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Wood, Katie

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Action Slips in Food Choices: A Measure of Habits and Goal-Directed Control

Katie M. J. Wood[1], Tina Seabrooke[2], and Chris J. Mitchell[1]

[1] University of Plymouth

[2] University of Southampton

Author note

Correspondence should be addressed to Katie Wood, School of Psychology, University of Plymouth, Devon, PL4 8AA, United Kingdom. Email: katie.wood@plymouth.ac.uk.

All data and analyses will be publicly archived at https://osf.io/yn3me/ upon publication of the manuscript.

Abstract

We report a new, simple instrumental action-slip task, which sets goal-directed action against putative S-R associations. On each training trial, participants were presented with one of two stimuli (blue or green coloured screen). One stimulus (S1) signalled that one joystick response (R1 – left or right push) would earn one of two rewards (O1 – jellybeans or Pringles points). A second stimulus (S2) signalled a different instrumental relationship (S2:R2-O2). On each test trial, participants were told which outcome could be earnt (O1/O2) on that trial. They were required to withhold responding until the screen changed colour to S1 or S2. On congruent test trials, the stimulus presented (e.g., S1) was associated with the same response (R1) as the outcome available on that trial (O1). On incongruent test trials, in contrast, the outcome (e.g., O1) preceded a stimulus that was associated with a different response (e.g., S2). Hence, in order to obtain the outcome (O1) on incongruent trials, participants were required to supress any tendency they might have to make the response associated with the stimulus (R2 in response to S2). In two experiments, participants made more errors on incongruent than congruent trials. This result suggests that, on incongruent trials, the stimulus drove responding (e.g., S2 increased R2 responding) in a manner that was inconsistent with goal-directed action (e.g., R1 responding to obtain O1) – an action slip. The results are discussed in terms of popular dual-process theories of instrumental action and a single-process alternative.

Keywords. habits, goal-directed control, action slips

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In changing environments, it is essential to flexibly adapt behaviour to the present circumstances. Instrumental learning is one important way in which animals learn to adapt behaviour to obtain valued outcomes, such as food or money, and avoid aversive outcomes such as pain (O'Doherty, Cockburn & Pauli, 2017).

Dual-process theories of instrumental learning propose that instrumental behaviours are controlled by two systems: a goal-directed system and stimulus-triggered habitual system (e.g., Dickinson & Balleine, 1994; Verplanken, 2018). The goal-directed system is suggested to facilitate deliberate, reward-driven actions, while the habitual system is suggested to produce comparatively automatic responses based on stimulus-response (S-R) associations. In this way, dual-process theories of instrumental learning capture a wide range of both adaptive and counterproductive reward-based behaviours. The goal-directed system is slow to respond and effortful, but highly sensitive to environmental changes. In contrast, the habitual system operates quickly and effortlessly, but is error-prone when the environment changes and old responses are no longer appropriate.

The outcome revaluation procedure is the canonical test of goal-directed versus habitual behaviour (de Wit & Dickinson, 2009; Dickinson, 1985). Animals first learn to perform instrumental responses to receive a reinforcing outcome. That outcome is then devalued, before instrumental responding for the outcome is reassessed in an extinction test. If an animal's behaviour is sensitive to the changed value of the outcome, then they should reduce their rate of responding for the outcome. If the animal has learnt an S-R association that does not incorporate any representation of the outcome (a habit), however, then responding for the devalued outcome should not change.

Adams (1982) provided a good example of the outcome revaluation procedure. In his first experiment, rats received either moderate or extensive training to press a lever to obtain sucrose pellets. For half of the rats, the sucrose pellets were then devalued by pairing them with lithium chloride-induced sickness. For the remaining animals, the sucrose pellets remained valuable. The number of lever-press responses performed by each group was then assessed in an extinction test, where no sucrose pellets were given. The rats that received moderate training performed fewer lever

press responses when the sucrose was devalued than when it was still-valued. For the extensively trained group, by contrast, sucrose devaluation had no significant effect on lever-press responses. Thus, the rats demonstrated goal-directed control after moderate instrumental training, but habitual control after extensive instrumental training.

The outcome revaluation procedure has also been used with human participants. Valentin et al.'s (2007) participants, for example, learnt to perform two instrumental actions to obtain different drinks. One of the rewards was then devalued by allowing unlimited consumption. In a subsequent extinction test, the participants responded more for the still-valued outcome than the devalued outcome, a clear demonstration of goal-directed control. This finding has since been conceptually replicated many times (e.g., de Wit et al., 2012; Liljeholm et al., 2015; Piray et al., 2016).

In contrast to the evidence for goal-directed control in humans, clear evidence for habits in humans has been hard to come by. Tricomi et al. (2009) obtained initially promising evidence; their participants learnt to press a button to obtain pictures of two foods (in the presence of different stimuli), to be consumed later. After either moderate or extensive training, one of the outcomes was devalued through selective satiation. In a subsequent extinction test, participants who received moderate training performed significantly fewer instrumental responses for the devalued outcome than the valued outcome. Extensively trained participants, by contrast, responded similarly for the still valued and devalued outcomes. Like Adam's (1982) findings in rodents, extended training promoted habitual behaviour.

Although Tricomi et al. (2009) provided exciting evidence of habitual responding in humans, subsequent research has not been so convincing. Notably, de Wit et al. (2018) reported five failures to induce habitual behaviour through overtraining in humans, including two failed replications of Tricomi et al.'s study. As de Wit et al. acknowledged, one can always argue that *more* training would have produced habitual control. The main conclusion from these studies, however, is that it is by no means easy to experimentally induce habits in humans through overtraining.

Another prominent line of work has sought evidence for habits in humans by combining the outcome revaluation procedure with an instrumental task in which the same stimuli, pictures of fruit,

could serve as both stimuli and the outcomes (de Wit et al., 2007; de Wit et al., 2013). Here, participants learn to perform two instrumental responses (R1 and R2) to earn different fruit outcomes, with their reaction time determining the number of points received. Each response is preceded by a discriminative stimulus, which is also a picture of a fruit. On *congruent* trials, the discriminative stimulus matched the outcome (e.g., S_{apple}: R1-O_{apple}; $S_{strawberry}$: R2 – $O_{strawberry}$). On *control* trials, the discriminative stimuli and outcomes were unique (e.g., S_{orange}: R1 – O_{plum}; S_{mango}: R2 – $O_{pineapple}$). The authors' main focus, however, was on *incongruent* trials, in which the discriminative stimulus was paired with an outcome that served, in a separate contingency, as the discriminative stimulus for a *different* response. For example, one contingency might involve S_{banana}: R1 – O_{kiwi} and another contingency would be S_{kiwi}: R2 – O_{banana}. Hence, kiwi and banana were paired with both R1 and R2, but played different roles (S or O) in each case. It was with the stimuli trained on these *incongruent* trials that de Wit et al. (2007) found evidence of habits.

