

Automatically Controlled: Task Irrelevance Fully Cancels Otherwise Automatic Imitation

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Abstract

Automatic imitation refers to the act of unintentionally mimicking observed actions. Inspired by a theoretical framework that allows for controlled yet unintentional processes, we tested whether automatic imitation depends on the task relevance of the to-be-imitated movements. Replicating previous results, we find that movements that are part of the participant's task set unintentionally influence response. Our key finding is that participants generally do not imitate similar and highly familiar movements that are not part of the task set and hence are task-irrelevant. Furthermore, the results of computational data modeling are consistent with the notion that task-relevance modulates the mental activation of information, as posited by the above theoretical framework. Our findings are not predicted and cannot be explained using current accounts of automatic imitation, such as Associative Sequence Learning or Theory of Event Coding. At a broader level, the key contribution of this study is in challenging the empirical basis for 'automatic imitation' by showing that the effects interpreted as imitation occur only for task relevant responses. This pattern lends itself to a different interpretation which is not related to imitation, automatic or otherwise, but rather to the general phenomenon of response compatibility effects.

Introduction

Human adults imitate observed movements and facial expressions in both social and nonsocial situations. Accordingly, in the past decades social and cognitive scientists have devoted extensive efforts to the study of imitation (Heyes, 2011).

Two general types of imitation behavior have been reported (Heyes, 2013). The first entails imitation of complex movements and behaviors and includes deliberate reenactment of another's unfamiliar movements, for example in order to learn a novel motor skill (Krishnan-Barman & Hamilton, 2019). The other type, often termed automatic imitation (Brass et al., 2000), which is thought to occur unintentionally. While individuals may not intend to mimic the observed movement of another, their behavior is still influenced by this observation. In the current study we focus on the latter - automatic imitation - and ask whether imitation is automatic in the sense that it is unselective for observed actions. We tested this using a key paradigm in the study of automatic imitation and found strong support that, in this paradigm at least, the behavioral effects that are interpreted as evidence of automatic imitation are in fact, highly selective. More specifically, the otherwise robust behavioral pattern that is thought to index automatic imitation all but disappears when observing task-irrelevant actions. This holds although the observed actions are simple, familiar, and virtually identical to those that are task relevant.

Background

Automatic imitation describes unintentional response tendencies caused by observing the actions of others, which ultimately may be either beneficial or damaging to performing the current task, as we elaborate below Automatic imitation has been studied using several tasks and measures, among them movement kinematics (Campione & Gentilucci, 2011) and applied force (Salama et al., 2011). However, the most common measure of automatic

imitation is response time. Much of the work on response time and on the question of whether imitation is automatic was driven by the imitation-inhibition task—a two-alternative forced-choice reaction time task presented in a seminal study by Brass et al., (2000). In their study, Brass et al. (2000) asked their participants to raise a finger in response to a symbolic cue shown on a computer screen: their index finger upon seeing the digit ‘1’ or their middle finger upon seeing the digit ‘2’. Simultaneous to the appearance of the response cue, a pronated hand appeared in the background raising either the index finger or the middle finger. The instructions did not mention any role for these observed hand movements, and the hand movements did not predict the cue and hence were uninformative regarding the appropriate response. And yet, compared to baseline trials in which the displayed model hand did not move, participants displayed a *compatibility effect* – they responded faster on compatible trials in which both the cue and distractor entailed raising the same finger as well as an *incompatibility effect* - slower responses on incompatible trials in which cue and distractor entailed raising different fingers. Thus, automatic imitation can be construed as a special case of stimulus-response compatibility effect, where the distractor stimulus is de-facto one of the responses to the cue (Heyes, 2011).

