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Automatic Imitation Remains Unaffected Under Cognitive Load

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Automaticity has been argued to be a core feature of the mental processes that guide social interactions, such as those underpinning imitative behaviors. To date, however, there is little known about the automaticity of imitative tendencies. In the current study, we used a finger movement stimulus-response compatibility task to index processes associated with controlling the urge to copy other people's actions. In addition, we manipulated the level of load placed on a secondary cognitive task to test if there is a capacity limit in the systems that filter distractor finger movement stimuli. Across three experiments, we showed that whether letter strings (Experiment 1), faces (Experiment 2), or hand postures (Experiment 3) are held in working memory, there was no impact on compatibility effects in the main task. These findings show that the cognitive operations that generate imitative tendencies are relatively efficient in that they operate the same whether or not a central resource is taxed heavily with nonsocial (letter strings) or social stimuli (faces and hand postures). Therefore, in the sense of persisting in the presence of a demanding cognitive load, this type of imitation behavior can be considered automatic.

Public Significance Statement

This study strongly suggests that the mental processes underpinning imitative behavior are relatively automatic, such that they are unaffected when concurrently performing a demanding secondary task.

Keywords: automaticity, imitation, cognitive load, stimulus-response compatibility

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Unintentional copying of others' behavior has been argued to perform key social functions by building affiliation and rapport between interaction partners (Chartrand & Lakin, 2013; Over & Carpenter, 2012). Moreover, it is claimed that fundamental social processes, such as the way we perceive and interact with others, influence each other in a relatively rapid and unintended fashion (Dijksterhuis & Bargh, 2001; Heyes, 2011). Given the pivotal role that automatic forms of imitation have been argued to play in everyday life, there has been surprisingly little research that has directly examined the automaticity of imitative tendencies. Therefore, the current study uses a dual-task paradigm to investigate one dimension of automaticity in relation to imitation—the extent to which automatic imitation endures under high cognitive load.

The traditional "two-systems" division between automatic and controlled processes (Posner & Snyder, 1975; Shiffrin & Schneider, 1977) has been expanded to construe automaticity as a multidimensional construct (Bargh, 1989, 1994; Melnikoff & Bargh, 2018; Moors & De Houwer, 2006). Accordingly, a behavior or effect can be more or less "automatic" in at least three senses: (a) it can be unintentional and, for example, occur without instruction; (b) it can be stimulus-driven and resistant to top-down control; and (c) it can be efficient, in the sense of persisting under concurrent cognitive load. To better understand the cognitive processes underlying automatic imitation, it is therefore important to consider the extent to which imitative tendencies are "automatic" with reference to these dimensions.

Unintentional Imitation

Evidence that automatic imitation is unintentional has been provided by developmental (Over & Carpenter, 2012; Ray & Heyes, 2011), social (Chartrand & Lakin, 2013), and cognitive psychology (Heyes, 2011). For example, during live social interactions, adults tend to copy the actions of a confederate without any instruction to do so (Chartrand & Bargh, 1999). In addition, laboratory-based measures of automatic imitation have been developed using stimulus response compatibility (SRC) paradigms (Brass, Bekkering, Wohlschläger, & Prinz, 2000; Kilner, Paulignan, & Blakemore, 2003; Stürmer, Aschersleben, & Prinz, 2000). The SRC measure of imitation typically involves performing simple finger, hand, or arm movements, while concurrently observing a compatible or incompatible action. In these experiments the primary task is independent to the observed body movement. Therefore, in the sense of being task-independent, influences of the

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observed movement on behavior can be considered "unintentional."

To elaborate, in one version of the task participants are instructed to make simple finger movements in response to a number "1" or "2" (Brass et al., 2000). Despite the observed finger movement being task-irrelevant, RTs are longer and performance more error-prone during incompatible than compatible conditions, with the difference between conditions known as the compatibility effect. Moreover, compared to a baseline condition where the observed hand is static, performance is facilitated in the compatible condition and also impaired in the incompatible condition (Brass et al., 2000). Therefore, such SRC measures have been argued to index processes associated with the unintentional urge to copy other people's actions (Brass & Heyes, 2005; Brass, Ruby, & Spengler, 2009; Heyes, 2011). In sum, evidence to date suggests that imitative behavior can be automatic in the sense that it is unintentional.

Top-Down Influences

Other research using SRC measures has shown that automatic imitation is not completely stimulus-driven in the sense that it can be modulated by participants' knowledge of the stimuli, or their task set. Manipulating viewers' knowledge or beliefs about the human or animate nature of the stimuli influences SRC measures (Gowen, Bolton, & Poliakoff, 2016; Klapper, Ramsey, Wigboldus, & Cross, 2014; Liepelt & Brass, 2010; Longo & Bertenthal, 2009; Stanley, Gowen, & Miall, 2007). For example, Klapper and colleagues (2014) found that the size of the compatibility effect evoked by the same movements of artificial, computer-rendered "fingers" was larger when participants were led to believe that these movements were generated by motion-tracking of real human behavior as compared to a computer algorithm.

Further, task instructions that vary the participants' attentional focus on action cues likewise modulate compatibility effects (Bach, Peatfield, & Tipper, 2007; Chong, Cunnington, Williams, & Mattingley, 2009). For example, Chong and colleagues (2009) found that directing participants' attention to a task-relevant stimulus feature that spatially overlapped with an observed hand action, or to the chirality of the hand itself, removed compatibility effects on response times. Findings such as these are in keeping with a multidimensional view of automaticity (Melnikoff & Bargh, 2018), by showing that imitative processes can exhibit some automatic features (unintentional), as well as some controlled features (top-down influences).

Cognitive Load

The extent to which imitation is automatic in terms of efficiency of processing and robustness to concurrent perceptual or cognitive load is less clear. In this context, a hallmark of automaticity would be a behavior or process that would not depend on the availability of a central cognitive resource and that could occur in parallel with other mental processes. Load theory provides a useful framework for testing automaticity in this sense (Lavie, 2005, 2010). Load theory distinguishes two major kinds of mental load: perceptual load and cognitive load. *Perceptual load* refers to increasing demand on sensory/perceptual processes, as would be produced by the addition of irrelevant visual or auditory stimuli concurrent to a primary imperative stimulus. In contrast, *cognitive load* increases the demands on a central, general process such as working memory.

Empirical demonstrations suggest that higher perceptual loads tend to dilute the effects of a given distractor, making them less impactful on the primary task. In contrast, higher concurrent cognitive load will tend to increase the impact of distractor events on a primary task (Lavie, Hirst, De Fockert, & Viding, 2004). The interpretation of the latter load effect is that when cognitive control resources are taxed through a secondary task, those same resources are not able to operate as effectively in filtering the influence of distracting stimuli on the primary task. For either kind of load (perceptual or cognitive), however, the absence of sensitivity to variation in load can be taken as an indicator of automaticity. In the present context, we can ask how behavioral measures of the tendency to imitate are influenced by concurrent load. To the extent that these effects resist effective load manipulations, the underlying processes associated with imitation can be said to be "automatic" in the third sense outlined above (i.e., persisting in a relatively unaffected manner in the presence of concurrent load).

To date, two previous studies have assessed the impact of load on SRC measures of imitation and the findings have been inconclusive. Catmur (2016) manipulated perceptual load by adding letter strings (including 1, 2, 4 or 6 items) to the basic SRC paradigm (Brass et al., 2000). With increasing perceptual load (increasing numbers of letters) the compatibility effect reversed, such that compatible trials produced longer RTs than incompatible trials. Although such findings demonstrate that observed finger movements are processed at high perceptual load, the results are difficult to reconcile with both our current understanding of load and of imitation effects. One feature of this approach in general is that perceptual load effects may be complicated by low-level visual interference or interactions between simultaneously presented stimuli (Benoni, 2018), such as letters and hand images in the case of Catmur (2016). As such, a clear picture has not yet emerged regarding the influence of perceptual load on imitation.

In contrast, Van Leeuwen and colleagues (2009) manipulated cognitive load in combination with an SRC measure of imitation. Concurrent to the SRC task, an auditory stream of letter names was presented. Participants in a high-load group had to respond when the letter they just heard was identical to the one they heard two trials previously (two-back). In comparison, a separate low-load group of participants performed an easier, immediate target-detection control task on the same auditory stream. The results did not show an interaction between the critical variables of load and compatibility, although power was limited by the use of a between-participants design. As such, there was minimal evidence that cognitive load influences the compatibility effect, which suggests that imitative tendencies are resistant to cognitive load manipulations.

