Predictions not commands: active inference in the motor system. *Brain Structure and Function*, 218(3), 611-643.
- Aicken, M. D., Wilson, A. D., Williams, J. H., & Mon-Williams, M. (2007). Methodological issues in measures of imitative reaction times. *Brain and Cognition*, 63(3), 304-308.
- Albers, C., & Lakens, D. (2018). When power analyses based on pilot data are biased: Inaccurate effect size estimators and follow-up bias. *Journal of experimental social psychology*, 74, 187-195.
- Anderson, S. F., Kelley, K., & Maxwell, S. E. (2017). Sample-size planning for more accurate statistical power: A method adjusting sample effect sizes for publication bias and uncertainty. *Psychological science*, 28(11), 1547-1562.
- Anisfeld, M. (1996). Only tongue protrusion modelling is matched by neonates. *Developmental Review*, 16, 149-161.
- Arbib, M. A., Billard, A., Iacoboni, M., & Oztop, E. (2000). Synthetic brain imaging: grasping, mirror neurons and imitation. *Neural Networks*, 13(8-9), 975-997.
- Bach, P., Allami Khalaf, B., Tucker, M., & Ellis, R. (2014). Planning-related motor processes underlie mental practice and imitation learning. *Journal of Experimental Psychology: General*, 143(3), 1277-1294.
- Bach, P., Bayliss, A.P., Tipper, S.P. (2011). The predictive mirror: interactions of mirror and affordance processes during action observation. *Psychonomic Bulletin & Review*, 18(1), 171-6.
- Bach, P. Fenton-Adams, W., Tipper, S.P. (2014). Can't touch this: the first-person perspective provides privileged access to predictions of sensory action outcomes. *Journal of Experimental Psychology: Human Perception and Performance*, 40(2), 457-64.
- Bach, P., Nicholson, T., & Hudson, M. (2014). The affordance-matching hypothesis: how objects guide action understanding and prediction. *Frontiers in Human Neuroscience*, 8.
- Bach, P., Peatfield, N.A., & Tipper, S.P. (2007). Focusing on body sites: the role of spatial attention in action perception. *Experimental Brain Research*, 178, 509-517.
- Bach, P. & Schenke, K. (2017). Predictive social perception: towards a unifying framework from action observation to person knowledge. *Social and Personality Psychology Compass*, 11(7), e12312
- Bach, P. & Tipper, S.P. (2006). Bend it like Beckham: embodying the motor skills of famous athletes. *Quarterly Journal of Experimental Psychology*, 59(12), 2033-2039.
- Bardi, L., Bundt, C., Notebaert, W., & Brass, M. (2015). Eliminating mirror responses by instructions. *Cortex*, 70, 128-136.
- Bellagamba, F., & Tomasello, M. (1999). Re-enacting intended acts: Comparing 12- and 18-month-olds. *Infant Behavior and Development*, 22(2), 277-282.

- Belot, M., Crawford, V. P., & Heyes, C. (2013). Players of Matching Pennies automatically imitate opponents' gestures against strong incentives. *Proceedings of the National Academy of Sciences*, 110(8), 2763-2768.
- Bekkering, H., Wohlschläger, A., & Gattis, M. (2000). Imitation of gestures in children is goal-directed. *Quarterly Journal of Experimental Psychology A*, 53(1), 153-164.
- Bertenthal, B. I., Longo, M. R., & Kosobud, A. (2006). Imitative response tendencies following observation of intransitive actions. *Journal of Experimental Psychology: Human Perception and Performance*, 32(2), 210.
- Bien, N., Roebroek, A., Goebel, R., & Sack, A. T. (2009). The brain's intention to imitate: the neurobiology of intentional versus automatic imitation. *Cerebral Cortex*, 19(10), 2338-2351.
- Binder, E., Dovern, A., Hesse, M. D., Ebke, M., Karbe, H., Saliger, J., ... & Weiss, P. H. (2017). Lesion evidence for a human mirror neuron system. *Cortex*, 90, 125-137.
- Bhattacharya, R., Devinney, T. M., & Pillutla, M. M. (1998). A formal model of trust based on outcomes. *Academy of management review*, 23(3), 459-472.
- Blakemore, S. J., & Decety, J. (2001). From the perception of action to the understanding of intention. *Nature reviews neuroscience*, 2(8), 561.
- Bouquet, C. A., Shipley, T. F., Capa, R. L., & Marshall, P. J. (2011). Motor contagion: Goal-directed actions are more contagious than non-goal-directed actions. *Experimental Psychology*, 58, 71-78.
- Bonini, L. (2017). The extended mirror neuron network: anatomy, origin, and functions. *The Neuroscientist*, 23(1), 56-67.
- Boyer, T. W., Longo, M. R., & Bertenthal, B. I. (2012). Is automatic imitation a specialized form of stimulus-response compatibility? Dissociating imitative and spatial compatibilities. *Acta Psychologica*, 139(3), 440-448.
- Brand, R. J., Baldwin, D. A., & Ashburn, L. A. (2002). Evidence for 'motionese': modifications in mothers' infant-directed action. *Developmental Science*, 5(1), 72-83.
- Brass, M., Bekkering, H., Wohlschläger, A., & Prinz, W. (2000). Compatibility between observed and executed finger movements: comparing symbolic, spatial, and imitative cues. *Brain and Cognition*, 44(2), 124-143.
- Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta psychologica*, 106(1-2), 3-22.
- Brass M., Derrfuss J., von Cramon D. Y. (2005) The inhibition of imitative and overlearned responses: a functional double dissociation. *Neuropsychologia* 43, 89-98
- Brass, M., & Heyes, C. (2005). Imitation: is cognitive neuroscience solving the correspondence problem?. *Trends in cognitive sciences*, 9(10), 489-495.
- Brass, M., & von Cramon, D. Y. (2004). Selection for cognitive control: a functional magnetic resonance imaging study on the selection of task-relevant information. *Journal of Neuroscience*, 24(40), 8847-8852.
- Byrne, R. W., & Russon, A. E. (1998). Learning by imitation: A hierarchical approach. *Behavioral and brain sciences*, 21(5), 667-684.
- Buttelmann, D., Carpenter, M., Call, J., & Tomasello, M. (2007). Enculturated chimpanzees imitate rationally. *Developmental Science*, 10(4).
- Call, J., & Carpenter, M. (2002). Three sources of information in social learning. *Imitation in Animals and Artifacts*, 211-228.