This stimulus-response compatibility effect, interpreted as evidence of automatic imitation, is considered to be the result of an automatic process (Cracco et al., 2018; Heyes, 2011), mainly because it shares some of the features associated with automatic processes. Automatic processes are often characterized by the presence of one or more of four features—they operate unintentionally, they do not require attention, they can operate outside of consciousness awareness and they operate fast (Moors & De Houwer, 2006). Below we elaborate on the similarities and differences between automatic imitation and automatic processes in general. First, as opposed to controlled processes, automatic processes are relatively unaffected by cognitive load (Shiffrin & Schneider, 1977), and there is evidence

that automatic imitation is no different. In a recent study (Ramsey et al., 2019), participants performed a modified version of the imitation-inhibition task while memorizing either one or several items in order to induce low or high working memory load, respectively. Although participants exhibited poorer accuracy when reporting the larger array of items compared to the single item, load had no effect on performance in the imitation-inhibition task. A different study (Catmur, 2016) found that perceptual load (rather than working memory load) reversed the compatibility effect on response speed. However, a more elaborate model of the data showed that the reversed compatibility effect occurs only for very slow responses. This latter result was brought as evidence that the processing of distractors is nevertheless *immune* to processing ('attentional') load and that a dedicated mechanism for processing social stimuli exists. A second – automatic inhibitory process – was stipulated to explain the (reversed) compatibility found (see below on speed as a feature of automatic vs. controlled processes).

Another key characteristic of automatic processes is unintentionality (Bargh, 1992; Shiffrin & Schneider, 1977). That is, an automatic process is not subject to intentional control (Bargh, 1989) and as such may be disruptive even in the face of strong incentives to counter it. For example, either one or both participants were blindfolded while playing a version of rock-paper-scissors for substantial sums of money (Belot, Crawford, & Heyes, 2013). When only one of the opponents was blindfolded, the seeing participant imitated the actions of the blindfolded opponent to an extent that exceeded chance, even though this response mode lowered earnings on some of the conditions. This mode of response was observed on conditions in which participants were rewarded for imitating the opponent and on conditions in which they were rewarded for avoiding imitation.

A third feature of automatic processes is their speed, automatic processes are fast relative to controlled ones (Moors & De Houwer, 2006). A common way to study the speed of automatic processes is to manipulate the duration between the onset of a distractor

stimulus that is expected to trigger an automatic process and a cue that is expected to trigger a controlled process. The reasoning is that as more time passes between the onset of the automatic processes, the greater the probability that a controlled process would be able to counter the automatic response. Generally, it seems that compatibility and incompatibility effects are weaker if a longer SOA is inserted between the distractor and the cue onset, as found by a meta-analysis on automatic imitation (Cracco et al., 2018). These are taken as evidence for the automaticity of imitation.

A final feature of automatic processes is the diminished role of awareness. In the context of automatic imitation, manipulation of awareness refers to either the distractor hand movement not being perceived consciously, or that subjects are unaware when they mistakenly imitate the distractor movement. However, in most studies of automatic imitation the distractor appears unmasked and for several hundred milliseconds and participants report that they are aware of the imitation behavior, which is consistent with the claim that automatic processes, such as automatic imitation can also occur consciously (Cracco et al., 2018). In the single study that used scrambled-image masking of distractor movements found that when the distractors were presented for a relatively long duration they led to compatibility effects, but not when presented for a brief period (Mele et al., 2014). Thus, there is some evidence that automatic imitation does depend on conscious perception of the distractor movements.

This brief review supports the conclusion that automatic imitation displays most the features characteristic of automatic processes. This does not entail that individuals always imitate observed actions, at least not overtly. First, automatic imitation can be subtle or minimal ('covert'; Heyes, 2011) and is therefore often measured as a change in response speed rather than in the probability of overt execution (Genschow et al., 2017). Response speed is thought to capture the competition between a controlled and intentional activation of

the appropriate response and an automatic and unintentional activation of the response that corresponds to the observed action (i.e., distractor; Cracco & Brass, 2019). Another explanation why imitation is not ubiquitous despite being automatic is that individuals can *intentionally* inhibit their imitation of observed actions to some degree, although whether this inhibition of automatic imitation is based on general executive functions or on more specialized social-cognitive modules is unclear (Spengler et al., 2010; van Leeuwen et al., 2009). Finally, other findings suggest that even when intentional inhibition is ruled out, other top-down processes that are a defining feature of controlled processes may modulate automatic imitation.