The aim of the present study was to test the extent to which a demanding secondary task influences SRC measures of automatic imitation. We focused on the influence of a central, cognitive load in part to remove concerns about complicating peripheral effects of interactions among visual elements (Benoni, 2018). Importantly, clear predictions were derived from load theory (Lavie, 2005, 2010). If there is an efficiency limit on the processes supporting automatic imitation, then increasing the concurrent load on working memory should increase the distracting nature of the irrelevant finger movements, thus producing an increased congruency effect. In contrast, if the compatibility effect is unaffected in the presence of high load, this would suggest that the tendency to imitate other's movements, at least as captured by the SRC task, is relatively automatic, in the sense of persisting in the face of a demanding cognitive task.

Experiment 1

Introduction

In the first experiment we built on previous successful manipulations of central load by testing working memory for letter arrays (Konstantinou, Beal, King, & Lavie, 2014). This approach means there is little overlap of perceptual features between the stimuli driving the load manipulation (letters) and the main SRC task (finger movements). Accordingly, if this procedure did reveal an effect of load on SRC, it would be attributable to demands on general processes that operate over different categories of items from different domains.

Method

Consistent with recent proposals (Simmons, Nelson, & Simonsohn, 2011, 2012), across all experiments, we report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study. In addition, following open science initiatives (Munafò et al., 2017), the raw data are freely available online (osf.io/suzrp). By making the raw data available, we enable others to pursue tests of alternative hypotheses, as well as more exploratory analyses.

Across all experiments, we determined our sample size by aiming to collect data for 50 usable data sets. For Experiments 2 and 3, we also preregistered this stopping rule as well as the hypotheses and analysis plan. Based on our target sample size, we performed a sensitivity analysis using G*Power. In the analyses based on analysis of variance (ANOVA), a sample of 50 participants would provide 80% power to detect conventionally large effects (partial eta squared, $\eta_p^2 > 0.14$). In the analyses based on one-tailed paired comparisons, a sample of 50 participants would provide 80% power to detect conventionally small to medium effects (Cohen's $d_z > 0.35$). A sample size of 50, therefore, provides relatively high confidence that if a small to moderate effect of load should exist, we would be able to detect it using paired comparisons between key conditions.

Participants. Fifty-nine participants took part in this experiment for monetary compensation or course credit. All participants provided informed consent and had normal or corrected-to-normal vision. Approval was obtained from the Research Ethics and Governance Committee of the School of Psychology at Bangor University. Participants were excluded if performance was 2.5 standard deviations away from the group mean average performance per condition in terms of accuracy on the working memory task ($n = 1$), as well as accuracy ($n = 3$) or reaction time (RT; $n = 1$) on the SRC task. In addition, one further participant completed only half the trials and withdrew from the experiment and was thus excluded. The final sample included 53 participants (14 males, $M_{\text{age}} = 21.45$, $SD_{\text{age}} = 3.67$, age range = 18 to 38).

Stimuli, task, and procedure. Before the main task, participants completed one practice block of an SRC task (32 trials), a working memory task (32 trials), and the main task, which combined the SRC and working memory tasks (32 trials). This practice phase was followed by eight blocks of the main task (256 trials). The SRC task was based on the SRC paradigm developed by Brass and colleagues (2000), which consisted of finger-lifting movement observation and execution. The hand stimuli comprised an image of a female hand positioned in the center of the screen and viewed from a third person perspective such that the fingers extended toward the participants. The first image was of the hand in a neutral position, while the remaining four images showed either an index or middle finger lift with a number "1" or "2" presented between the index and middle finger. Participants were asked to hold down the "m" and "n" keys on the keyboard with their index and middle fingers of the right hand, respectively. They were instructed to lift their index finger when they saw a number "1" and their middle finger when they saw the number "2." Thus, there were four possible trial types, two of which were compatible, and two of which were incompatible. In the compatible condition, participants were cued to perform the same finger-lifting movement that they observed (i.e., an index finger movement with a "1" or a middle finger movement with a "2"). In the incompatible condition, the executed and observed movements were different (i.e., an index finger movement with a "2" or a middle finger movement with a "1").

For the working memory task, participants were presented with a memory set consisting of one (low load condition) or six (high load condition) letters presented in a circular array in the center of the screen. The letters were randomly chosen on each trial from the set (FHKLMTVWYX), with the constraint that no letters were duplicated within a high load trial. The letters were presented such that each letter occurred with equal probability in any of the six positions in the circular array (see Konstantinou et al., 2014, for a similar manipulation of working memory load). For the low load condition, five of the letters were replaced by circular dots in the array. Participants were instructed to remember the letter/s presented in the circular array throughout the retention interval because they would be asked to verify whether a probe letter, which was presented after the retention interval, was present in the initial circular array. At the end of the retention interval, participants were then asked to verify whether a probe letter was present (press key "e") or absent (press key "d") in the circular array of letters shown at the start of the trial. For half of the trials (present trials), the probe letter was drawn from those that had appeared in the array. For the other half (absent trials), the probe letter was not one that had appeared in the initial array. All letters in both the "present" and "absent" trials came from the same overall letter set (FHKLMTVWYX).

The imitation task was presented during the retention interval of the working memory task (see Figure 1). Participants were asked to press down on the "m" and "n" keys with the index and middle fingers of their right hand and keep their left index and middle fingers on the "e" and "d" keys, respectively. Each trial started with six dots presented in a circular array for 500 ms. The memory set of letters (either one or six) was then presented for 1,000 ms, followed by a central fixation dot for 2,000 ms. The neutral hand stimulus of the imitation task was then presented on the screen for a random interstimulus interval of 500, 700, or 1,000 ms, followed

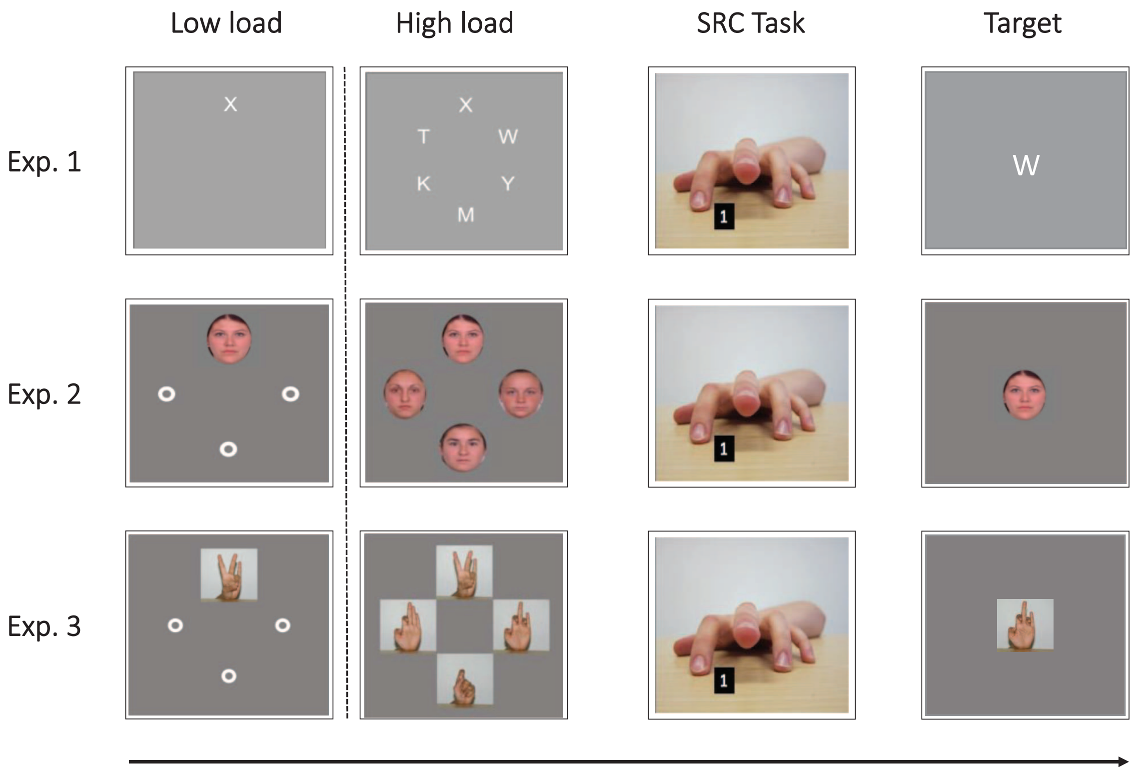

Figure 1. Experimental design and stimuli across each experiment. Each experiment had the same basic structure. First, there was a set of stimuli to be held in memory, which could either be a single item (low load) or multiple items (high load). Whilst keeping this working memory content in mind for later verification, participants performed a stimulus response compatibility task (SRC task), which consisted of finger-lifting movement observation and execution. As such, the observed finger movement could be compatible or incompatible to the performed finger movement with the imperative cue (a "1" or "2") being independent to any observed finger movement. Following the SRC task, a target appeared and participants had to verify whether the item was part of the stimuli presented at the start of the trial. Across Experiments 1 to 3, we used letters, faces, and hand postures as stimuli to hold in working memory. See the online article for the color version of this figure.