- Campbell, M. E., & Cunnington, R. (2017). More than an imitation game: Top-down modulation of the human mirror system. *Neuroscience & Biobehavioral Reviews*, 75, 195-202.
- Camus, T., Hommel, B., Brunel, L., & Brouillet, T. (2018). From anticipation to integration: the role of integrated action-effects in building sensorimotor contingencies. *Psychonomic bulletin & review*, 25(3), 1059-1065.
- Carpenter, M., Call, J., & Tomasello, M. (2005). Twelve and 18 month olds copy actions in terms of goals. *Developmental Science*, 8(1).
- Carpenter, M., Akhtar, N., & Tomasello, M. (1998). Fourteen- to 18-month-old infants differentially imitate intentional and accidental actions. *Infant Behavior and Development*, 21, 315–330.
- Carpenter, M., Nagell, K., & Tomasello, M. (1998b). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development*, 63, 1–176.
- Castiello, U., Lusher, D., Mari, M., Edwards, M., & Humphreys, G. (2002). Observing a human or a robotic hand grasping an object: Differential motor priming effects. W. Prinz, B. Hommel (Eds.), *Common Mechanisms in Perception and Action, Attention and Performance XIX*, Oxford Univ. Press, New York
- Catmur, C. (2016). Automatic imitation? Imitative compatibility affects responses at high perceptual load. *Journal of Experimental Psychology: Human Perception and Performance*, 42(4), 530.
- Catmur, C. (2015). Understanding intentions from actions: Direct perception, inference, and the roles of mirror and mentalizing systems. *Consciousness and Cognition*, 36, 426-433.
- Catmur, C., & Heyes, C. (2011). Time course analyses confirm independence of imitative and spatial compatibility. *Journal of Experimental Psychology: Human Perception and Performance*, 37(2), 409.
- Catmur, C., Walsh, V., & Heyes, C. (2009). Associative sequence learning: the role of experience in the development of imitation and the mirror system. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 364(1528), 2369-2380.
- Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: the perception–behaviour link and social interaction. *Journal of Personality and Social Psychology*, 76 (6), 893.
- Chartrand, T. L., & Dalton, A. N. (2009). Mimicry: Its ubiquity, importance, and functionality. *Oxford handbook of human action*, 458-483.
- Chartrand, T. L., & Van Baaren, R. (2009). Human mimicry. *Advances in experimental social psychology*, 41, 219-274.
- Chiavarino, C., Bugiani, S., Grandi, E., & Colle, L. (2013). Is Automatic Imitation Based on Goal Coding or Movement Coding? A Comparison of Goal-Directed and Goal-Less Actions. *Experimental Psychology*, 60(3), 213-225.
- Chaminade, T., Meltzoff, A. N., & Decety, J. (2005). An fMRI study of imitation: action representation and body schema. *Neuropsychologia*, 43(1), 115-127.
- Chong, T., Cunnington, R., Williams, M., & Mattingley, J. (2008). The role of selective attention in matching observed and executed actions. *Neuropsychologia*, 47(3), 786-795.
- Cohen Kadosh, R., Lammertyn, J., & Izard, V. (2008). Are numbers special? An overview of chronometric, neuroimaging, developmental and comparative studies of magnitude representation. *Progress in Neurobiology*, 84(2), 132-147.

- Cook, R., Bird, G., Lünser, G., Huck, S., & Heyes, C. (2011). Automatic imitation in a strategic context: players of rock–paper–scissors imitate opponents' gestures. *Proceedings of the Royal Society of London B: Biological Sciences*, rspb20111024.
- Cook, R., Press, C., Dickinson, A., & Heyes, C. (2010). Acquisition of automatic imitation is sensitive to sensorimotor contingency. *Journal of Experimental Psychology: Human Perception and Performance*, 36(4), 840.
- Corriveau, K. H., Min, G., Chin, J., & Doan, S. (2016). Do as I do, not as I say: Actions speak louder than words in preschoolers learning from others. *Journal of Experimental Child Psychology*, 143, 179-187.
- Cracco, E., Bardi, L., Desmet, C., Genschow, O., Rigoni, D., De Coster, L., & Brass, M. (2018). Automatic imitation: A meta-analysis. *Psychological bulletin*.
- Cracco, E., & Brass, M. (2019). Reaction time indices of automatic imitation measure imitative response tendencies. *Consciousness and cognition*, 68, 115-118.
- Craighero, L., Bello, A., Fadiga, L., & Rizzolatti, G. (2002). Hand action preparation influences the responses to hand pictures. *Neuropsychologia*, 40(5), 492-502.
- Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. (1999). Action for perception: a motor-visual attentional effect. *Journal of experimental psychology: Human perception and performance*, 25(6), 1673.
- Craighero, L., Fadiga, L., Umiltà, C. A., & Rizzolatti, G. (1996). Evidence for visuomotor priming effect. *Neuroreport*, 8(1), 347-349.
- Cramér, H. (2016). *Mathematical methods of statistics (PMS-9) (Vol. 9)*. Princeton university press.
- Csibra, G. (2008). Action mirroring and action understanding: An alternative account. Sensorimotor foundations of higher cognition. *Attention and performance XXII*, 435-459.
- Csibra G. (2007). Action mirroring and action understanding: An alternative account. In Haggard P., Rosetti Y., Kawato M. (Eds.), *Attention and performance: Vol. 22. Sensorimotor foundations of higher cognition* (pp. 435–459). Oxford, England: Oxford University Press.
- Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences*, 13, 148-153.
- Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, 122(3), 371.
- Darwin, C. (1871). 2003. *The descent of man. Gibson Square, London.*
- Dennett, D. C. (1989). *The intentional stance*. MIT press.
- Dickerson, K., Gerhardstein, P., Zack, E., & Barr, R. (2013). Age-related changes in learning across early childhood: A new imitation task. *Developmental Psychobiology*, 55(7), 719-732.
- Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: a neurophysiological study. *Experimental Brain Research*, 91(1), 176-180.
- Dimberg, U. (1982). Facial reactions to facial expressions. *Psychophysiology*, 19(6), 86-89.
- Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reaction to emotional facial expressions. *Psychological Science*, 11, 86 – 89.
- Dindo, H., & Schillaci, G. (2010). An adaptive probabilistic approach to goal-level imitation learning. In 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems (pp. 4452-4457). IEEE.