On each test trial, a specific fruit was devalued; participants were told that responding for this fruit would reduce the total number of points earned. The results showed that participants were unable to appropriately avoid responding for the devalued outcomes in the *incongruent* condition, and so they lost points on these trials. This suggested that their (very accurate) responses during training were not based on knowledge of the fruit outcomes. In contrast, test performance was very good on *congruent* and *control* trials, suggesting that outcome knowledge was good in these conditions (see de Wit et al., 2007, de Wit et al., 2013; Sjoerds et al., 2013; de Wit et al. 2012; de Wit et al., 2009; de Wit et al., 2011). However, this conclusion has since been called into question. De Houwer et al. (2018) provided evidence that participants were in fact behaving in a goal-directed way in the *incongruent* condition. They showed that participants' responses were not directed towards the fruit outcomes but towards the outcome of the points earned. A manipulation of the points outcome (rather than the fruit outcome) revealed goal-directed behaviour that was equally strong in all groups.

In summary, the outcome devaluation procedure – the canonical assay of goal-directed versus habitual control – has, in two paradigms, failed to provide compelling evidence in humans for the habitual controller that is proposed by the dual-process theory of instrumental learning. Tricomi et

al.'s (2009) study failed to replicate (de Wit et al., 2018), and participants in de Wit et al.'s (2007, 2013) fruit task appear, on closer inspection (de Houwer et al., 2018), to be behaving in a goal-directed fashion. Another issue is that both paradigms rely on null effects to provide evidence of habitual control. To demonstrate habits in Tricomi et al.'s (2009) overtraining paradigm, it is necessary to observe no difference in rates of responding for the valued and devalued outcomes. Similarly, in de Wit et al.'s (2007, 2013) fruit task, responding must be no different from chance on *incongruent* trials. As De Houwer et al. (2018) noted, such null effects *could* reflect habitual control, but they could equally reflect other factors such as poor learning. Thus, even when evidence of habits has been reported, that evidence is subject to alternative interpretation.

The high-profile failures to experimentally induce habits in humans (e.g., de Wit et al., 2018), and the concerns around interpretations of null effects (e.g., De Houwer et al., 2018), prompted Luque et al. (2020) to develop a new assay of habitual control. They argued that looking for changes in overt responding after overtraining was impractical in experiments with human participants, because too much training would be required. Instead, they argued that looking for changes in *reaction times* (RTs) would be a more viable approach. In Luque et al.'s (2020) experiments, participants learned that, in the presence of each stimulus, one response would earn a high-value diamond, and another response would earn a low-value diamond. Some of the diamonds were then made worthless (devaluation). When a previously high-value diamond was devalued, the optimal response would be to switch to the alternative response which produced the previously lower-value, but now still *valuable*, diamond. The authors observed an *RT switch cost*, where choosing the alternative, optimal response came with slowed responding, particularly with extended training and when participants were placed under time pressure.

Luque et al.'s (2020) work suggests that habits can be revealed in humans, following outcome devaluation, through slowed RTs rather than response selection (Luque et al., 2020). In our current study, we were keen to pursue the idea that a habit, learned in the laboratory, could produce more than just a slowing of an optimal response, but also result in non-optimal/incorrect responding. Our approach was slightly different to that usually taken in the learning field. We did not manipulate

outcome value. Rather, we used a simple interference procedure in which a putative habit, possibly S-R in nature, was set against a goal-directed action. Evidence for habitual behaviour would then be seen when responses are determined by an S-R relationship, or habit, that undermines goal-directed action. In this way, our procedure is similar to that used by Brass, Bekkering & Prinz (2001) to show how observing one finger moving can lead to participants moving that finger, rather than the "correct" finger on that trial – an effect that could be described as "automatic imitation". Our main aim was to create a simple procedure to show habitual behaviour that was easy to implement and interpret.

Experiment 1

In Experiment 1, participants first learned three hierarchical stimulus-response-outcome (S-R-O) relationships (see Table 1). In the presence of stimulus S1, R1 responses earned points toward outcome O1, while R2 responses earned no points. Stimulus S2, by contrast, signalled that R2 responses would yield points towards outcome O2, while R1 responses would earn no points. S3 trials were included as control trials, with neither instrumental response producing points on these trials. On each trial, the participants were instructed to perform an instrumental response as quickly as possible, because their reaction time would dictate the number of points that they obtained (for correct responses).

In the test phase, each trial began with the presentation of either outcome O1 or O2. The participants were instructed to perform the response that previously produced that outcome during the training phase (i.e., O1 → R1, O2 → R2). Importantly, participants were required to withhold their response until either S1, S2, or S3 was presented. The presented stimuli could be either congruent or incongruent (or neutral in case of S3) to the outcome that was presented at the start of the trial. That is, the stimulus could be associated with the same response as the presented outcome (e.g., O1 followed by S1, both associated with R1) – a congruent trial – or the alternative response (e.g., O1 followed by S2, associated with R1 and R2 respectively) – an incongruent trial. Although the participants could only respond after the stimulus appeared, they were instructed to ignore the stimulus and instead respond, as quickly as possible, with the response that was associated with the outcome presented at the start of the trial.

We expected participants to easily perform the correct response on congruent trials where the response associated with the goal (the outcome) was the same as that associated with the stimulus. Correct responding should be more difficult on incongruent trials, however, because here the outcome and stimulus are associated with different responses. In this way, we expected poorer response accuracy on incongruent trials than congruent trials. The difference in accuracy on the two trial types can be interpreted as the extent to which the stimulus (inappropriately) controlled responding on incongruent trials – a measure of habit learning.

We also anticipated that any congruency effect would be exaggerated by increasing the delay between the outcome and stimulus presentations. Longer delays should present more opportunity for participants to lose focus of the original goal, thereby increasing the errors on incongruent trials. In Experiment 1, we therefore manipulated the time interval between the outcome and stimulus presentations.

Method

Participants. Forty-one undergraduate psychology students (36 females, five males) from University of Plymouth participated in exchange for course credit. The participants were aged between 18 and 45 years (M = 20.68 years, SD = 5.25 years).

Design. The manipulations were made at test. The experiment followed a 3 (congruency: congruent, incongruent, baseline) by 2 (delay: short, long) repeated-measures design. The dependent variables were response accuracy and RT during the test phase.

Apparatus. The experiment was programmed using E-Prime (https://pstnet.com/) and was presented on a 22-inch computer. Instrumental responses were performed using a joystick. Left and right movements on the joystick were counterbalanced across participants with respect to their allocation as instrumental responses R1 or R2.

Stimuli. The three discriminative stimuli (S1, S2 and S3) were green, blue, and yellow background screen colours. Two pictures, one of Pringles and another of jellybeans, served as the two outcomes (O1 and O2) that accompanied the points that participants could win. The screen colours green and blue, and the outcome pictures, were counterbalanced across participants when they were

assigned to their roles of S1 or S2, or O1 or O2. The control stimulus S3 was the same screen colour for all participants – yellow.