by a number cue and finger movement, which stayed onscreen until a response or for a maximum of 2,000 ms. Participants had to lift their right-hand index or middle finger depending on the number cue. After the participant responded to the number cue in the SRC task, the memory probe letter was then presented. Participants then had to press either the "d" or "e" key with their left hand indicating whether the letter was absent or present respectively in the memory set presented earlier. The memory probe target letter stayed on screen until a response was made or for a maximum of 3,000 ms. Each trial was self-paced and participants were given a short break every 32 trials in the main task. Thus, there were four trial types in the main task, formed by crossing load (low or high) factorially with SRC (compatible or incompatible).

Data analysis. Accuracy on the working memory task was defined as the proportion of trials that the target was correctly recognized as being present or absent from the initial array of stimuli. A 2 (load: low, high) × 2 (compatibility: compatible, incompatible) repeated measures ANOVA was performed on working memory accuracy data. A main effect of load was predicted such that accuracy would be lower for high than low memory loads.

Accuracy on the SRC task was defined as the proportion of trials where the correct finger was lifted in response to the number cue. In addition, RT on the SRC task was defined as the time taken between the appearance of the number cue (the imperative stimulus) and the response of the participant. To make sure that RTs reflected performance on compatible versus incompatible trials, and in line with typical practice, only correct trials on the SRC task were used to calculate RTs. For both accuracy and for RT on the SRC task, a 2 (load: low, high) × 2 (compatibility: compatible, incompatible) repeated measures ANOVA was performed.

Based on prior research (reviewed in Heyes, 2011), we expected a main effect of compatibility for accuracy and for RT, such that the incompatible condition would be slower and more error-prone than the compatible condition. To support the hypothesis that processes underpinning automatic imitation are influenced by cognitive load, a Load × Compatibility interaction would be expected, such that the compatibility effect would be larger under high than low load. Because the size of the interaction effect was central to testing our primary hypothesis, we also estimated compatibility effects for low and high load conditions separately by calculating the mean difference and 95% confidence interval between compatibility conditions. We then directly estimated the size of the difference in compatibility effects between low and high load conditions by again calculating the mean difference and 95% confidence interval. We used one-tailed 95% confidence intervals to reflect our clear directional hypothesis that high load should result in greater SRC effects than low load.

We report effect sizes in original units (e.g., milliseconds) using mean differences between conditions and 95% confidence intervals. Standardized effect sizes were also calculated for ANOVA using partial eta squared (η_p^2) and for paired comparisons using Cohen's d_z (Cohen, 1992; Lakens, 2013). In cases where a null result was found using null hypothesis significance testing, we used a Bayesian paired samples *t* test to quantify evidence for the null hypothesis compared to the experimental hypothesis. To do so, a Bayes factor (BF_{01}) was calculated, which can be interpreted as evidence for the null hypothesis compared to the experimental hypothesis, given the data. Benchmark criteria from Jeffreys (1961) were used for interpreting Bayes factors. All statistical analyses were performed using JASP (JASP Team, 2018) and all results figures were produced using R (R Core Team, 2018).

Results

Data for Experiment 1 are visualized in Figure 2 and effect sizes for key compatibility effects are reported in Table 1.

Working memory accuracy. On average, all conditions were above chance performance as demonstrated by the 95% confidence intervals not including 50% (Figure 2A).

Table 1
Paired Contrasts Effect Sizes for Reaction Time Data in Experiment 1

Experiment and condition	Compatibility effect Milliseconds [95% confidence interval]	Cohen's d_z	BF_{01}
Experiment 1			
General compatibility			
Low load	72.57 [59.60, ∞]	1.29	
High load	67.57 [58.59, ∞]	1.73	
High–low load	−5.00 [−15.07, ∞]	−.11	11.44

Note. BF = Bayes factor.

Further, a 2 (load: low, high) × 2 (compatibility: compatible, incompatible) repeated measures ANOVA showed a significant main effect of load $F(1, 52) = 195.93$, $p < .001$, $\eta_p^2 = 0.79$, which had an effect size that is conventionally considered large (Figure 2A). There was no significant main effect of compatibility $F(1, 52) = 0.20$, $p = .66$, $\eta_p^2 < 0.01$ and no significant interaction between load and compatibility $F(1, 52) = 0.03$, $p = .87$, $\eta_p^2 < 0.01$. The effect sizes for the main effect of compatibility and the two-way interaction were close to zero. The main effect of load shows that participants were less accurate on the working memory task in the high load than low load condition (Figure 2A).

SRC task.

Accuracy. Average accuracy was over 90% in all conditions (Figure 2B). Further, a 2 (load: low, high) × 2 (compatibility: compatible, incompatible) repeated measures ANOVA showed no significant main effect of load, $F(1, 52) = 0.08$, $p = .77$, $\eta_p^2 < 0.01$, with an effect size close to zero. There was a significant main effect of compatibility $F(1, 52) = 50.74$, $p < .001$, $\eta_p^2 = 0.49$, but no significant interaction between load and compatibility, $F(1, 52) = 0.76$, $p = .39$, $\eta_p^2 = 0.01$. The effect size for the main effect of compatibility is conventionally considered large and the effect size for the two-way interaction was close to zero. The main effect of compatibility shows that participants were less

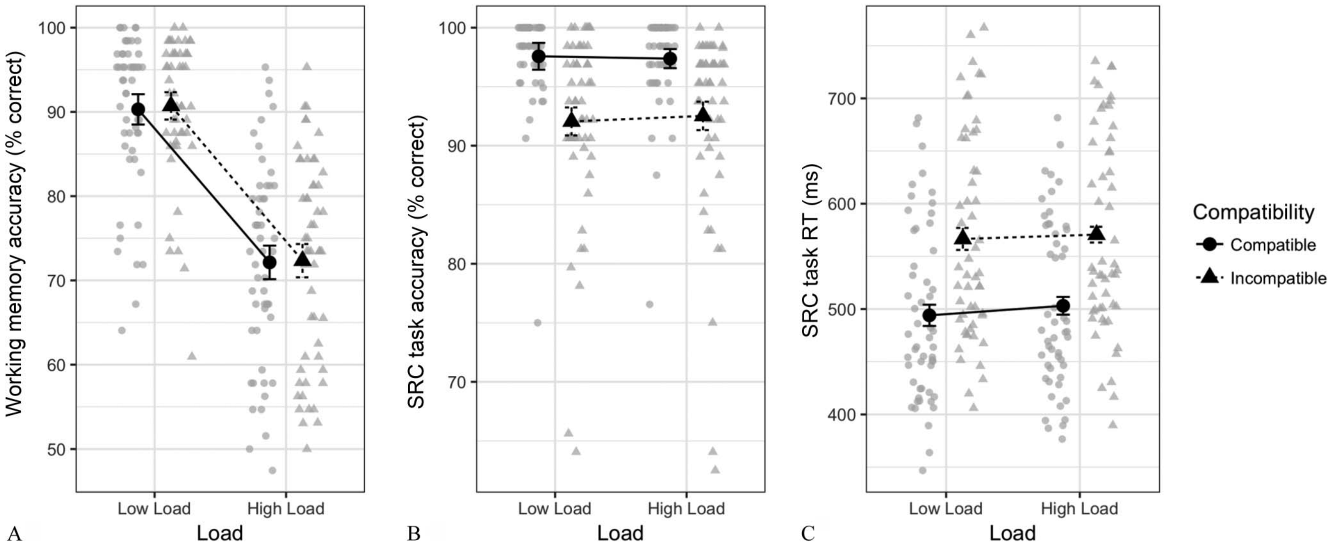

Figure 2. Results for Experiment 1. Working memory accuracy (A) and SRC task accuracy (B) reported in % correct and SRC task RT (C) reported in milliseconds across conditions of general compatibility and load. Black bars show mean average group performance, with gray markers showing individual participant data points. SRC = stimulus response compatibility; RT = reaction time; ms = milliseconds. Error bars are 95% confidence intervals.

accurate on the imitation task in the incompatible condition than the compatible condition (Figure 2B).