- Doneva, S. P., Atkinson, M. A., Skarratt, P. A., & Cole, G. G. (2017). Action or attention in social inhibition of return? *Psychological research*, 81(1), 43-54.
- Duffy, K., & Chartrand, T. (2015). Mimicry: Causes and consequences. *Current Opinion in Behavioral Sciences*, 3, 112-116.
- Edwards, M. G., Humphreys, G. W., & Castiello, U. (2003). Motor facilitation following action observation: A behavioural study in prehensile action. *Brain and cognition*, 53(3), 495-502.
- Elsner, B. (2007). Infants' imitation of goal directed actions: the role of movements and action effects. *Acta Psychologica*, 124(1), 44-59
- Elsner, B., & Aschersleben, G. (2003). Do I get what you get? Learning about the effects of self-performed and observed actions in infancy. *Consciousness and Cognition*, 12(4), 732-751.
- Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. *Journal of experimental psychology: human perception and performance*, 27(1), 229.
- Eshuis, R., Coventry, K. R., & Vulchanova, M. (2009). Predictive eye movements are driven by goals, not by the mirror neuron system. *Psychological Science*, 20(4), 438-440.
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G\*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149-1160.
- Failing, M., Nissens, T., Pearson, D., Le Pelley, M., & Theeuwes, J. (2015). Oculomotor capture by stimuli that signal the availability of reward. *Journal of Neurophysiology*, 114(4), 2316-2327.
- Fernald, A. (1985). Four-month-old infants prefer to listen to motherese. *Infant behavior and development*, 8(2), 181-195.
- Ferrari, P. F., Bonini, L., & Fogassi, L. (2009). From monkey mirror neurons to primate behaviours: possible 'direct' and 'indirect' pathways. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1528), 2311-2323.
- Ferrari, P. F., & Coudé, G. (2018). Mirror neurons, embodied emotions, and empathy. In *Neuronal Correlates of Empathy* (pp. 67-77). Academic Press.
- Festinger, L., & Carlsmith, J. M. (1959). Cognitive consequences of forced compliance. *The journal of abnormal and social psychology*, 58(2), 203.
- Fischer, M. (2003). Spatial representations in number processing--evidence from a pointing task. *Visual Cognition*, 10(4), 493-508.
- Flanders, J. P. (1968). A review of research on imitative behavior. *Psychological bulletin*, 69(5), 316.
- Fogassi, L. (1998). Neurons responding to the sight of goal-directed hand/arm actions in the parietal area PF (7b) of the macaque monkey. In *28th Annual Meeting of Society for Neuroscience*.
- Gallagher, S. (2015). How embodied cognition is being disembodied. *The Philosophers' Magazine*, (68), 96-102.
- Gallese, V. (2001). The 'shared manifold' hypothesis. From mirror neurons to empathy. *Journal of consciousness studies*, 8(5-6), 33-50.
- Gallese, V. (2005). Embodied simulation: From neurons to phenomenal experience. *Phenomenology and the cognitive sciences*, 4(1), 23-48.
- Gallese, V. (2009). Motor abstraction: A neuroscientific account of how action goals and intentions are mapped and understood. *Psychological Research PRPF*, 73(4), 486-498.
- Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain*, 119(2), 593-609.