Procedure. Before the instrumental training phase, participants were told that they could earn Pringles and jellybeans points by moving the joystick left and right, and that they would need to learn the relationship between the food, screen colour, and response. Each training trial began with a fixation cross, presented centrally and in grey, with the statement "*Please centralise the joystick*". Once the joystick was centralised, the fixation turned black (500ms), before being replaced by one of the discriminative stimuli (background screen colour). The participants had to perform an instrumental response (left or right movement of joystick) as quickly as possible. Correct responses (see Table 1) were reinforced with points. The number of points that the participants earned on any given trial depended on how quickly they responded (see Table 2 for details of the RT-points conversion rate). Once the response was made, a picture of the reward (jellybeans or Pringles) was presented, along with the points earned on that trial. An exception to this rule was that, if the correct response was registered more than 2s after the stimulus appeared onscreen, a message appeared stating that the response was too slow. The participants first completed six practice training trials, on which the target zones for the instrumental responses were highlighted on the screen. These target zones were two rectangles, one on the far-left and one on the far-right, both the full height of the screen, which indicated to participants where they needed to move the joystick cursor, to the left or right, for a response to be registered. The practice training trials were followed by 252 instrumental training trials. This training phase was separated into three blocks of 84 trials. The stimuli (S1, S2, and S3) were each presented on 28 trials per block, in random order. Each block was separated by a two-minute break.

At the end of the training phase, participants were presented with a knowledge test to ascertain their understanding of the S:R-O relationships. This involved presenting a stimulus, (e.g., S1), with the question "When the screen was this colour, which joystick response produced a reward?". Participants were required to respond left or right with the joystick to show their knowledge of the correct response to earn points for that stimulus (in this case, R1). Once participants had made

their response, both outcomes (O1 and O2) were presented onscreen vertically with the number 1 or 2 beside them. Participants were required to press the corresponding button to indicate which reward they could win (in this case, O1).

Each test trial began with the fixation cross from the training phase, indicating that participants should centralise their joystick. Once the joystick was centralised, one of the outcome pictures from the training phase (jellybeans or Pringles) was presented centrally for 2000ms. The interval between the presentation of the outcome (O) and the stimulus (S) on test was manipulated to create two conditions: short delay (2-3 seconds) verses long delay (10-11 seconds). The precise delay on any given trial was randomly determined between the upper and lower limits. Participants had to then perform the correct instrumental response (see Table 1) as quickly as possible after the stimulus (S) was presented (screen changed to blue, green or yellow). They were also told that they would lose points if they moved the joystick before the screen changed colour. The trial ended if the joystick was registered as not central at any point from the onset of the outcome and before the onset of the stimulus, and the participants were informed that they had moved the joystick too early.

Participants completed four blocks of 16 test trials. These 16 trials consisted of two presentations of each trial: congruent trials (O1-S1 and O2-S2), incongruent trials (O1-S2 and O2-S1), and baseline trials (O1-S3 and O2-S3). Half of each of these trial types were presented with a short delay, the remainder with a long delay. The main test was preceded by one practice block of 16 trials, and the order of trials within every block was randomly determined for each participant. Trials in which the participants moved the joystick too early (i.e., during the outcome presentation or delay period) or too slowly (more than 2 s after the discriminative stimulus was presented) were repeated in a random order at the end of each block, to obtain a complete dataset from each participant. Feedback was not presented during the test phase, but participants were instructed that points would continue accumulating (see Lee et al., 2021). At the end of the test, the participants were given a randomly determined (range 3-6) number of each reward for consumption.

Results

Exclusions. We chose to exclude participants who achieved less than 80% accuracy on the final test, because we were concerned that these participants may have misunderstood the instructions. Specifically, participants who performed poorly on the final test may have thought that they were to respond to the stimulus that was presented on each test trial, rather than the outcome. This would produce a large congruency effect (good performance on congruent trials but comparatively poor performance on incongruent trials), but it would not be a true demonstration of habitual responding. We therefore took 80% accuracy during the test as a conservative cut-off for differentiating participants who had and had not understood the task instructions. Any demonstration of a congruency effect under these circumstances would be against the backdrop of good overall performance, which would suggest that the participant had understood the test instructions. Five participants were excluded on this basis. For interested readers, we report the comparable results with all participants in the Supplementary Materials.

Training. As can be seen in Figure 1, the participants learnt the S-R-O contingencies quickly during the training phase. This was further confirmed in the contingency knowledge tests, where all but one participant correctly answered both knowledge questions.

Test accuracy. Figure 2 shows the mean percentage of correct responses in the test, separated by congruency and delay condition. A 3 (congruency condition: congruent, incongruent, baseline) × 2 (delay condition: short, long) repeated-measures ANOVA revealed a significant main effect of congruency condition $F(2,70) = 9.93$, $p < .001$, generalised eta squared (n_g^2) = .06, $BF_{10} > 100$. The participants performed more accurately on congruent trials than baseline trials, $t(71) = 3.05$, $p = .003$, $d_z = 0.47$, $BF_{10} = 8.76$, and incongruent trials, $t(71) = 3.72$, $p < .001$, $d_z = 0.69$, $BF_{10} = 59.05$. Accuracy on baseline and incongruent trials did not differ, $t(71) = 1.29$, $p = .20$, $d_z = 0.24$, $BF_{10} = 0.29$. There was also a significant main effect of delay, although the Bayes Factor was inconclusive, $F(1, 35) = 4.62$, $p = .04$, $n_g^2 = .01$, $BF_{10} = 1.04$. The congruency by delay interaction was not significant, $F(2, 70) = 2.26$, $p = .11$, $n_g^2 = .02$, $BF_{10} = 0.59$.

Test reaction times. The mean reaction times during the test phase, for trials in which the correct response only was performed, can be found in Figure 3. A 3 (congruency condition: congruent, incongruent, baseline) × 2 (delay condition: short, long) repeated-measures ANOVA revealed a significant main effect of congruency, $F(2, 70) = 6.60$, $p = .002$, $n_g^2 = .01$, $BF_{10} = 1.73$. The participants responded more slowly on baseline trials than congruent trials, $t(71) = 3.88$, $p < .001$, $d_z = 0.71$, $BF_{10} = 95.00$, and incongruent trials, $t(71) = 2.82$, $p = .006$, $d_z = 0.44$, $BF_{10} = 4.94$. No significant difference was observed between congruent and incongruent trials, $t(71) = 0.48$, $p = .63$, $d_z = 0.08$, $BF_{10} = 0.14$. There was also a significant main effect of delay, with participants performing more quickly after a long delay than after a short delay, $F(1, 35) = 32.07$, $p < .001$, $n_g^2 = .04$, $BF_{10} > 100$. The congruency by delay interaction was not significant, $F(2, 70) = 0.50$, $p = .61$, $n_g^2 = .0006$, $BF_{10} = 0.12$.