Reaction time. A 2 (load: low, high) × 2 (compatibility: compatible, incompatible) repeated measures ANOVA showed no significant main effect of load $F(1, 52) = 2.35$, $p = .13$, $\eta_p^2 = 0.04$. However, there was a trend toward high load leading to longer RTs in general, but this was a relatively small effect size (Figure 2C). There was a significant main effect of compatibility, $F(1, 52) = 139.11$, $p < .001$, $\eta_p^2 = 0.73$, but no significant interaction between load and compatibility $F(1, 52) = 0.69$, $p = .41$, $\eta_p^2 = 0.01$. The effect size for the main effect of compatibility is conventionally considered large and the effect size for the two-way interaction was close to zero. The main effect of compatibility shows that participants were slower to respond in the incompatible than compatible condition (Figure 2C). The lack of interaction shows that the compatibility effect does not vary between load conditions.

To further interrogate our key hypothesis, we estimated effect sizes for the primary paired comparisons of interest. To do so, we calculated the compatibility effect for high and low load conditions separately and then compared them to each other. When considered separately, average compatibility effects were large (Cohen's $d_z > 1.2$) and the lower bound of the 95% confidence intervals were both above zero for low load and high load conditions (Figure 2C; Table 1). When the compatibility effect for High load was directly compared to Low load, there was not even a trend for a difference in the predicted direction $d_z = -0.11$ (Figure 2C; Table 1). In addition, a Bayesian paired samples *t* test showed that the null was 11 times more likely than the experimental effect ($BF_{01} = 11.44$). In sum, both low and high load conditions have a nonzero compatibility effect, but the compatibility effect does not differ as a function of load.

Discussion

The results demonstrate a clear effect of central load on working memory performance, as well as a clear compatibility effect in the SRC task. Both of these findings replicate previous work and demonstrate that the manipulations were successful. Importantly, there was no meaningful influence of load on compatibility effect. The findings, therefore, provide initial evidence that the cognitive processes supporting the tendency to imitate another person's actions operate in a relatively efficient manner, which is independent of central cognitive resources. This pattern is consistent with the third sense of automaticity described in the General Introduction (i.e., that imitative effects persist under concurrent cognitive load).

There are two limitations to this initial conclusion, which Experiment 2 addresses. First, the version of the automatic imitation paradigm used in Experiment 1 combined spatial and imitative compatibility features. For example, in an incompatible trial, the identity of the observed finger movement was different to the finger movement required by the participant (imitative compatibility), as well as being in an incongruent spatial location relative to the required movement on the left-right axis (spatial compatibility). As such, it is possible that load effects may have operated differently on these SRC components and obscured the effects of interest.

Second, based on theories of working memory structure (Allen, Baddeley, & Hitch, 2017; Baddeley, 1992; Baddeley & Hitch, 1974), it may be that the working memory subsystem(s) supporting the encoding of letters may be distinct from systems involved in perceiving the finger movements, even though both were presented in the visual modality. That is, storing the working memory stimuli (letters) may have depended on the activity of a phonological buffer—although given the brevity of the presentation, recoding the letters in this way would likely prove challenging. The finger-movement displays were, by definition, not intended to be encoded into working memory; yet their perception may, if anything, have a relatively stronger influence on a visuospatial memory system. Previous findings from the load theory program are not fully supportive of this view, however. For example, manipulation of working memory load (memory for digits) influenced both behavioral and neural measures of interference from face images on a name-categorization task (de Fockert, Rees, Frith, & Lavie, 2001). Nonetheless, these considerations highlight that the absence of a load effect could in principle reflect not (or not only) the automaticity of imitation, but the architecture of cognitive systems that cope with distinct kinds of information.

Experiment 2

Introduction

In Experiment 2, we addressed these issues by making two principal changes. First, we disentangled spatial and imitative compatibility effects by using a version of the automatic imitation task that provides separate spatial and imitative interference measures (Bertenthal, Longo, & Kosobud, 2006; Boyer, Longo, & Bertenthal, 2012; Catmur & Heyes, 2011).

Second, we used face stimuli instead of letters as the basis for a load manipulation. Loading working memory with a social rather than a verbal stimulus achieved two objectives. It increased the domain overlap between the load stimuli (faces) and the primary task (finger movements). Furthermore, compared to letters, unfamiliar and highly homogenous computer-rendered faces are much more difficult to subvocalize or verbalize. In both respects, then, we would expect a greater overlap between the perceptual and cognitive mechanisms engaged by the two tasks.

We had the same set of hypotheses and used the same basic design and analysis pipeline as in Experiment 1, all of which we preregistered in advance of the experiment commencing (https://aspredicted.org/mk99b.pdf).

Method

Participants. Fifty-five participants took part in this experiment for monetary compensation or course credit. All participants provided informed consent and had normal or corrected-to-normal vision. Approval was obtained from the Research Ethics and Governance Committee of the School of Psychology at Bangor University. Participants were excluded if performance was 2.5 standard deviations away from the group mean in terms of accuracy on the working memory task ($n = 5$), as well as accuracy ($n = 2$) or RT on the SRC task. The final sample included 48 participants (15 men, $M_{age} = 24.90$, $SD_{age} = 3.29$, age range = 21 to 39).

Stimuli, task, and procedure. The tasks used in Experiment 2 were similar to Experiment 1 but with the following two changes. First, we calculated an imitative compatibility effect independent of spatial compatibility in the SRC task (Catmur & Heyes, 2011). To do so, participants viewed an image of an index or middle finger lift of either a right or left hand, but always responded with their right hand. Using right and left-hand images produced eight trial types and four main conditions of interest. For example, when cued to lift their index finger while observing a left-hand index finger lift, the observed movement is both imitatively compatible (same finger), as well as spatially compatible (same side of space to the executed movement). In contrast, when observing a right-hand index finger lift, the participant's response is imitatively compatible (same finger) but it is not on the same side of space (they are spatially incompatible). Thus, participants performed the same (imitatively compatible) or different (imitative incompatible) finger movement on the same (spatially compatible) or different (spatially incompatible) side of space to the observed finger movement, giving rise to the following four conditions:

1. Imitatively and spatially compatible
2. Imitatively and spatially incompatible
3. Imitatively compatible and spatially incompatible
4. Imitatively incompatible and spatially compatible

Second, we used face stimuli instead of letters as basis for a load manipulation (see Figure 1). In the high load condition, four faces were presented in the memory set, while in the low load condition, one face was presented. Faces were presented in a circular array in a similar manner to Experiment 1. Participants were asked to remember the faces during the retention interval and then respond whether the memory probe face stimulus was present or absent in the memory set at the end of the retention interval. Face stimuli included 20 female faces obtained from http://faceresearch.org (DeBruine & Jones, 2017). The faces were edited to be 160 × 160 pixels in size and were presented in color and modified such that only the inner face (eyebrows, eyes, nose, and mouth) was shown on a gray background.

Data analysis. Data were analyzed in an identical manner to Experiment 1, except we performed a 2 (load: low, high) × 2 (spatial compatibility: compatible, incompatible) × 2 (imitative compatibility: compatible, incompatible) repeated measures ANOVA on working memory accuracy, as well as SRC accuracy and RT. Although the design, data, and hypotheses remain identical to those that we preregistered, the above ANOVA structure is subtly different to one that we preregistered. The way we preregistered the ANOVA for Experiments 2 and 3 is intuitive because it focused on analyzing compatibility type (spatial vs. imitative) as a function of load and compatibility. However, the preregistered ANOVA structure could be criticized on the grounds that some factors, which are treated as independent, are actually not independent. Therefore, in Experiments 2 and 3, we choose to report the ANOVA as above to ensure that the factors are treated independently. As in Experiment 1, we estimated key effect sizes by calculating RT compatibility effects as a function of compatibility type and load. The spatial compatibility effect was calculated by subtracting RTs on spatially compatible trials from spatially incompatible trials. The imitative compatibility effect was calculated by subtracting RTs on imitatively compatible trials from imitatively incompatible trials. Again, these analyses were driven by the main focus of the research question, which was to characterize the size of compatibility effects across different degrees of load.