In the context of the current study, a good example of modulation of automatic imitation by top-down processes is the effect of explicit task instructions on the typical pattern of results obtained using the imitation-inhibition task. Chong, Cunnington, Williams, and Mattingley (2009) reported no incompatibility effect when participants were asked to attend to a color patch shown on top of the distractor hand stimulus that served as a Go/No-Go cue. In contrast, when participants were asked to attend to the type of grasp the hand performed, participants exhibited an incompatibility effect (as found by Brass et al., 2000). The presence or absence of an incompatibility effect may be attributed to top-down guidance of selective attention that serves to filter out irrelevant attributes of observed actions. In a study by Longo, Kosobud, and Bertenthal (2008), participants performed the imitation-inhibition task, but in one condition the distractor hand appeared in a biomechanically impossible configuration. Participants displayed an incompatibility effect regardless of whether it was possible to imitate the model's finger tapping. Yet when participants were instructed that the distractor hand would be placed in a biomechanically impossible position, the authors found no such incompatibility effect. Longo et al., claimed that automatic

imitation depends on the participants' 'task-set' following the task instructions, which in this case was subject to top-down control.

Relevant frameworks for explaining automatic imitation

The evidence reviewed above shows that the stimulus-response compatibility interpreted as automatic imitation results from a mental process that shares characteristics with automatic processes (e.g., unintentionally) and is modulated by one that shares characteristics with controlled processes (e.g., intentionality).

The notion that a clear dichotomy exists between automatic and controlled processes has been challenged time and again (Anderson & Folk, 2012, 2014; Bargh, 1989; Eitam & Higgins, 2010; Higgins & Eitam, 2014; Spruyt, Tibboel, De Schryver, & De Houwer, 2018). In fact, various scholars have proposed so-called conditional or graded automaticity (Bargh, 1989; Gollwitzer & Schaal, 1998) and/or dissolution of the artificially clear boundaries between automatic and controlled processes (De Houwer, 2019; Melnikoff & Bargh, 2018; Osman, 2018).

Accordingly, a theory explaining automatic imitation should accommodate a mixture of the attributes of controlled processes (e.g., sensitivity to top-down influences) and automatic processes (e.g., unintentionality), namely explaining conditional automatic imitation. In the next sections we selectively review relevant theories.

Associative Sequence Learning (ASL)

One candidate framework for explaining automatic imitation is Associative Sequence Learning (ASL; Heyes & Ray, 2000). ASL originated as a proposed solution to the correspondence problem – how an agent translates an observed action into a series of motor commands to reproduce the action. Its key postulation is that imitative ability is learned rather than innate (Catmur et al., 2009; cf. Rizzolatti & Craighero, 2004).

According to ASL, upon observing a novel action the agent first parses the action into a set of sensory—primarily visual—action units, which through sheer observation are then associated according to the sequence followed by the model. Second, each unit in the sequence must be enacted and rehearsed individually in the appropriate sequence to reinforce the association between the sensory representation of the observed action unit and the matching motor pattern and between the individual patterns. Finally, when the agent observes this familiar action, sensorimotor associations will serve to increase the activation of the motor command corresponding to the observed action.

Thus, the key mechanisms in ASL are the sensorimotor learning processes associating visual input with motor output. Online imitation of others is thought to be related to the Mirror Neuron System (Cook et al., 2014), a collection of areas in the inferior frontal and parietal human cortices that exhibit similar activation patterns when a person observes or executes an action (Rizzolatti & Craighero, 2004). It is not clear, however, whether the mirror neuron originates in general sensorimotor learning processes such as those described by ASL (Cook et al., 2010, 2014; Heyes, 2010) or in a dedicated system developed to support imitative actions (Rizzolatti & Craighero, 2004; cf. Lingnau et al., 2009).

Can ASL explain conditional (or 'top-down' regulated) automatic imitation? In Heyes, Bird, Johnson, and Haggard (2005; Experiment 2), participants underwent two experimental sessions. In the first session they were instructed to respond to the distractor either by performing the displayed action or by performing a different action, depending on the experimental condition. In the second session on the following day, participants were instructed to carry out a pre-instructed action in each block, regardless of the action executed by the model agent. Those trained to imitate distractor actions exhibited a compatibility effect whenever the pre-instructed action was the same as the distractor action and an incompatibility effect whenever the pre-instructed action differed from the distractor action.