Discussion

Participants were given instrumental S:R-O training and were then required to execute goal-directed actions to earn jellybeans and Pringles reward points on test. These goal-directed actions (e.g., R1 to obtain O1) were affected by the presentation of stimuli that signalled that a response could now be made. In particular, accuracy on incongruent test trials (e.g., when O1 was followed by S2) was lower than accuracy on congruent trials (e.g., when O1 was followed by S1). A dual-process interpretation of these 'action slips' observed on incongruent trials would be that the participants' goal-directed action (e.g., R1 to obtain O1) was prevented by an S-R habit (e.g., R2 triggered by S2) when the two behaviours were set in opposition.

The analysis above – that performance was hindered on incongruent test trials by the priming of an incompatible response (by the stimulus) – would suggest that performance should be worse in the incongruent condition than in a neutral baseline condition. In fact, there was no difference between performance on incongruent and baseline trials in Experiment 1. This would suggest that incongruent trials did not produce action slips. Rather, performance on congruent trials was enhanced by the presentation of the compatible stimulus (e.g., S1 following O1), relative to the other two conditions; the *compatible* stimulus on congruent test trials appeared to *help* participants to respond

accurately. One aspect that limits interpretation of the data is that, overall, accuracy was very good. Indeed, accuracy was particularly good after the exclusion criteria were applied, because participants who had less than 80% accuracy were removed from the analysis. Such good accuracy, particularly where accuracy approaches ceiling, may limit the ability to detect differences between the conditions. It is possible that, if overall accuracy was poorer, a significant difference in accuracy on the incongruent and baseline trials would have been observed.

Before it is concluded that the current finding is evidence for a stimulus-supported enhancement of performance in the congruent condition, rather than action slips in the incongruent condition, it is worth considering the differences between the baseline stimulus, S3, and the other stimuli, S1 and S2. Stimulus S3 was never followed by reward, whichever response was executed during training. This may have led to some frustration for the participants; there was no 'correct' response to the baseline stimulus S3 during training. Perhaps then, stimulus S3 became an aversive stimulus, and this negative value interfered with performance on baseline test trials (e.g., O1 followed by S3). Alternatively, perhaps the salience of S3 was maintained throughout training, in a way that the salience of S1 and S2 was not. Consistent with this idea, presentation of S3 slowed responding (longer RTs were seen to S3 than to S1 and S2) on test. It would appear that it was difficult to execute the chosen response on test in the presence of S3. One speculative possibility is that S3 was more salient on test than S1 and S2 because it was not followed by consistent responses in training (see e.g., Pearce & Hall, 1980); there was no correct response to S3, so responses would have been chosen at random. This increased salience of S3 may then have distracted the participant and prevented fast/accurate responding on test.

The analysis above points to a more general issue about appropriate control conditions in experiments such as the one presented here. Stimuli S1 and S2 and outcomes O1 and O2 are exactly equated in the current design. It is not, however, possible to create a baseline condition that is equal in its motivational and attentional properties to the two experimental conditions. A novel S3 on test might be more salient, and a familiar S3 that was not involved in instrumental training might be aversive. An S3 that was followed by reward regardless of the response made may also become more

salient. Hence, wherever the observed baseline response accuracy lies relative to the experimental conditions, it may have been artificially increased or decreased by factors that are irrelevant to the experimental manipulation. On reflection, we feel that perhaps the baseline condition implemented here is of limited utility. In the subsequent experiment, we removed the baseline condition, leaving the simpler and more elegant bidirectional control design.

The delay manipulation did not affect the number of action slips observed (short versus long delay between presentations of outcome O and stimulus S). Our expectation was that, in the long delay condition (10-11s between O and S), participants would find it harder to maintain the outcome O in working memory before the stimulus S was presented. This might lead to more stimulus-consistent responses (errors) on incongruent trials. Increasing the delay between presentation of the outcome O and stimulus S on test did not, however, have this effect. In fact, if anything, the congruent-incongruent difference in accuracy was larger for the short delay condition (around 5%) than the long delay condition (around 2%). One explanation for the absence of any effect of delay on action slips is simply that the delay manipulation was not strong enough in this experiment. Perhaps an O-S delay of a minute or two minutes may have led to much greater mind wandering and therefore greater action slips on incongruent trials. A second possible reason for the absence of an effect is that maintaining the goal, or the prepared response, in mind is trivially easy in this task; no other event occurs in the delay between presentation of the outcome O and stimulus S that might displace the goal/correct response from working memory. We examined this idea further in Experiment 2.

A final, more complex, reason why we saw no effect of delay might have been that there were two processes in operation, one facilitated by the short delay and one by the long delay, which cancelled one another out. For example, it may be that the short delay condition allows easy maintenance of the goal in working memory, but the long delay condition allows greater time for the participants to prepare their response. That is, the short delay (2-3s) may not always have been enough time for participants to prepare the appropriate response R for that trial (given the presented outcome O). This would then lead to an increase in action slips on short incongruent trials. Some support for this hypothesis comes from the observation that overall responding was faster on long

delay trials than short delay trials (see Figure 3). Hence, the failure to see a difference in the size of the action slip effect between the long and short delay conditions may have been due to better response preparation in the long delay condition and lower mind-wandering in the short delay condition.

One small outstanding point relates to the training performance. One might expect accuracy to be close to 100% on such a simple task, rather than the 95% accuracy observed. Our only explanation for this poorer than expected performance is that participants were responding as quickly as possible to maximise points earned. This is not usual for an instrumental training task. To some extent, participants can choose how accurate they want to be; faster responses earn more points, but incorrect responses earn zero points. Perhaps 5% errors was deemed acceptable in the pursuit of faster responses by our participants.

The main finding from Experiment 1 was that performance on incongruent trials produced poorer performance than on congruent trials, which provides prima facie evidence for action slips. In a subsequent experiment, we sought to replicate this effect and make an initial test of the idea that distraction in the delay between outcome O and stimulus S on test might increase the number of action slips observed.

Experiment 2

Experiment 2 replicated the main features of Experiment 1 but without a manipulation of O-S delay on test and with the addition of a distraction task between O and S presentation on some test trials. We also did not include a baseline condition (see discussion above). We used a moderate O-S delay of 3-4s for all test trials. Given the absence of an effect of delay in Experiment 1, our main concern in Experiment 2 was to allow time to implement the distraction task between presentation of the outcome (O) and stimulus (S) on test trials. Our hypothesis was that the distraction task might disrupt the maintenance of the goal in working memory and therefore render the participants more susceptible to influence of the incompatible stimulus on incongruent trials. On distraction trials, a photograph of a person was presented, and participants were asked to rate verbally how much they

liked each photograph. This was meant as a mild distraction to trigger mind-wandering (Schooler et al., 2011), rather than a task that would displace all items from working memory and thereby reduce performance to chance.

Overall, the experiment manipulated O-S congruence and distraction on test orthogonally. We predicted that performance would be poorer on incongruent than congruent test trials, and that this difference would be more marked when a distraction was present.

Method

Participants. Sixty-six undergraduate psychology students (57 females, 9 males) from the University of Plymouth participated in exchange for course credit. The participants were aged between 18 and 34 years (M = 20.41 years, SD = 2.87 years).