Results

Data for Experiment 2 are visualized in Figure 3 and effect sizes for key compatibility effects are reported in Table 2. Complete

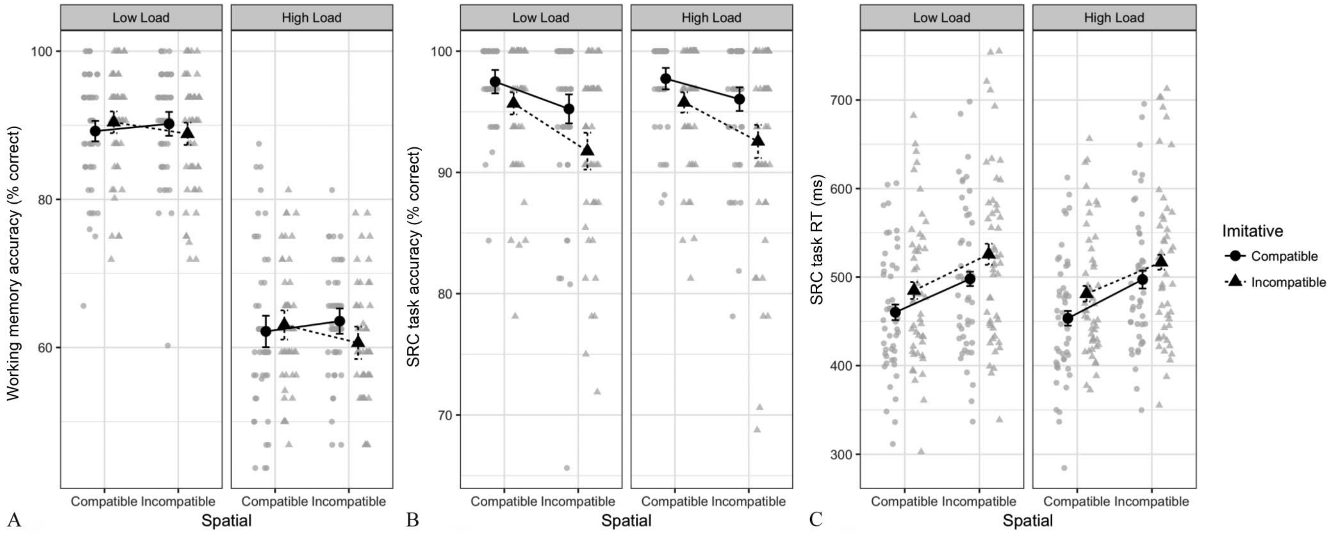

Figure 3. Results for Experiment 2. Working memory accuracy (A) and SRC task accuracy (B) reported in % correct and SRC task RT (C) reported in milliseconds across conditions of spatial and imitative compatibility as well as load. Black bars show mean average group performance, with gray markers showing individual participant data points. Abbreviations: SRC = stimulus response compatibility; RT = reaction time; ms = milliseconds. Error bars are 95% confidence intervals.

Table 2
Paired Contrasts Effect Sizes for Reaction Time Data in Experiments 2 and 3

	Experiment 2: Compatibility effect			Experiment 3: Compatibility effect		
Condition	Milliseconds [95% CI]	Cohen's d_z	BF_{01}	Milliseconds [95% CI]	Cohen's d_z	BF_{01}
Spatial compatibility (imitatively compatible)						
Low load	37.70 [28.72, ∞]	1.02		35.05 [25.87, ∞]	.92	
High load	43.75 [33.47, ∞]	1.03		31.68 [22.98, ∞]	.87	
High–low load	6.05 [−4.38, ∞]	.14	2.47	−3.36 [−14.37, ∞]	−.07	9.17
Spatial compatibility (imitative incompatible)						
Low load	40.96 [28.69, ∞]	.81		33.77 [24.41, ∞]	.87	
High load	35.63 [24.67, ∞]	.79		30.31 [17.98, ∞]	.87	
High–low load	−5.33 [−17.80, ∞]	−.10	10.24	−3.46 [−17.13, ∞]	−.06	8.68
Imitative compatibility (spatially compatible)						
Low load	24.59 [13.86, ∞]	.56		9.04 [1.74, ∞]	.30	
High load	27.68 [18.62, ∞]	.74		15.45 [3.70, ∞]	.32	
High–low load	3.09 [−9.61, ∞]	.06	4.51	6.41 [−4.09, ∞]	.15	2.34
Imitative compatibility (spatially incompatible)						
Low load	19.56 [8.23, ∞]	.42		7.76 [−1.70, ∞]	.20	
High load	27.85 [15.36, ∞]	.54		14.07 [3.98, ∞]	.33	
High–low load	−8.29 [−20.40, ∞]	−.17	12.79	6.31 [−6.79, ∞]	.12	3.02

Note. CI = confidence interval; BF = Bayes factor.

statistical information on the ANOVAs conducted are reported in Supplementary Table S1 in the online supplemental material.

Working memory accuracy. On average, all conditions were above chance performance as demonstrated by the 95% confidence intervals not including 50% (Figure 3A). Further, a 2 (load: low, high) × 2 (spatial compatibility: compatible, incompatible) × 2 (imitative compatibility: compatible, incompatible) repeated measures ANOVA showed a main effect of load, $F(1, 47) = 1368.45$, $p < .001$, $\eta_p^2 = 0.97$. The effect size for the influence of load was large and in the expected direction such that accuracy was lower in the high than low load conditions (Figure 3A). There was also a Spatial Compatibility × Imitative Compatibility interaction, $F(1, 47) = 6.42$, $p = .02$, $\eta_p^2 = 0.12$, which showed that the imitative compatibility effect (lower accuracy in incompatible than compatible conditions) was larger at spatially incompatible than compatible levels. All other main effects and interactions were not significant and effect sizes were close to zero (Figure 3A; Supplementary Table S1 in the online supplemental material).

SRC task.

Accuracy. Average accuracy was over 90% in all conditions (Figure 3B). Further, a 2 (load: low, high) × 2 (spatial compatibility: compatible, incompatible) × 2 (imitative compatibility: compatible, incompatible) repeated measures ANOVA showed a main effect of spatial compatibility, $F(1, 47) = 32.96$, $p < .001$, $\eta_p^2 = 0.41$, and a main effect of imitative compatibility, $F(1, 47) = 36.98$, $p < .001$, $\eta_p^2 = 0.44$. There was also a Spatial Compatibility × Imitative Compatibility interaction, $F(1, 47) = 5.33$, $p = .03$, $\eta_p^2 = 0.10$. All other main effects and interactions were not significant and effect sizes were close to zero or small (Supplementary Table S1 in the online supplemental material). The effect sizes for the influence of both spatial and imitative compatibility were large and in the expected direction such that accuracy was lower in the incompatible than compatible conditions (Figure 3B). In addition, the interaction showed that the imitative compatibility effect was larger at spatially incompatible than compatible levels.

Reaction time. A 2 (load: low, high) × 2 (spatial compatibility: compatible, incompatible) × 2 (imitative compatibility: compatible, incompatible) repeated measures ANOVA showed a main effect of spatial compatibility, $F(1, 47) = 76.59$, $p < .001$, $\eta_p^2 = 0.62$, and a main effect of imitative compatibility, $F(1, 47) = 30.08$, $p < .001$, $\eta_p^2 = 0.39$. There was also a trend toward a main effect of load $F(1, 47) = 5.69$, $p = .08$, $\eta_p^2 = 0.07$. No other main effects or interactions were significant and effect sizes were close to zero or small (Supplementary Table S1 in the online supplemental material). Both main effects of spatial and imitative compatibility were large and demonstrated that RTs were longer in incompatible than compatible conditions (Figure 3C). The trend toward a main effect of load revealed that RTs were shorter in the high than in the low load condition.