- Gallese, V., & Goldman, A. (1998). Mirror neurons and the simulation theory of mind-reading. *Trends in cognitive sciences*, 2(12), 493-501.
- Gao, T., McCarthy, G., & Scholl, B. J. (2010). The wolfpack effect: Perception of animacy irresistibly influences interactive behavior. *Psychological science*, 21(12), 1845-1853.
- Gattis, M., Bekkering, H., & Wohlschläger, A. (2002). Goal-directed imitation. In A. Meltzoff, & W. Prinz (Eds.). *The imitative mind* (pp. 183–205). Cambridge: Cambridge University Press.
- Gergely, G., Bekkering, H., & Király, I. (2002). Developmental psychology: Rational imitation in preverbal infants. *Nature*, 415 (6873), 755-755.
- Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: The naive theory of rational action. *Trends in Cognitive Sciences*, 7(7), 287-292.
- Girelli, L., Lucangeli, D., & Butterworth, B. (2000). The development of automaticity in accessing number magnitude. *Journal of Experimental Child Psychology*, 76(2), 104-122. doi: 10.1006/jecp.2000.2564
- Gelman, R., Durgin, F., & Kaufman, L. (1995). Distinguishing between animates and inanimates: Not by motion alone. *Causal cognition: A multidisciplinary debate*, 150-184.
- Genschow, O., Florack, A., & Wänke, M. (2013). The power of movement: Evidence for context-independent movement imitation. *Journal of Experimental Psychology: General*, 142(3), 763.
- Genschow, O., & Schindler, S. (2016). The influence of group membership on cross-contextual imitation. *Psychonomic bulletin & review*, 23(4), 1257-1265.
- Genschow, O., van Den Bossche, S., Cracco, E., Bardi, L., Rigoni, D., & Brass, M. (2017). Mimicry and automatic imitation are not correlated. *PloS one*, 12(9), e0183784.
- Gergely, G., Bekkering, H., & Király, I. (2002). Developmental psychology: Rational imitation in preverbal infants. *Nature*, 415(6873), 755.
- Gergely, G., & Csibra, G. (2006). Sylvia's recipe: The role of imitation and pedagogy in the transmission of cultural knowledge. *Roots of human sociality: Culture, cognition, and human interaction*, 229-255.
- Giesen, C., Scherdin, K., & Rothermund, K. (2017). Flexible goal imitation: Vicarious feedback influences stimulus-response binding by observation. *Learning & behavior*, 45(2), 147-156.
- Gillmeister, H., Catmur, C., Liepelt, R., Brass, M., & Heyes, C. (2008). Experience-based priming of body parts: a study of action imitation. *Brain research*, 1217, 157-170.
- Gowen, E., Stanley, J., & Miall, R. C. (2008). Movement interference in autism-spectrum disorder. *Neuropsychologia*, 46(4), 1060-1068.
- Girelli, L., Lucandeli, D., & Butterworth, B. (2000). The development of automaticity in accessing number magnitude. *Journal of Experimental Child Psychology*, 76(2), 104-122.
- Grafton, S. T., & Hamilton, A. F. D. C. (2007). Evidence for a distributed hierarchy of action representation in the brain. *Human Movement Science*, 26(4), 590-616.
- Greenwald, A.G. (1970) Sensory feedback mechanisms in performance control: with special reference to the ideo-motor mechanism. *Psychol. Rev.*, 77, 73-99
- Greenwald, A. G. (1972). On doing two things at once: time sharing as a function of ideomotor compatibility. *Journal of experimental psychology*, 94(1), 52.
- Hamilton, A. F. (2015). The neurocognitive mechanisms of imitation. *Current Opinion in Behavioral Sciences*, 3, 63-67

- Hamilton, A. D. C., Joyce, D. W., Flanagan, J. R., Frith, C. D., & Wolpert, D. M. (2007). Kinematic cues in perceptual weight judgement and their origins in box lifting. *Psychological research*, 71(1), 13-21.
- Hauf, P., Elsner, B., & Aschersleben, G. (2004). The role of action effects in infants' action control. *Psychological Research*, 68(2/3), 115–125.
- Hayes, S. J., Roberts, J. W., Elliott, D., & Bennett, S. J. (2014). Top-down attentional processes modulate the coding of atypical biological motion kinematics in the absence of motor signals. *Journal of experimental psychology: human perception and performance*, 40(4), 1641.
- Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *The American journal of psychology*, 57(2), 243-259.
- Hennenlotter, A., Dresel, C., Castrop, F., Ceballos-Baumann, A. O., Wohlschläger, A. M., & Haslinger, B. (2008). The link between facial feedback and neural activity within central circuitries of emotion—New insights from Botulinum toxin–induced denervation of frown muscles. *Cerebral Cortex*, 19(3), 537-542.
- Heyes, C. (2001). Causes and consequences of imitation. *Trends in cognitive sciences*, 5(6), 253-261.
- Heyes, C. M. (1993). Imitation, culture and cognition. *Animal Behaviour*, 46(5), 999-1010.
- Heyes, C. (2010). Mesmerising mirror neurons. *Neuroimage*, 51(2), 789-791.
- Heyes, C., & Ray, E. (2004). Spatial SR compatibility effects in an intentional imitation task. *Psychonomic Bulletin & Review*, 11(4), 703-708.
- Heyes, C., Bird, G., Johnson, H., & Haggard, P. (2005). Experience modulates automatic imitation. *Cognitive Brain Research*, 22(2), 233-240.
- Heyes, C. (2011). Automatic imitation. *Psychological Bulletin*, 137(3), 463.
- Heyes, C. M. (2012). “Imitation - associative and context-dependent,” in *Tutorials in Action Science*, eds W. Prinz, M. Beisert, and A. Herwig (Cambridge, MA: MIT Press).
- Hickok, G. (2009). Eight problems for the mirror neuron theory of action understanding in monkeys and humans. *Journal of cognitive neuroscience*, 21(7), 1229-1243.
- Hickok, G., & Hauser, M. (2010). (Mis) understanding mirror neurons. *Current Biology*, 20(14), R593-R594.
- Hoehl, S., Keupp, S., Schleihauf, H., McGuigan, N., Buttelmann, D., & Whiten, A. (2019). ‘Over-imitation’: A review and appraisal of a decade of research. *Developmental Review*, 51, 90-108.
- Hofree, G., Urgen, B. A., Winkielman, P., & Saygin, A. P. (2015). Observation and imitation of actions performed by humans, androids, and robots: an EMG study. *Frontiers in human neuroscience*, 9, 364.
- Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). Codes and their vicissitudes. *Behavioral and Brain Sciences*, 24(5), 910-926.
- Horner, V., Whiten, A., Flynn, E., & de Waal, F. B. (2006). Faithful replication of foraging techniques along cultural transmission chains by chimpanzees and children. *Proceedings of the National Academy of Sciences*, 103(37), 13878-13883.
- Huang, C. T., Heyes, C., & Charman, T. (2002). Infants' behavioral reenactment of "failed attempts": exploring the roles of emulation learning, stimulus enhancement, and understanding of intentions. *Developmental Psychology*, 38(5), 840.
- Huang, C.-T., Heyes, C. M., & Charman, T. (2002). Infants' behavioral re-enactment of 'failed attempts': Exploring the roles of emulation learning, stimulus enhancement and understanding of intentions. *Developmental Psychology*, 38, 840–855.