Design and Stimuli. The experiment followed a 2 (congruency condition: congruent, incongruent) by 2 (distraction condition: distraction, no distraction) repeated-measures design. The dependent variables were response accuracy and RT during the test phase. The two outcomes were the same as Experiment 1 (Pringles or jellybeans pictures) and the stimuli were also the same as Experiment 1, but we omitted the baseline condition, so only green and blue background screen colours were used (see Table 3 for Experiment 2 design). Finally, thirty photographs of famous people (faces only) were used for the distraction manipulation. These faces were repeated once every face in the list had been presented.

Procedure. The procedure was the same as the congruent and incongruent conditions of Experiment 1, with the following exceptions. Participants completed four practice training trials, followed by 240 instrumental training trials. This training phase was separated into three blocks of 80 trials. Stimulus S1 was presented on half of the trials in each block and S2 was presented on the remaining trials.

On test, there was a 3-4s delay between the presentation of the outcome and the stimulus on every test trial. On distraction trials, if the joystick was kept central throughout the delay, a photograph of a person was presented (also throughout the delay). Each photograph was individually presented with a white background and placed in the centre of the screen. Participants were asked to

rate verbally how much they liked each photograph, using a scale between 1 (“Don’t like at all”) and 7 (“Like very much”). On no distraction trials, the screen remained blank for an equivalent duration. If the joystick was registered as not central during this time, the trial ended, and the participants were informed that they had moved the joystick too quickly.

Participants completed four blocks of eight test trials (as in Table 3). These eight trials consisted of the two presentations of each congruent trial (O1-S1 and O2-S2) and two presentations of each incongruent trial (O1-S2 and O2-S1), each presented with and without the distraction task.

Results

Exclusions. The exclusion criteria from Experiment 1 were applied. Nineteen participants were removed for achieving less than 80% accuracy on the final test, leaving 47 participants.

Training. As in Experiment 1, the participants learnt the contingencies quickly, with a long period during which participants were asymptote (see Figure 4).

Test response accuracy. Figure 5 shows the mean percentage of correct responses during the test, separated by congruency and distraction conditions. The graph suggests that the participants were more accurate on congruent trials than incongruent trials, and that this pattern was not affected by the distraction manipulation. A 2 (congruency condition: congruent vs. incongruent) by 2 (distraction condition: distraction vs. no distraction) repeated-measures ANOVA confirmed this conclusion. Most importantly, there was a significant main effect of congruency on response accuracy, $F(1, 46) = 10.49$, $p = .002$, $n_g^2 = .06$, $BF_{10} > 100$, with higher accuracy in congruent trials than in incongruent trials. There was no significant effect of distraction, $F(1, 46) = 0.61$, $p = .44$, $n_g^2 = .002$, $BF_{10} = 0.18$, or congruency × distraction interaction, $F(1, 46) = 0.09$, $p = .76$, $n_g^2 = .0004$, $BF_{10} = 0.22$.

Test reaction times. As in Experiment 1, a comparable analysis was conducted on the RTs for correct trials only at test (Figure 6). There was a main effect of distraction condition, $F(1, 46) = 18.65$, $p < .001$, $n_g^2 = .04$, $BF_{10} > 100$, with participants responding more quickly on no distraction trials than distraction trials. No significant effect of congruency condition, $F(1, 46) = 2.92$, $p = .09$, $n_g^2 = .004$, $BF_{10} = 0.48$, or congruency × distraction interaction, $F(1, 46) = 0.10$, $p = .75$, $n_g^2 = .0001$, $BF_{10} = 0.23$, was observed.

Discussion

As in Experiment 1, participants made more errors on incongruent trials than congruent trials. Hence, the presentation of stimuli that were incompatible with achieving the goal (due to the response with which they were associated in training) undermined participants' goal-directed behaviour – action slips. Our distraction manipulation had no impact on the number of action slips observed. It was a light distraction task and may have been insufficient to affect participants' accuracy. The distraction task did slow participants' responses, however, suggesting that it did have some impact. The most important finding from Experiment 2 was that the action slip effect seen in Experiment 1 was replicated.

General Discussion

In two experiments, we saw evidence for habitual behaviour. Participants were first given training on two instrumental contingencies (S1:R1-O1 and S2:R2-O2) to obtain Pringles or jellybeans points. Subsequently, each test trial began with the presentation of a picture of one of the rewards (O1 or O2) to signal which was available on that trial. Participants were required to withhold responding until a stimulus was presented (S1 or S2) after a delay. Once that stimulus was presented, participants were required to respond as quickly as possible to maximise the number of points earned. In both experiments, responding was more accurate when the presented stimulus was congruent with available outcome (i.e., O1 followed by S1, or O2 followed by S2) than when the stimulus was incongruent with the outcome (i.e., O1 followed by S2, or O2 followed by S1). These results indicate that the stimuli presented on incongruent trials disrupted goal-directed behaviour; participants' responses were influenced by the stimuli presented, even though participants were instructed explicitly to ignore those stimuli.

In both experiments, an additional manipulation was implemented – the delay between O and S on test (Experiment 1) and the addition of a distraction on test (Experiment 2). Neither of these manipulations affected the number of errors observed. Both manipulations did, however, increase participants' reaction times. It may be that participants became aware that the short delay trials and distraction trials were more difficult, and so took more time over those trials to ensure that their

responses were as accurate as possible. The scoring system on test would have rewarded this adjustment; incorrect responses scored zero points, whereas increasing reaction time by less than 100ms (the kind of increase we observed) would have led to a maximum reduction of a single point. In general, when accuracy is rewarded more than speed, participants are likely, if possible, to adapt to the kinds of interventions in place in our experiments to maintain high levels of accuracy. Perhaps a scoring system that heavily penalizes slightly slower responses would reveal effects of a delay or distraction manipulation.

One initial question is how the main effect of congruence – our observation of stimulus-driven action slips – relates to other similar results already in the literature. The standard manipulation to test for stimulus-driven behaviour is to devalue the outcome between training and test (Adams and Dickinson, 1981; de Wit et al., 2018; Luque et al., 2020; Tricomi et al., 2009). A reduction in responding for the devalued outcome indicates goal-directed behaviour. In contrast, maintenance of responding for the low value outcome, perhaps following more extended training, is usually taken as evidence of stimulus-driven (e.g., S-R) responding. In these past experiments, it is the value of the outcome that is manipulated. Goal-directed behaviour is thought to be the consequence of the outcome and a belief about how to obtain that outcome (Heyes & Dickinson, 1990). In our experiments, we varied the availability of the two outcomes across test trials, by manipulating participants' beliefs about which reward could be obtained on each trial. Hence, our focus was on participants' beliefs about the efficacy of the instrumental contingencies in place on any given trial, rather than the value of the outcome. Nevertheless, in both approaches, goal-directed action is set against stimulus-driven responding.