The lack of interaction between load and either type of compatibility suggests that compatibility effects are not influenced by load. To interrogate the RT data further, we estimated effect sizes for key paired contrasts. These paired contrasts demonstrated that compatibility effects are present, on average, across all compatibility types and levels of load with effect sizes ranging from 0.42 to 1.03 Cohen's d_z (see Table 2). In addition, and consistent with prior work (Bertenthal et al., 2006; Boyer et al., 2012; Catmur & Heyes, 2011; Darda, Butler, & Ramsey, 2018), spatial compatibility effects were 1.5–2 times larger, on average, than imitative compatibility effects.

In terms of our key hypothesis, direct comparison of compatibility effects between high and low load revealed that there was not even a trend for a difference in the predicted direction (i.e., high > low). For spatial compatibility, the difference between high and low load was small or close to zero at imitatively compatible ($d_z = 0.14$) and incompatible levels ($d_z = -0.10$). In addition, a Bayesian paired samples t test showed that the null was over 2 or 10 times more likely than the experimental effect at imitatively compatible ($BF_{01} = 2.47$) and incompatible levels ($BF_{01} = 10.24$; Table 2). Likewise, for imitative conflict, the difference between high and low load was close to zero at spatially compatible ($d_z = 0.06$) and incompatible levels ($d_z = -0.17$). In addition, a Bayesian paired samples t test showed that the null was over 4 or 12 times more likely than the experimental effect at spatially compatible (BF_{01} = 4.51) and incompatible levels (BF_{01} = 12.79; Table 2). In summary, spatial and imitative compatibility effects were present at low and high levels of load, but in both cases the compatibility effects did not differ as a function of load.

Discussion

Similar to Experiment 1, we found no influence of a demanding cognitive load task on automatic imitation, despite clear evidence for load effects and for both imitative and spatial compatibility effects. These findings held in spite of greater overlap between the type of material used in the working memory task and the primary task, relative to Experiment 1. The findings, therefore, provide further evidence that the cognitive systems that support imitative tendencies operate in a relatively automatic manner, which is robust in the face of substantial concurrent demand on the cognitive resources that hold faces in memory.

We next conducted a third experiment with the aims of further confirming our findings, and of bringing the demands of the two tasks still closer together. Even though faces are clearly social stimuli, there are nonetheless obvious visual feature differences between faces and hand actions. As such, in the third experiment, we loaded working memory with images of hands holding different postures so that the overlap of the content of the two tasks was essentially complete.

The third experiment also permitted one unexpected result from Experiment 2 to be evaluated further. The SRC task had an influence on working memory performance, such that a lower working memory accuracy was found in the imitatively incompatible than compatible conditions and this effect was larger at spatially incompatible than compatible levels. Given that this type of SRC influence on working memory was not anticipated and there was no impact of the SRC task on working memory performance in Experiment 1, we thought that further evidence was required before we provide speculative comments on this effect.

Experiment 3

Introduction

In Experiment 3, we tested the efficiency of processes controlling automatic imitation when the contents of working memory load are matched in a much closer manner to the contents of the main task. To do so, we used hand postures as load stimuli. Unlike the previous two experiments, which used letters and faces, hand postures have essentially identical stimulus features as the stimuli in the SRC task. Therefore, if independence of compatibility effects from memory load is again observed, it would be impossible to claim that this arose due to the stimuli from the two tasks drawing on perceptual/memory systems that are differentiated as a function of stimulus material. Again, we had the same set of hypotheses and used the same basic design and analysis pipeline as in the previous experiments, all which we preregistered in advance of the experiment commencing (https://aspredicted.org/up27p.pdf).

Method

Participants. Fifty-nine participants took part in this experiment for monetary compensation or course credit. All participants provided informed consent and had normal or corrected-to-normal vision. Approval was obtained from the Research Ethics and Governance Committee of the School of Psychology at Bangor University. Participants were excluded if performance was 2.5 standard deviations away from the group mean average performance per condition in terms of accuracy on the working memory task (n = 2), as well as accuracy (n = 4) or RT (n = 4) on the SRC task. The final sample included 49 participants (12 men, M_{age} = 20.80, SD_{age} = 4.14, age range = 18 to 42).

Stimuli, task, and procedure. The tasks used in Experiment 3 were similar to Experiment 2 but with the following change: we used hand stimuli instead of faces as the basis for a load manipulation (see Figure 1). In the high load condition, four hand postures were presented in the memory set in a circular array, while in the low load condition, one hand posture was presented. Participants were asked to remember the hand posture/s during the retention interval and then respond whether the memory probe hand posture stimulus was present or absent in the memory set at the end of the retention interval. The 20 hand stimuli depicted 20 different single-hand postures typical of Indian classical dance presented from the same frontal viewpoint. All postures were demonstrated by a single female actor so that memory performance could not depend on variations in shape or texture between actors. Participants did not have any experience with Indian classical dance and were not familiar with the hand postures, thus making the stimuli difficult to verbalize or subvocalize.

Data analysis. Data analysis procedures were identical to Experiment 2.

Results

Data for Experiment 3 are visualized in Figure 4 and effect sizes for key compatibility effects are reported in Table 2. Complete statistical information on the ANOVAs conducted are reported in Supplementary Table S1 in the online supplemental material.

Working memory accuracy. On average, performance across all conditions was above chance performance as demonstrated by the 95% confidence intervals not including 50% (Figure 4A). Further, a 2 (load: low, high) × 2 (spatial compatibility: compatible, incompatible) × 2 (imitative compatibility: compatible, incompatible) repeated measures ANOVA showed a main effect of load, $F(1, 48) = 486.54$, $p < .001$, $\eta_p^2 = 0.91$. All other main effects and interactions were not significant and effect sizes were close to zero or small (Supplementary Table S1 in the online supplemental material). The effect size for the influence of load was large and in the expected direction such that accuracy was lower in the high than low load conditions (Figure 4A).

SRC task.

Accuracy. Mean average accuracy was over or approaching 90% in all conditions (Figure 4B). Further, a 2 (load: low, high) × 2 (spatial compatibility: compatible, incompatible) × 2 (imitative compatibility: compatible, incompatible) repeated measures ANOVA showed a main effect of spatial compatibility, $F(1, 48) = 46.08$, $p < .001$, $\eta_p^2 = 0.49$, and a main effect of imitative compatibility, $F(1, 48) = 9.40$, $p < .004$, $\eta_p^2 = 0.16$. There was also a Spatial Compatibility × Imitative Compatibility interaction, $F(1, 48) = 5.44$, $p = .024$, $\eta_p^2 = 0.10$. The effect sizes for the influence of both spatial and imitative compatibility were large and in the expected direction such that accuracy was lower in the

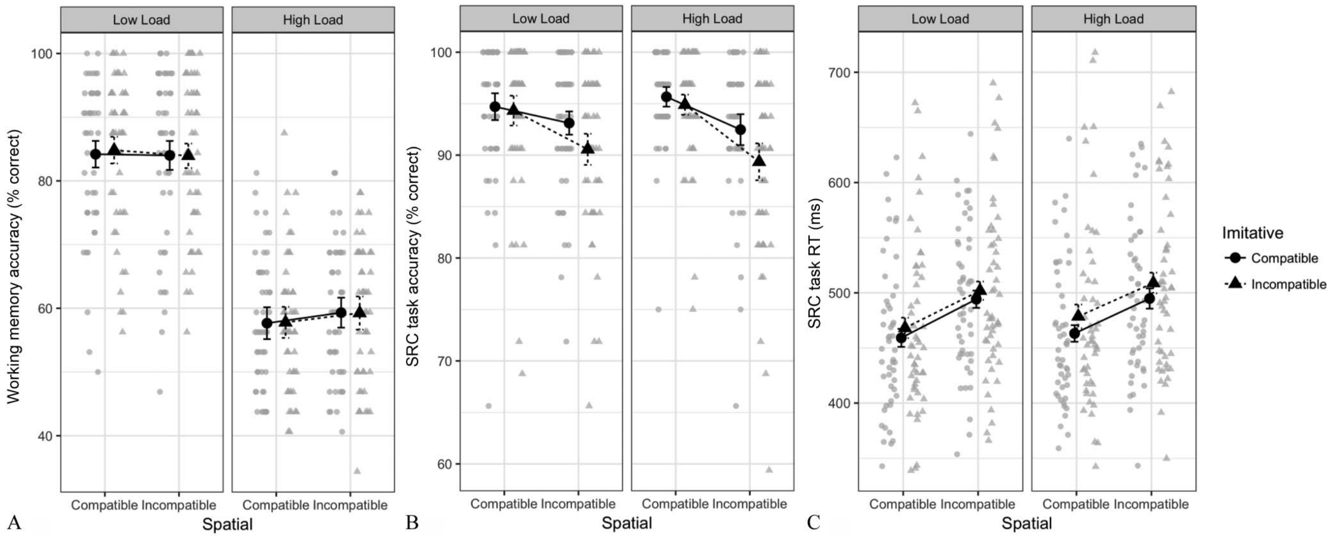

Figure 4. Results for Experiment 3. Working memory accuracy (A) and SRC task accuracy (B) reported in % correct and SRC task RT (C) reported in milliseconds across conditions of spatial and imitative compatibility as well as load. Black bars show mean average group performance, with gray markers showing individual participant data points. Abbreviations: SRC = stimulus response compatibility; RT = reaction time; ms = milliseconds. Error bars are 95% confidence intervals.