- Hudson, M., Nicholson, T., Ellis, R., & Bach, P. (2016). I see what you say: Prior knowledge of other's goals automatically biases the perception of their actions. *Cognition*, 146, 245-250.
- Hudson, M., Nicholson, T., Simpson, W. A., Ellis, R., & Bach, P. (2016). One step ahead: The perceived kinematics of others' actions are biased toward expected goals. *Journal of Experimental Psychology: General*, 145(1), 1-7.
- Hyman, R. (2007). Ouija, dowsing, and other seductions of ideomotor action. *Tall tales about the mind & brain: Separating fact from fiction*, 411-424.
- Iacoboni, M., Koski, L. M., Brass, M., Bekkering, H., Woods, R. P., Dubeau, M. C., ... & Rizzolatti, G. (2001). Reafferent copies of imitated actions in the right superior temporal cortex. *Proceedings of the national academy of sciences*, 98(24), 13995-13999.
- Iacoboni, M. (2005). Neural mechanisms of imitation. *Current Opinion in Neurobiology*, 15(6), 632-637.
- Iacoboni, M. (2009). Imitation, empathy, and mirror neurons. *Annual Review of Psychology*, 60, 653-670.
- Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, G. (1999). Cortical mechanisms of human imitation. *Science*, 286, 2526-2528.
- Jackson, P. L., Meltzoff, A. N., & Decety, J. (2006). Neural circuits involved in imitation and perspective-taking. *Neuroimage*, 31(1), 429-439.
- James, W. (1890). The perception of reality. *Principles of psychology*, 2, 283-324.
- Jansson, E., Wilson, A. D., Williams, J. H., & Mon-Williams, M. (2007). Methodological problems undermine tests of the ideo-motor conjecture. *Experimental Brain Research*, 182(4), 549-558.
- Jones, S. S. (2006). Exploration or imitation? The effect of music on 4-week-old infants' tongue protrusions. *Infant Behavior and Development*, 29(1), 126-130.
- Joyce, K., Schenke, K., Bayliss, A. & Bach, P. (2015). Looking ahead: Anticipatory cuing of attention to objects others will look at. *Cognitive Neuroscience*, 1-8. DOI: 10.1080/17588928.2015.1053443
- Kaspar, K., Gameiro, R. R., & König, P. (2015). Feeling good, searching the bad: Positive priming increases attention and memory for negative stimuli on webpages. *Computers in Human Behavior*, 53, 332-343.
- Keysers, C., & Gazzola, V. (2010). Social neuroscience: mirror neurons recorded in humans. *Current biology*, 20(8), R353-R354.
- Keysers, C., Kohler, E., Umiltà, M. A., Nanetti, L., Fogassi, L., & Gallese, V. (2003). Audiovisual mirror neurons and action recognition. *Experimental Brain Research*, 153(4), 628-636.
- Keupp, S., Behne, T., Zachow, J., Kasbohm, A., & Rakoczy, H. (2015). Over-imitation is not automatic: Context sensitivity in children's overimitation and action interpretation of causally irrelevant actions. *Journal of Experimental Child Psychology*, 130, 163-175.
- Kilner, J., Hamilton, A. F. D. C., & Blakemore, S. J. (2007). Interference effect of observed human movement on action is due to velocity profile of biological motion. *Social neuroscience*, 2(3-4), 158-166.
- Kilner, J., Paulignan, Y., & Blakemore, S. (2003). An interference effect of observed biological movement on action. *Current Biology*, 13, 522-525.
- Klapper, A., Ramsey, R., Wigboldus, D., & Cross, E. S. (2014). The control of automatic imitation based on Bottom-Up and Top-Down cues to animacy: Insights from brain and behavior. *Journal of cognitive neuroscience*, 26(11), 2503-2513.

- Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: cognitive basis for stimulus-response compatibility--a model and taxonomy. *Psychological review*, 97(2), 253.
- Lakin, J. L., Jefferis, V. E., Cheng, C. M., & Chartrand, T. L. (2003). The chameleon effect as social glue: Evidence for the evolutionary significance of nonconscious mimicry. *Journal of nonverbal behavior*, 27(3), 145-162.
- Lavie, N. (2006). The role of perceptual load in visual awareness. *Brain research*, 1080(1), 91-100.
- Leighton, J., Bird, G., Orsini, C., & Heyes, C. (2010). Social attitudes modulate automatic imitation. *Journal of Experimental Social Psychology*, 46(6), 905-910.
- Leighton, J., & Heyes, C. (2010). Hand to mouth: automatic imitation across effector systems. *Journal of Experimental Psychology: Human Perception and Performance*, 36(5), 1174.
- Liepelt, R., Prinz, W., & Brass, M. (2010). When do we simulate non-human agents? Dissociating communicative and non-communicative actions. *Cognition*, 115(3), 426-434.
- Liepelt, R., von Cramon, D., & Brass, M. (2008). What is matched in direct matching? Intention attribution modulates motor priming. *Journal of Experimental Psychology: Human Perception and Performance*, 34(3), 578.
- Longo, M. R., Kosobud, A., & Bertenthal, B. I. (2008). Automatic imitation of biomechanically possible and impossible actions: Effects of priming movements versus goals. *Journal of Experimental Psychology: Human Perception and Performance*, 34(2), 489.
- Lotze, M., & Halsband, U. (2006). Motor imagery. *Journal of Physiology-paris*, 99(4-6), 386-395.
- Lyons, D. E., Damrosch, D. H., Lin, J. K., Macris, D. M., & Keil, F. C. (2011). The scope and limits of overimitation in the transmission of artefact culture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366(1567), 1158-1167.
- Lyons, D. E., Young, A. G., & Keil, F. C. (2007). The hidden structure of overimitation. *Proceedings of the National Academy of Sciences of the United States of America*, 104, 19751-19756. doi:10.1073/pnas.0704452104
- Longo, M. R., & Bertenthal, B. I. (2009). Attention modulates the specificity of automatic imitation to human actors. *Experimental Brain Research*, 192(4), 739-744.
- Manzone, J., Cole, G. G., Skarratt, P. A., & Welsh, T. N. (2017). Response-specific effects in a joint action task: social inhibition of return effects do not emerge when observed and executed actions are different. *Psychological research*, 81(5), 1059-1071.
- Massen, C., & Prinz, W. (2009). Movements, actions and tool-use actions: an ideomotor approach to imitation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1528), 2349-2358.
- McGuigan, N., Makinson, J., & Whiten, A. (2011). From over-imitation to super-copying: Adults imitate causally irrelevant aspects of tool use with higher fidelity than young children. *British Journal of Psychology*, 102(1), 1-18.
- Meltzoff, A. N. (1993). Molyneux's babies: Cross-modal perception, imitation and the mind of the preverbal infant. *Spatial representation: Problems in philosophy and psychology*, 219-235.

- Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. *Developmental Psychology*, 31, 838–850.
- Meltzoff, A. N. (1988a). Infant imitation after a 1-week delay: Long-term memory for novel acts and multiple stimuli. *Developmental Psychology*, 24, 470-47
- Meltzoff, A.N. (2002) Imitation as a mechanism of social cognition: Origins of empathy, theory of mind, and the representation of action. *In Handbook of Childhood Cognitive Development* (Goswami, U., ed.), Blackwell Publishers
- Meltzoff, A. N., & Moore, M. K. (1977). Imitation of facial and manual gestures by human neonates. *Science*, 198(4312), 75-78.
- Meltzoff, A. N., & Moore, M. K. (1979). Interpreting "imitative" responses in early infancy. *Science*, 205(4402), 217-219.
- Moore, M. K., & Meltzoff, A. N. (2008). Factors affecting infants' manual search for occluded objects and the genesis of object permanence. *Infant Behavior and Development*, 31(2), 168-180.
- Meltzoff, A. N., & Moore, M. K. (1997). Explaining facial imitation: A theoretical model. *Infant and child development*, 6(3-4), 179-192.
- Merten, K., & Nieder, A. (2012). Active encoding of decisions about stimulus absence in primate prefrontal cortex neurons. *Proceedings of the National Academy of Sciences*, 109(16), 6289-6294.
- Moraru, C. A., Gomez, J. C., & McGuigan, N. (2016). Developmental changes in the influence of conventional and instrumental cues on over-imitation in 3-to 6-year-old children. *Journal of Experimental Child Psychology*, 145, 34-47.
- Mukamel, R., Ekstrom, A. D., Kaplan, J., Iacoboni, M., & Fried, I. (2010). Single-neuron responses in humans during execution and observation of actions. *Current biology*, 20(8), 750-756.
- Naber, M., Eijgermans, W., Herman, A. S., Bergman, A., & Hommel, B. (2016). Similarity of actions depends on the functionality of previously observed actions. *Journal of experimental psychology: human perception and performance*, 42(5), 719.
- Newman-Norland, R. D., Noordzij, M. L., Meulenbroek, R. G., and Bekkering, H. (2007). Exploring the brain basis of joint action: co-ordination of actions, goals, and intentions. *Soc. Neurosci.* 2, 48–65.
- Nuerk, H. C., Wood, G., & Willmes, K. (2005). The universal SNARC effect: The association between number magnitude and space is amodal. *Experimental psychology*, 52(3), 187-194.
- Nielsen, M. (2006). Copying actions and copying outcomes: social learning through the second year. *Developmental psychology*, 42(3), 555.
- Nielsen, M., & Blank, C. (2011). Imitation in young children: When who gets copied is more important than what gets copied. *Developmental psychology*, 47(4), 1050.
- Nielsen, M., Moore, C., & Mohamedally, J. (2012). Young children overimitate in third-party contexts. *Journal of experimental child psychology*, 112(1), 73-83.
- Nielsen, M., & Tomaselli, K. (2010). Overimitation in Kalahari Bushman children and the origins of human cultural cognition. *Psychological science*, 21(5), 729-736.
- Nishizawa, H., Kimura, T., & Goh, A. C. (2015). The effect of different imitation models on the accuracy and speed of imitation of movement. *Journal of physical therapy science*, 27(11), 3417-3420.
- Obhi, S. S., & Hogeveen, J. (2013). The controlled imitation task: a new paradigm for studying self-other control. *PeerJ*, 1, e161.