The current approach may have one advantage over devaluation studies in the investigation of habitual behaviour. In many studies of outcome devaluation, goal-directed behaviour is evidenced by a change (a reduction) in responding as a consequence of the reduced value of the outcome. Conversely, stimulus-driven behaviour is evidenced by the *absence* of any effect of outcome devaluation (e.g., Tricomi et al., 2009). Our current procedure reverses this pattern; evidence of stimulus-driven responding is seen through a difference in accuracy between the congruent and

incongruent conditions. In that sense, the current procedure has the advantage of providing positive evidence for habits.

While we have taken the significant difference in accuracy between the congruent and incongruent trials as evidence of habitual behaviour, it is important to acknowledge that accuracy rates did not significantly differ between the incongruent and baseline trials in Experiment 1. If accuracy had been significantly poorer in the incongruent condition than the baseline condition, it would have provided even stronger evidence of habitual control. That said, it is difficult to interpret the function of the baseline trials, which is why we removed them from Experiment 2. A direct comparison of congruent and incongruent trials allows for a cleaner experimental design, but we acknowledge that it is unclear at this stage whether the incongruent stimuli interfere with goal-directed action, or whether the congruent stimuli *facilitate* goal-directed action (or both). We do not have an easy way to distinguish these possibilities at present, but testing these possibilities will be an important avenue for further research.

A dual-process explanation of the action slips made on incongruent trials is that participants' goal-directed behaviour (e.g., for O1 by responding R1) is undermined by an incompatible response triggered by the presentation of an incompatible stimulus (e.g., S2 that is associated with R2). The proposed mechanism underlying the incompatible response is an S-R link formed during training. This link affects behaviour automatically – quickly and perhaps outside of the participant's awareness (see Moors & De Houwer, 2006). Furthermore, the S-R mechanism is argued to be qualitatively different from the goal-directed system; it is evolutionarily older and has a distinct neural basis (e.g., Killcross & Coutureau, 2003). This S-R mechanism is the predominant explanation for action slips (Watson & de Wit, 2018).

We would not, however, suggest that the current data provide unambiguous support for the S-R model of habits. Our results merely demonstrate a way in which habitual behaviour can be observed in the laboratory. There are alternative explanations to the S-R account (see De Houwer, 2019 for a fuller discussion of this issue). We agree that the knowledge acquired when participants learn to execute response R in the presence of stimulus S (e.g., S1-R1) to earn reward points could be

described in terms of an association between S and R. This association might indeed be a link that allows activation to pass automatically from S to R. But equally, knowledge of the S-R relationships could be represented in propositional form (e.g., Mitchell et al., 2009; Seabrooke et al., 2016). For example, participants may learn that "to earn rewards, I must make a left response when the screen turns green". On incongruent test trials in which O1 is followed by S2, this S2-R2 knowledge can be expected to compete with the instructed goal to earn the depicted reward O1 by making the appropriate response, R1. That is, there is a competition between two propositions: "execute R1 to earn O1" versus "execute R2 in the presence of S2 to receive reward". This interpretation is different from the dual-process account in that it does not postulate a separate low-level S-R system, which takes over control after many learning trials.

We acknowledge that, by interpreting the congruency effect observed as evidence for habitual control, we have somewhat "stretched" the definitions of habits, at least as interpreted within the learning literature. As noted in the Introduction, insensitivity to outcome devaluation manipulations is typically regarded as the canonical measure of habitual control, at least in the animal learning literature (e.g., Adams, 1981). Still, there is a substantial but largely distinct literature that seeks to examine habits in humans from the ideomotor literature (e.g., Elsner & Hommel, 2001). In these studies, researchers often seek evidence of habits not through outcome devaluation manipulations, but rather through performance on reaction time and interference tasks similar to that used here (e.g., Brass et al., 2001; see also Stroop, 1935). Gaining a clear picture of exactly how performance in paradigms from these separate traditions relate will be an important area for future research.

To conclude, the current study suggests a new and very simple method to demonstrate habitual behaviour in the laboratory. The evidence for habits comes, not from the absence of an effect of outcome devaluation, but from the presence of stimuli that promote a different response from that which is consistent with the overall goal. Our hope is that this procedure might be helpful in future studies investigating the nature of habitual behaviour, in particular, in testing the default S-R interpretation of habits against the alternatives.

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Table 1

Design of Experiment 1

Instrumental Training			Test			
Stimulus	**Response**	**Outcome**	**Outcome**	**Stimulus**	**Correct Response**	**Test Trial**
S1	R1 →	O1	O1	S1	R1	Congruent
	R2 →	Ø		S2	R1	Incongruent
S2	R2 →	O2	O2	S2	R2	Congruent
	R1 →	Ø		S1	R2	Incongruent
S3	R1 →	Ø	O1	S3	R1	Baseline
	R2 →	Ø	O2	S3	R2	Baseline

Note. S1, S2 and S3 represent the screen colour (green/blue/yellow), R1 and R2 represent instrumental responses (left/right), and O1 and O2 represent food outcomes (jellybeans/Pringles). Ø represents "no outcome".

Table 2

Relationship Between Reaction Times and Points During Training

Reaction Time (ms)	Points
Less than or equal to 200	10
201-400	9
401-600	8
601-800	7
801-1000	6
1001-1200	5
1201-1400	4
1401-1600	3
1601-1800	2
1801-2000	1
More than 2000	0