incompatible than compatible conditions. In addition, the interaction between compatibility types replicated Experiment 2 and showed that the imitative compatibility effect was larger at spatially incompatible than compatible levels. There was also a Load × Spatial compatibility interaction, $F(1, 48) = 5.67$, $p = .021$, $\eta_p^2 = 0.11$, which showed that the difference in accuracy between compatible and incompatible conditions was greater at high than low levels of load. This latter interaction effect is consistent with the view that a reduction in cognitive control may lead to a more potent impact of task-irrelevant stimulus features and thus more errors. However, the effect is difficult to interpret because it is not consistent with Experiment 2, where no interaction between load and spatial compatibility was observed on SRC task accuracy. Moreover, even if the effect was consistent across experiments, it would only relate to understanding automaticity in spatial interference control and not the control of imitation, which is the primary focus of the current paper. Therefore, we do not attempt to interpret the result any further. All other main effects and interactions were not significant and effect sizes were close to zero (Supplementary Table S1 in the online supplemental material).

Reaction time. A 2 (load: low, high) × 2 (spatial compatibility: compatible, incompatible) × 2 (imitative compatibility: compatible, incompatible) repeated measures ANOVA showed a main effect of spatial compatibility, $F(1, 48) = 98.20$, $p < .001$, $\eta_p^2 = 0.67$, and a main effect of imitative compatibility, $F(1, 48) = 12.72$, $p = <0.001$, $\eta_p^2 = 0.21$. No other main effects or interactions were significant and effect sizes were close to zero or small (Figure 4C; Supplementary Table S1 in the online supplemental material). One of the small effects warrants further discussion because of its pertinence to the primary research question. The Load × Imitative compatibility interaction showed a nonsignificant and small effect ($\eta_p^2 = 0.03$) in the hypothesized direction, such that imitative compatibility was marginally larger in the high than low load condition. Although this is a small effect, which our study was not designed to detect with reasonable confidence (>80% statistical power), given the pertinence to our primary question, we evaluate it further below using paired contrasts to estimate effect sizes further.

The lack of a clear interaction effect between load and either type of compatibility suggests that compatibility effects remain largely unaffected by load. To interrogate the RT data further, we estimated effect sizes for key paired contrasts. These paired contrasts demonstrated that compatibility effects are present, on average, across all compatibility types and levels of load with effect sizes ranging from 0.20 to 0.92 Cohen's d_z (see Table 2). In addition, consistent with findings from Experiment 2 and prior work (Bertenthal et al., 2006; Boyer et al., 2012; Catmur & Heyes, 2011; Darda et al., 2018), spatial compatibility effects were several times larger, on average, than imitative compatibility effects.

In terms of our key hypothesis, direct comparison of compatibility effects between high and low load revealed that there was not convincing evidence for a difference in the predicted direction (i.e., high > low). For spatial compatibility, the difference between high and low load was close to zero at imitatively compatible ($d_z = -0.07$) and incompatible levels ($d_z = -0.06$). In addition, a Bayesian paired samples t test showed that the null was eight or nine times more likely than the experimental effect at imitatively compatible ($BF_{01} = 9.17$) and incompatible levels ($BF_{01} = 8.68$; Table 2). Likewise, for imitative conflict, the difference between high and low load was small at spatially compatible ($d_z = 0.15$) and incompatible levels ($d_z = 0.12$) and 95% confidence interval estimates overlapped with zero. In addition, a Bayesian paired samples t test showed that the null was over 2 or 3 times more likely than the experimental effect at spatially compatible ($BF_{01} = 2.34$) and incompatible levels ($BF_{01} = 3.02$; Table 2). Therefore, although the imitative compatibility effect was numerically larger under high than low load, the effect remained small and relatively inconsistent with the null effect being several times more likely than the experimental effect. In summary, spatial and imitative compatibility effects were present at low and high levels of load, but in both cases, there was no clear evidence that compatibility effects differed as a function of load.

Discussion

Similar to Experiments 1 and 2, we found no clear influence of a demanding cognitive load task on automatic imitation, despite clear load effects on working memory, as well as clear imitative and spatial compatibility effects. This finding held even though the content used for the two tasks was essentially identical in nature. The findings from the third experiment, therefore, confirm that the cognitive systems behind imitative tendencies operate in a relatively efficient manner, which is independent of central cognitive resources.

General Discussion

Over three experiments, we replicated expected stimulus-response compatibility effects and central working memory load effects. In none of these experiments, however, did we find convincing evidence for an influence of central load on the size of the compatibility effects. Experiments 2 and 3 confirmed this pattern separately for spatial and imitative compatibility effects. Further, the same pattern held across a range of types of visual material used in the working memory task (letters, faces and hand postures). This demonstrates that the robustness of imitation effects in the presence of load did not depend on the content held in working memory nor on its similarity to the action stimuli.

As tested here using SRC measures, the tendency to imitate others' actions is not modulated by the presence of a demonstrably difficult cognitive load. Therefore, in the sense of persisting in the presence of cognitive load, this type of imitation behavior can be considered automatic. Before further considering the implications of these findings for understanding the cognitive processes that support automatic imitation, we first consider alternative interpretations and limitations of our findings.

Possible Alternative Interpretations

One possibility when demonstrating a lack of interaction is that the load manipulation was ineffective. However, this is unlikely given that the manipulation of cognitive load produced large effect sizes on working memory performance. A related concern is that the load task is so effective that working memory performance in the high load condition is not distinguishable from chance. In that event, it could be that participants essentially gave up on those trials, which might render them more like low-load trials and thus explain the lack of difference between load conditions. However, this was not the case. Performance on high load conditions was above chance (on average) across all three experiments. Furthermore, in all three experiments, when we removed individuals with performance in the high load condition that approached chance (<55%), the pattern of results remained largely the same (Supplementary Tables S2 and S3 in the online supplemental material). We acknowledge that in Experiment 3, this secondary analysis was based on a relatively small subsample of participants ($n = 13$), which reduces our sensitivity to detect effects, but nonetheless, based on evidence across all three experiments, there remained no compelling or consistent evidence for an effect of load on compatibility effects.

A further consideration is that a lack of evidence for an interaction reflects a lack of sensitivity. There are grounds that make this unlikely. We used a high-power design, which provided 80% power to detect effects that are typically considered small to medium (Cohen's d_z 0.35 and above). Even in Experiments 2 and 3, where, after excluding outliers, the final sample dipped below our target of $N = 50$, we still had 80% power to detect small to medium effect sizes (Cohen's d_z 0.36 and above). Moreover, we replicated the same pattern of effects in three separate experiments. Therefore, we are relatively confident that if an effect of load existed, which was in the range of Cohen's d_z 0.35–0.36 or higher, we would have been able to detect it.

Consistent with recent recommendations (Cumming, 2012; Gigerenzer, 2018), explicitly considering the sensitivity of our design and interpreting effect sizes, rather than simply making binary distinctions based on a p value criterion (e.g., $p < .05$), has important implications for the type of conclusion that we can make. Indeed, based on the power of our experimental design, we cannot rule out the possibility that cognitive load has a small effect on SRC measures of automatic imitation, but we can suggest with some confidence that medium and large effects are unlikely. Based on our findings, therefore, the best current estimate is that cognitive load has a near-zero effect on SRC measures of automatic imitation with the caveat that small effects of load remain a possibility. Future work using considerably more powerful designs, which, for example, would require hundreds of participants per experiment, would be needed to confidently conclude that small effects of load are also unlikely. In sum, the implication for theories of imitation is that we can be relatively confident that the systems supporting automatic imitation are largely indifferent to cognitive load and operate in a relatively automatic manner.