- Ocampo, B., Kritikos, A., & Cunnington, R. (2011). How frontoparietal brain regions mediate imitative and complementary actions: an fMRI study. *PLoS One*, 6(10), e26945.
- O'Doherty, J. P., Cockburn, J., & Pauli, W. M. (2017). Learning, reward, and decision making. *Annual review of psychology*, 68, 73-100.
- Olineck, K. M., & Poulin-Dubois, D. (2005). Infants' ability to distinguish between intentional and accidental actions and its relation to internal state language. *Infancy*, 8(1), 91-100.
- Opfer, J. E., & Gelman, S. A. (2011). Development of the animate-inanimate distinction. *The Wiley-Blackwell handbook of childhood cognitive development*, 2, 213-238.
- Over, H., & Carpenter, M. (2009). Priming third-party ostracism increases affiliative imitation in children. *Developmental science*, 12(3), F1-F8.
- Over, H., & Carpenter, M. (2012). Putting the social into social learning: explaining both selectivity and fidelity in children's copying behaviour. *Journal of Comparative Psychology*, 126 (2), 182.
- Over, H., & Gattis, M. (2010). Verbal imitation is based on intention understanding. *Cognitive Development*, 25(1), 46-55.
- Pelphrey, K. A., & Morris, J. P. (2006). Brain mechanisms for interpreting the actions of others from biological-motion cues. *Current Directions in Psychological Science*, 15(3), 136-140.
- Petersik, J. T., & Rosner, A. (1990). The effects of position cues on the appearance of stimulus elements in a bistable apparent movement display. *Perception & psychophysics*, 48(3), 280-284.
- Pickering, M. J., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and brain sciences*, 27(2), 169-190.
- Prinz, W. (2005). An ideomotor approach to imitation. *Perspectives on imitation: From neuroscience to social science*, 1, 141-156.
- Ramsey, R., Cumming, J., Eastough, D., & Edwards, M. G. (2010). Incongruent imagery interferes with action initiation. *Brain and Cognition*, 74(3), 249-254.
- Ramsey, R., Darda, K. M., & Downing, P. E. (2019). Automatic imitation remains unaffected under cognitive load. *Journal of Experimental Psychology: Human Perception and Performance*, 45(5), 601.
- Range, F., Viranyi, Z., & Huber, L. (2007). Selective imitation in domestic dogs. *Current Biology*, 17(10), 868-872.
- Ray, E., & Heyes, C. (2011). Imitation in infancy: the wealth of the stimulus. *Developmental science*, 14(1), 92-105.
- Richardson, M. J., Marsh, K. L., Isenhower, R. W., Goodman, J. R., & Schmidt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science*, 26(6), 867-891.
- Rizzolatti, G. (2005). The mirror neuron system and its function in humans. *Anatomy and embryology*, 210(5-6), 419-421.
- Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature reviews neuroscience*, 2(9), 661.
- Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annu. Rev. Neurosci.*, 27, 169-192.
- Rizzolatti, G., & Fabbri-Destro, M. (2008). The mirror system and its role in social cognition. *Current Opinion in Neurobiology*, 18(2), 179-184.

- Rizzolatti, G., & Fogassi, L. (2014). The mirror mechanism: recent findings and perspectives. *Phil. Trans. R. Soc. B*, 369(1644), 20130420.
- Rizzolatti, G., & Luppino, G. (2001). The cortical motor system. *Neuron*, 31(6), 889-901.
- Rizzolatti, G., & Sinigaglia, C. (2016). The mirror mechanism: a basic principle of brain function. *Nature Reviews Neuroscience*, 17(12), 757.
- Rizzolatti, G., & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nature reviews neuroscience*, 11(4), 264.
- Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: just like one's own? *Cognition*, 88(3), B11-B21.
- Roseman, I. J., Wiest, C., & Swartz, T. S. (1994). Phenomenology, behaviors, and goals differentiate discrete emotions. *Journal of personality and social psychology*, 67(2), 206.
- Schwier, C., Van Maanen, C., Carpenter, M., & Tomasello, M. (2006). Rational imitation in 12-month-old infants. *Infancy*, 10(3), 303-311.
- Scott, M. W., Emerson, J. R., Dixon, J., Tayler, M. A., & Eaves, D. L. (2019). Motor imagery during action observation enhances automatic imitation in children with and without developmental coordination disorder. *Journal of experimental child psychology*, 183, 242-260.
- Shaki, S., Fischer, M. H., & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic bulletin & review*, 16(2), 328-331.
- Shea, N. (2009). Imitation as an inheritance system. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1528), 2429-2443.
- Shin, Y. K., Proctor, R. W., & Capaldi, E. J. (2010). A review of contemporary ideomotor theory. *Psychological bulletin*, 136(6), 943.
- Simon, J. R. (1969). Reactions toward the source of stimulation. *Journal of experimental psychology*, 81(1), 174.
- Skarratt, P. A., Cole, G. G., & Kingstone, A. (2010). Social inhibition of return. *Acta psychologica*, 134(1), 48-54.
- Southgate, V., Chevallier, C., & Csibra, G. (2009). Sensitivity to communicative relevance tells young children what to imitate. *Developmental Science*, 12(6), 1013-1019.
- Spengler, S., Brass, M., Kühn, S., & Schütz-Bosbach, S. (2010). Minimizing motor mimicry by myself: Self-focus enhances online action-control mechanisms during motor contagion. *Consciousness and cognition*, 19(1), 98-106.
- Stanley, J., Gowen, E., & Miall, R. C. (2007). Effects of agency on movement interference during observation of a moving dot stimulus. *Journal of Experimental Psychology: Human Perception and Performance*, 33(4), 915.
- Stel, M., & Van Knippenberg, A. (2008). The role of facial mimicry in the recognition of affect. *Psychological Science*, 19(10), 984.
- Stel, M., & Vonk, R. (2010). Mimicry in social interaction: Benefits for mimickers, mimicked, and their interaction. *British Journal of Psychology*, 101(2), 311-323.
- Stürmer, B., Aschersleben, G., & Prinz, W. (2000). Correspondence effects with manual gestures and postures: a study of imitation. *Journal of Experimental Psychology: Human Perception and Performance*, 26(6), 1746.
- Subiaul, F., Cantlon, J. F., Holloway, R. L., & Terrace, H. S. (2004). Cognitive imitation in rhesus macaques. *Science*, 305(5682), 407-410.