Table 3

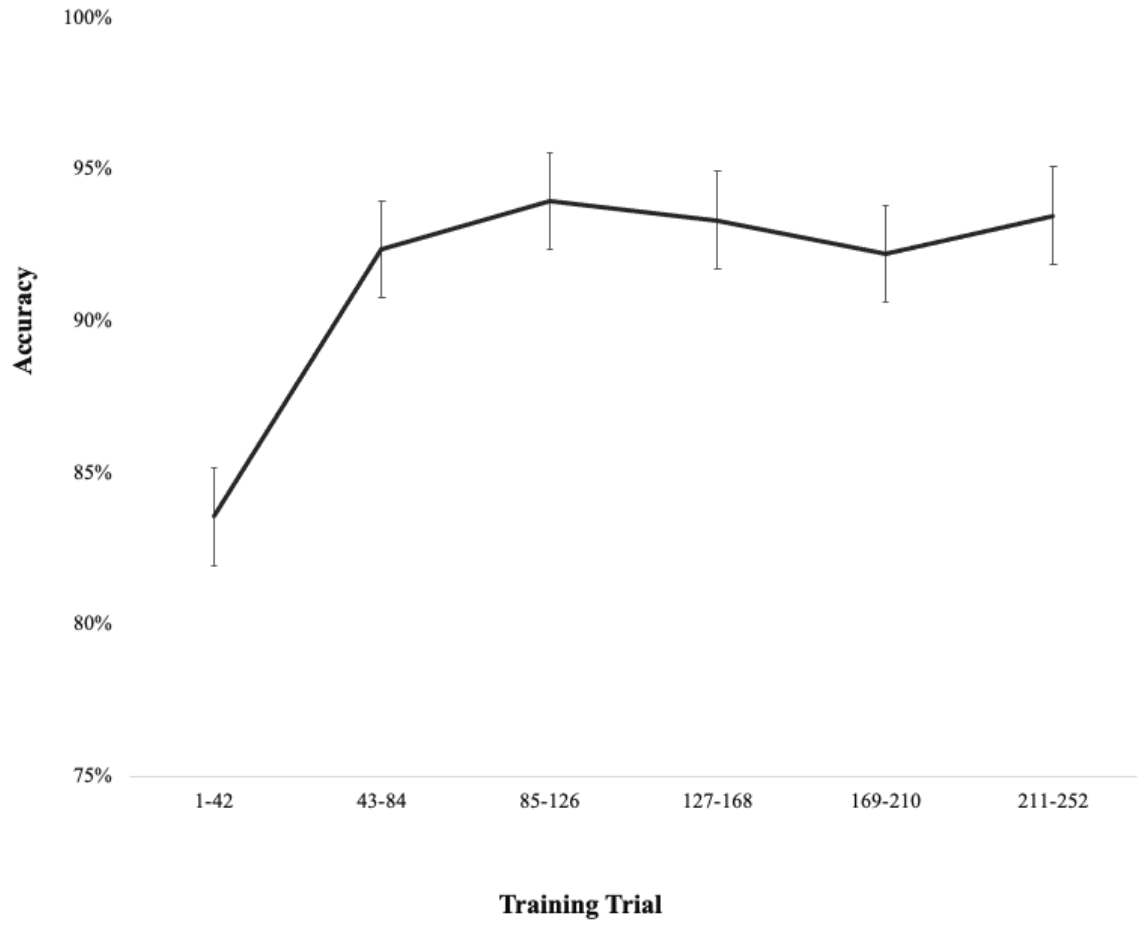
Design of Experiment 2

Instrumental Training			**Test**			
Stimulus	**Response**	**Outcome**	**Outcome**	**Stimulus**	**Correct Response**	**Test Trial**
S1	R1	O1	O1	S1	R1	Congruent
	R2	Ø		S2	R1	Incongruent
S2	R2	O2	O2	S2	R2	Congruent
	R1	Ø		S1	R2	Incongruent

Note. S1 and S2 represent the screen colour (green/blue), R1 and R2 represent instrumental responses (left/right), and O1 and O2 represent food outcomes (jellybeans/Pringles).

Figure 1

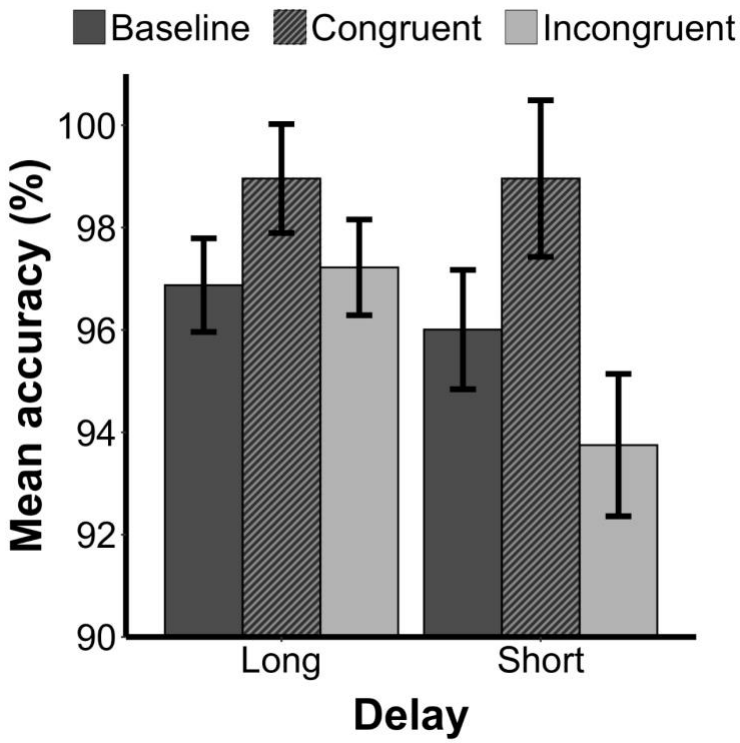
Accuracy of Training Trials in Experiment 1



Note. This line graph shows the mean accuracy across training trials for S1 and S2 in Experiment 1 (excluding trials with baseline stimuli).

Figure 2

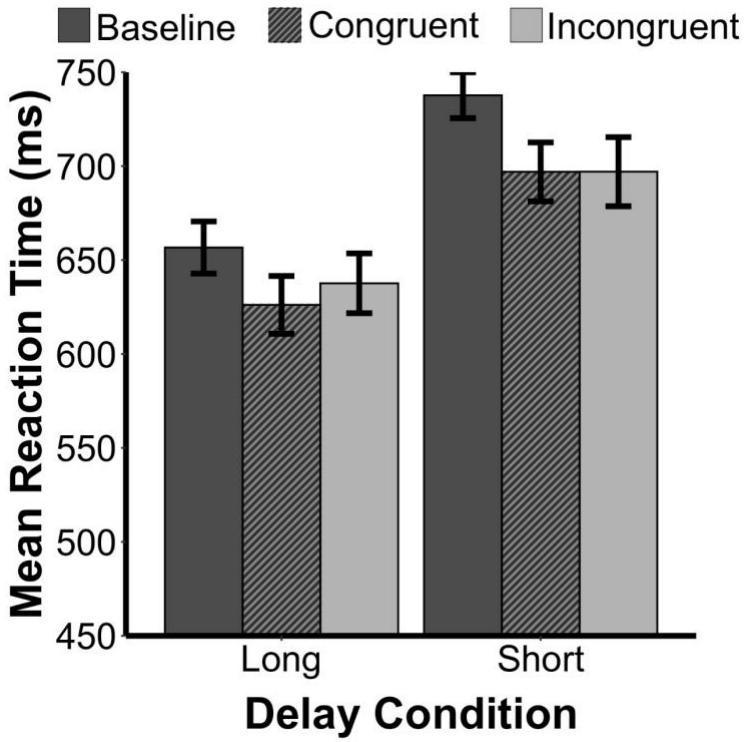
Accuracy Results of Experiment 1



Note. This bar graph shows mean accuracy in test trials by congruency and delay. Error bars represent difference-adjusted, 95% within-subjects confidence intervals (Baguley, 2012).