A final logical possibility is that the type of SRC task used has a ceiling effect—that is, that there is some inherent limit to the extent to which RTs can be slowed on incompatible trials or facilitated on compatible trials. In that case, we would not be able to test our prediction of an increased imitative compatibility effect driven by central cognitive load. Contrary to this proposal, however, prior work shows that the SRC task can be modulated by several factors such as situations that promote affiliation through eye contact (Wang, Newport, & Hamilton, 2010), group membership (Gleibs, Wilson, Reddy, & Catmur, 2016), and facial expressions (Butler, Ward, & Ramsey, 2016), as well as when interacting with more human-like, rather than robotic, agents (Kilner et al., 2003; Klapper et al., 2014; Press, 2011). Other work has shown that when prosocial attitudes are generated (Cook & Bird, 2011; Leighton, Bird, Orsini, & Heyes, 2010), or prosocial gestures are signaled (Cracco, Genschow, Radkova, & Brass, 2018), imitation increases. Also, across our current experiments, the absolute size of the SRC effect is variable, which further suggests that it can be moved by other manipulations. As such, it does seem that in a variety of contexts the size of the SRC effect can be modulated.

Implications for Understanding the Cognitive Bases of Automatic Imitation

The current results develop our understanding of automaticity in the cognitive systems that underpin spontaneous copying behaviors. Indeed, the findings complement prior work that shows automatic imitation is unintentional (e.g., Brass et al., 2000) and work that shows that automatic imitation is influenced by beliefs and task orientation (Gowen et al., 2016; Klapper et al., 2014; Liepelt & Brass, 2010; Longo & Bertenthal, 2009; Stanley et al., 2007; Bach et al., 2007; Chong et al., 2009). Here we add an extra dimension to the understanding of automaticity in imitation. In the sense of persisting in the presence of cognitive load, this type of imitation behavior can be considered automatic. That is, the cognitive operations that generate and/or control imitative tendencies operate the same whether or not a central resource is taxed heavily. Therefore, in keeping with proposals to move beyond a strictly "two-systems" view of automaticity (Bargh, 1989, 1994; Melnikoff & Bargh, 2018; Moors & De Houwer, 2006), the present work helps to show how imitative processes can exhibit automatic features (unintentional, efficient), as well as controlled features (top-down influences). Future research should probe, more specifically, which components of imitation exhibit automatic functionality. For example, the task used in the current study measures a composite of the urge to imitate, as well as the control of this urge. Therefore, in theory, automaticity could be apparent at one or both of these levels, and both are of interest when attempting to understand mechanisms of social cognition.

There are at least two distinct cognitive structures that could account for these results, which future research should investigate further. First, a "social-is-special" account would suggest that hand movements and other social signals are processed through a specialized channel. Under such an account, conflict between cues would influence behavior without (or only minimally) drawing on any systems that maintain visual information in working memory. This structure would be consistent with a domain-specific view of control in automatic imitation (Brass et al., 2009).

In contrast, a second "nothing-is-special" account suggests that social and nonsocial forms of response conflict, at least as measured here, are managed by a domain-general system that shares little in common with the system that retains stimuli in working memory for later retrieval. This is consistent with evidence that shows storage and control processes rely on partly dissociable cognitive and neural structures (Baddeley, 2012; D'Esposito et al., 1995; Miller & Cohen, 2001; Repovš & Baddeley, 2006; Smith & Jonides, 1999). In addition, a domain-general view of selection and control can easily account for the results observed in Experiments 2 and 3, whereby similar effects of load were observed on two different types of conflict (spatial and imitative). Such findings are also consistent with recent neuroimaging studies, which demonstrated that a common frontoparietal brain circuit is involved in resolving both spatial and imitative conflict (Cross, Torrisi, Reynolds Losin, & Iacoboni, 2013; Darda et al., 2018). Importantly, future work is required to directly test between these two accounts of the cognitive structure that underpins how automatic imitation effects persist under high cognitive load. Under either account, however, the results show that imitative tendencies function automatically in the sense that they draw minimally or not at all on central executive resources, as instantiated in the working memory task that we used. Of course, it remains possible that automatic imitation can be influenced by load manipulations that tax different aspects of central processing resources, a possibility that should be explored in future studies to test the extent to which our findings generalize across different components of executive control.

Several other lines of research provide important context for the current findings. Similar cognitive load manipulations do impact other conflict tasks—both social and nonsocial. Therefore, it is not the case that all types of conflict can resist cognitive load (Lavie, 2005, 2010). For example, maintaining an array of letters in working memory (similar to Experiment 1), produces increased interference in a conflict task that involves detecting a target letter in the presence of a peripheral distractor letter (Konstantinou et al., 2014). Therefore, it appears that when working memory is loaded with content (e.g., letters) that is also required during a conflict task, an effect of load is observed (de Fockert et al., 2001). In the present study, however, the results were different. Even in Experiment 3, when the content of working memory storage was identical (hand postures) to the content of the conflict task (hand movements), conflict remained unaffected by load.

Conversely, other dimensions of social cognition also show resistance to cognitive load manipulations. Interference effects in other social SRC tasks persist in the presence of load, such as in gaze-cueing (Hayward & Ristic, 2013; Law, Langton, & Logie, 2010) and Level 1 visual perspective taking tasks (Qureshi, Apperly, & Samson, 2010). In contrast, however, interference does not persist under load during implicit false belief tracking; instead, under higher load, belief tracking reduces (Schneider, Lam, Bayliss, & Dux, 2012). These findings offer two implications. First, a domain-general control network, which is efficient and operates with many different inputs, such as imitation (hands/actions), social attention (eye gaze) and perspective taking (head orientation and line of sight) may operate in social cognition. Second, belief reasoning may engage a partially separate mechanism to the above social and cognitive processes, which relies on a separate system that encompasses more elaborate resources, which do not persist under load. As such, these studies may point toward a signature limit to controlling social processes.

A final literature, which contextualizes our findings further, is work showing that other "automatic" social–cognitive processes are subject to modulation, including by concurrent cognitive load. For example, studies have shown that increasing cognitive load will increase the reliance on stereotypes in encoding or recalling personal information (Macrae, Hewstone, & Griffiths, 1993; Stangor & Duan, 1991). More specifically, Gilbert and Hixon (1991) distinguish effects of cognitive load on activating versus applying stereotypes. Therefore, there may yet be social situations where imitative tendencies are influenced by concurrent cognitive load, thus mirroring work on stereotype activation. Indeed, as argued previously, future research should consider social context and social factors more generally when attempting to characterize imitative processes and functions (Over & Carpenter, 2012).

The present results along with previous findings point toward a factorial combination of three major dimensions that future studies may explore in depth. Specifically, future studies should systematically manipulate the amount (low or high) and type (perceptual or cognitive) of load and their effects on a variety of conflict tasks (social and nonsocial). By doing so, the results may reveal general principles that govern the operation of cognitive mechanisms across domains, as well as within domains, and therefore help to adjudicate between the two general frameworks outlined above (social-is-special vs. nothing-is-special).

Conclusion

It has been claimed that social interactions are governed in important ways by relatively automatic cognitive processes, such as those that underpin imitative tendencies (Dijksterhuis & Bargh, 2001; Heyes, 2011). To date, however, little is known about the structure of such automatic processes, as well as how they may operate in social cognition. Here we provide richer detail on the nature of such automaticity by demonstrating that imitative tendencies remain unaffected under a demonstrably difficult cognitive load. Indeed, the cognitive operations that generate imitative tendencies are relatively efficient in that they operate the same whether or not a central resource is taxed heavily. Therefore, in the sense of persisting in the presence of cognitive load, this type of imitation behavior can be considered automatic. Taken together with prior findings, the current work provides empirical support for proposals that move beyond a strictly “two-systems” view of automaticity (Bargh, 1989, 1994; Melnikoff & Bargh, 2018; Moors & De Houwer, 2006), by showing how imitative processes can exhibit automatic features (unintentional, efficient), as well as controlled features (top-down influences).

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