- Subiaul, F., Patterson, E. M., Schilder, B., Renner, E., & Barr, R. (2015). Becoming a high-fidelity–super–imitator: what are the contributions of social and individual learning?. *Developmental Science*, 18(6), 1025-1035.
- Surtees, A., Apperly, I.A. & Samson, D. (2016). I've got your number: Spontaneous perspective-taking in an interactive task. *Cognition*, 150, 43-52.
- Thill, S., Caligiore, D., Borghi, A. M., Ziemke, T., & Baldassarre, G. (2013). Theories and computational models of affordance and mirror systems: an integrative review. *Neuroscience & Biobehavioral Reviews*, 37(3), 491-521.
- Tipper, S.P. & Bach, P. (2011). The face inhibition effect: Social contrast or motor competition? *Journal of Cognitive Psychology*, 23(1), 45-51.
- Tomasello, M. 1996. Do apes ape? In: *Social learning in animals: The roots of culture*, edited by C. M. Heyes and B. G. Galef, 319-346. New York: Academic Press.
- Tomasello, M., Kruger, A. C., & Ratner, H. H. (1993). Cultural learning. *Behavioral and Brain Sciences*, 16(3), 495-511.
- Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human perception and performance*, 24(3), 830.
- Van Baaren, R. B., Maddux, W. W., Chartrand, T. L., De Bouter, C., & van Knippenberg, A. (2003). It takes two to mimic: behavioral consequences of self-construals. *Journal of Personality and Social Psychology*, 84(5), 1093.
- Van der Wel, R. P. R. D., Sebanz, N., & Knoblich, G. (2013). Action perception from a common coding perspective. In: *People watching: Social, perceptual, and neurophysiological studies of body perception*, 101-119.
- Wang, Y., Newport, R., & Hamilton, A. F. D. C. (2010). Eye contact enhances mimicry of intransitive hand movements. *Biology letters*, rsbl20100279.
- Wang, Y., & Hamilton, A. F. D. C. (2012). Social top-down response modulation (STORM): a model of the control of mimicry in social interaction. *Frontiers in Human Neuroscience*, 6.
- Washburn, M. F. (1908). *The animal mind: A textbook of comparative psychology*. New York: Macmillan.
- Washburn, M. F. (1917). *The Social Psychology of Man and the Lower Animals. Studies in Psychology Contributed by Colleagues and Former Students of Edward Bradford Titchener*. Worcester, MA: Louis. N. Wilson (1917): 11-17.
- Watson-Jones, R. E., Legare, C. H., Whitehouse, H., & Clegg, J. M. (2014). Task-specific effects of ostracism on imitative fidelity in early childhood. *Evolution and Human Behavior*, 35(3), 204-210.
- Wegner, D. M. (1994). Ironic processes of mental control. *Psychological review*, 101(1), 34.
- Wertheimer, M. (2012) Experimentelle Studien über das Sehen von Bewegung, *Z. Psycho!*, 61, 161-265
- Wilks, M., Collier-Baker, E., & Nielsen, M. (2015). Preschool children favor copying a successful individual over an unsuccessful group. *Developmental Science*, 18(6), 1014-1024.
- Williams, L. E., & Bargh, J. A. (2008). Keeping one's distance: The influence of spatial distance cues on affect and evaluation. *Psychological Science*, 19(3), 302-308.
- Williamson, R. A., & Brand, R. J. (2014). Child-directed action promotes 2-year-olds' imitation. *Journal of Experimental Child Psychology*, 118, 119-126.
- Whiten, A., McGuigan, N., Marshall-Pescini, S., & Hopper, L. M. (2009). Emulation, imitation, over-imitation and the scope of culture for child and chimpanzee.

- Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1528), 2417-2428.
- Wertheimer, M. (1912). Experimentelle studien uber das sehen von bewegung. *Zeitschrift fur Psychologie*, 61.
- Wohlschläger, A., & Bekkering, H. (2002). Is human imitation based on a mirror-neuron system? Some behavioural evidence. *Experimental Brain Research*, 143(3), 335-341.
- Wohlschläger, A., Gattis, M., & Bekkering, H. (2003). Action generation and action perception in imitation: an instance of the ideomotor principle. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 358(1431), 501-515.
- Wu, Y., Evans, B. G., & Adank, P. (2019). Sensorimotor training modulates automatic imitation of visual speech. *Psychonomic bulletin & review*, 1-8.
- Van Baaren, R. B., Maddux, W. W., Chartrand, T. L., De Bouter, C., & Van Knippenberg, A. (2003). It takes two to mimic: behavioral consequences of self-construals. *Journal of personality and social psychology*, 84(5), 1093.
- van der Wel, R. P., Sebanz, N., & Knoblich, G. (2014). Do people automatically track others' beliefs? Evidence from a continuous measure. *Cognition*, 130(1), 128-133.
- van Schie, H. T., van Waterschoot, B. M., & Bekkering, H. (2008). Understanding action beyond imitation: reversed compatibility effects of action observation in imitation and joint action. *Journal of Experimental Psychology: Human Perception and Performance*, 34(6), 1493.
- Van Zandt, T., & Townsend, J. T. (1993). Self-terminating versus exhaustive processes in rapid visual and memory search: An evaluative review. *Perception & Psychophysics*, 53(5), 563-580.
- Xiaojun, Z., Xuqun, Y., Changxiu, S., Shuoqiu, G., & Chaoyi, H. (2014). Reference Valence Effects of Affective S–R Compatibility: Are Visual and Auditory Results Consistent?. *PloS one*, 9(4), e95085.
- Zentgraf, K., Stark, R., Reiser, M., Künzell, S., Schienle, A., Kirsch, P., ... & Munzert, J. (2005). Differential activation of pre-SMA and SMA proper during action observation: effects of instructions. *Neuroimage*, 26(3), 662-672.
- Zwicker, J., & Müller, H. J. (2010). Observing fearful faces leads to visuo-spatial perspective taking. *Cognition*, 117(1), 101-105.

## Appendix A



*broken glass*

How painful do you imagine it would be to grasp this object?

--	--	--	--	--

Not at all

Very much

To what degree do you judge this from personal experience?

--	--	--	--	--

Not at all

Very much



*cactus*

How painful do you imagine it would be to grasp this object?

--	--	--	--	--

Not at all

Very much

To what degree do you judge this from personal experience?

--	--	--	--	--

Not at all

Very much



*Intact glass*

How painful do you imagine it would be to grasp this object?

--	--	--	--	--

Not at all

Very much

To what degree do you judge this from personal experience?

--	--	--	--	--

Not at all

Very much



*orange*

How painful do you imagine it would be to grasp this object?

--	--	--	--	--

Not at all

Very much

To what degree do you judge this from personal experience?

--	--	--	--	--

Not at all

Very much