Figure 3

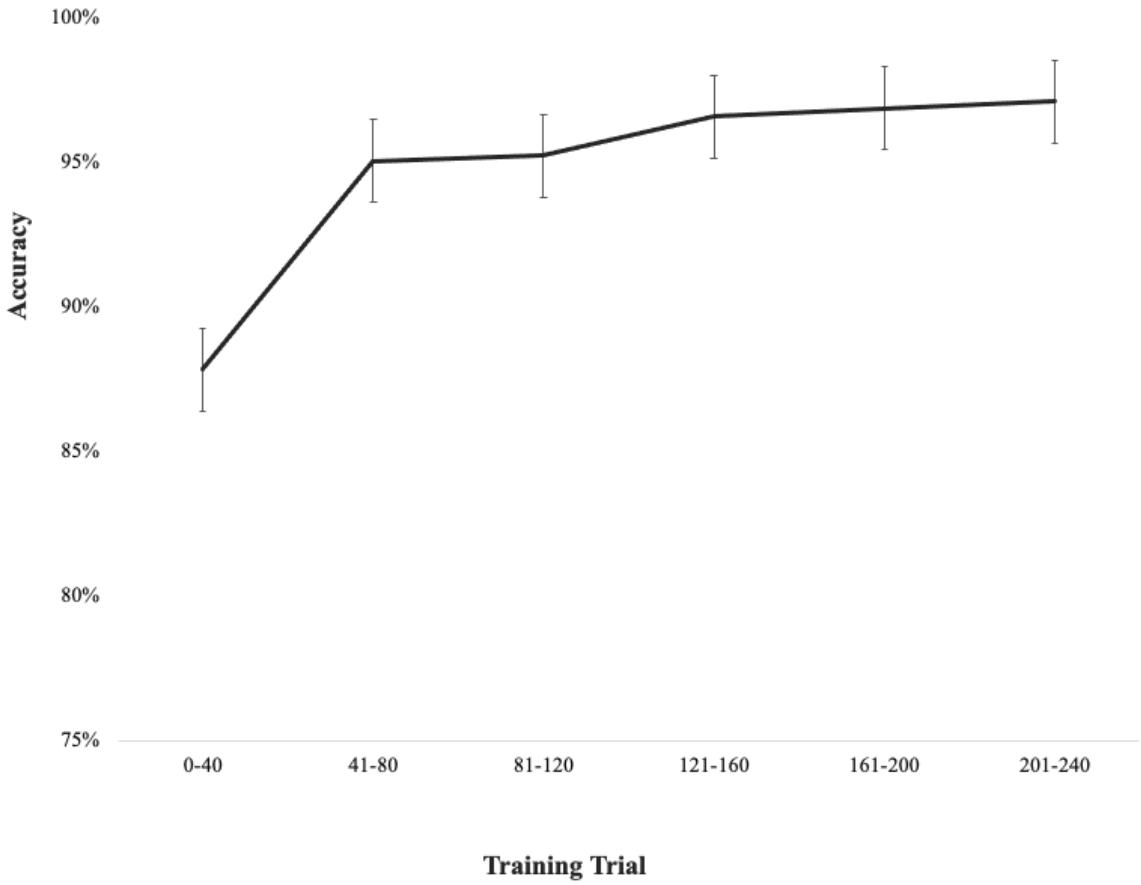
Reaction Time Results of Experiment 1



Note. This bar graph shows mean reaction time (RT) by congruency and delay. Error bars represent difference-adjusted, 95% within-subjects confidence intervals (Baguley, 2012).

Figure 4

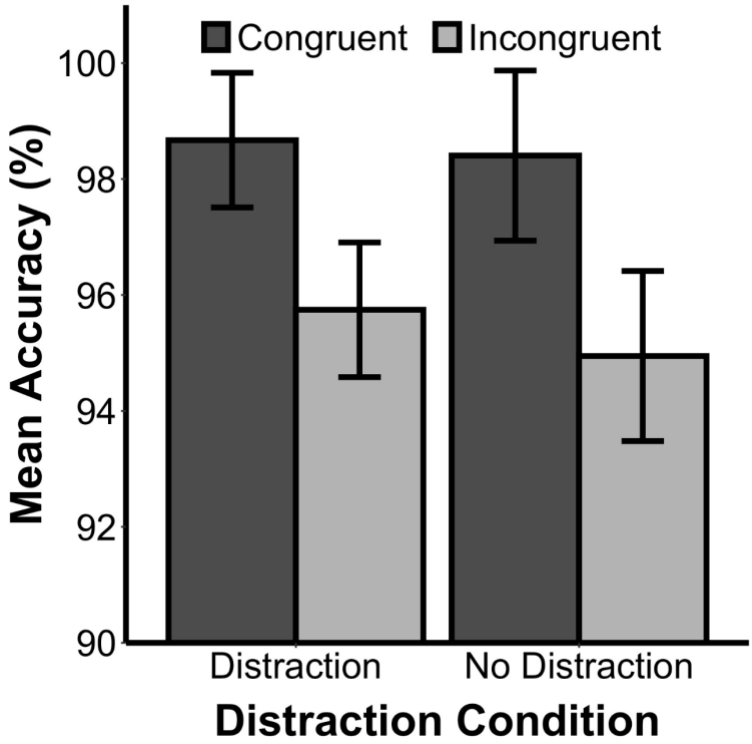
Results of Experiment 2



Note. This line graph shows the mean accuracy scores across training trials for S1 and S2 in Experiment 2.

Figure 5

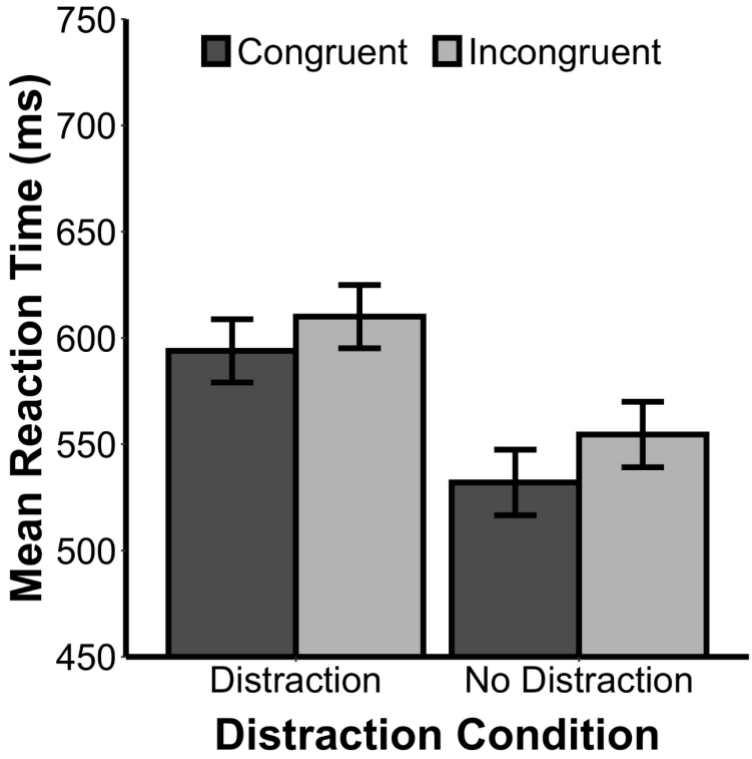
Accuracy Results of Experiment 2



Note. This bar graph shows mean accuracy by congruency and distraction. Error bars represent difference-adjusted, 95% within-subjects confidence intervals (Baguley, 2012).

Figure 6

Reaction Times Results of Experiment 2



Note. This bar graph shows reaction time (RT) by congruency and distraction. Error bars represent difference-adjusted, 95% within-subjects confidence intervals (Baguley, 2012).