In contrast, those trained to respond with the opposite action to the one they observed exhibited no differences between the compatible and incompatible trials. Thus, ASL can explain the lack of automatic imitation *only* when novel sensorimotor associations can be shown to mitigate the effect of those that were previously learned.

Theory of event-coding (TEC)

Another framework seemingly capable of accounting for automatic imitation is the theory of event coding (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001). Based on ideomotor theory (Greenwald, 1970; James, 1890), TEC implicitly assumes that overt actions are closely tied to the activation of their mental representation. Specifically, TEC posits commonly coded bi-directional associations between representations of a motor response and a sensory event. Ex-theory, the agent learns that an action causes some external event (e.g., finger-snapping leads to a loud clicking sound), leading to the generation of an *event file* (Hommel, 2004), a mental construct that binds together sensory information, the current task context and related responses.

Not unlike ASL, once an event file is generated, activating a representation of the sensory event can itself activate the associated motor program (e.g., the sound of finger-snapping increases the probability of the agent striking thumb against finger). TEC is a good candidate for a mechanistic explanation of automatic imitation (Brass & Heyes, 2005; Paulus, 2012; Wohlschläger et al., 2003). It posits that observing a model performing a highly familiar action will activate a representation of associated motor responses, leading to competition between the observed action and the appropriate response (e.g., the one cued in the imitation inhibition task).

Can TEC explain conditional automatic imitation? One possibility is that ubiquitous automatic imitation fails to occur because it loses out to competing action-effect associations. This can be seen in a study in which participants were asked to respond freely using one of

two fingers, with each action causing the monitor to display a manual action. (Bunlon et al., 2015). Depending on the experimental condition, the produced image was either the same as the participant's response or an incompatible one (i.e., the same response using a different finger). In a subsequent test phase, participants were asked to imitate the observed hand movement. Participants who had been trained with the incompatible response were slower to imitate the cued action than to respond to an incompatible cue, suggesting that training with reversed action can interfere with automatic imitation of overlearned effects. Note that this training differs from the training in the aforementioned ASL studies (e.g., Heyes et al., 2005), as here the participants' action elicited the displayed hand stimulus and not the other way around, in contrast with the process suggested by ASL where actions are initially disassembled into motor sequences (Heyes, 2001; Heyes & Ray, 2000).

A second TEC-related study showed that the expected compatibility effect can be reversed even without any further learning (van Schie et al., 2008), contra ASL. Participants performed two concurrent tasks. In the main task they were instructed either to imitate the action of the model or to carry out the alternative response. In the secondary task, in which the model's hand was colored, participants were instructed to execute a predetermined action regardless of the model's action. Note that participants whose main task required them to perform an action complementary to that of the model were slower to execute an imitative action on the secondary task (i.e., a reversed compatibility effect). Thus, regardless of the different perceptual features of the two task contexts, participants applied a single sensorimotor association with no need for unique training.

The ROAR framework: relevance-based automaticity

A third framework that may explain why automatic imitation occurs or fails to occur is the *Relevance of Activated Representation* (ROAR; Eitam & Higgins, 2010, 2016; Usher et al., 2018). ROAR was conceived as a sketch of a mechanistic explanation for how the

external activation of mental content can be unintentionally regulated by the mind. ROAR's key premise is that a mental representation is activated by an external or internal stimulus as a function of the activated representation's current relevance. This relevance is rapidly and independently computed, with relevance to the current task as a key element in the computation. Note that mental processes such as learning and memory, action selection, and automatic imitation—as proposed in this paper—use only activated representations. Hence, the stimuli that (briefly) stimulate task-irrelevant representations should not have much impact on behavior.

Irrelevance-induced 'blindness' provides a powerful demonstration of the utility of this framework (Eitam et al., 2015; Wyble et al., 2019; see also, Eitam et al., 2013). To induce this cognitive blindness, participants were shown two different colored concentric circles at the center of the screen, where only the outer circle was relevant to the task. This extremely simple stimulus was presented for a relatively long duration (500 milliseconds) without any masking or concurrent load (Wyble et al., 2019). After about 50 trials in which participants were asked to report the color of the relevant circle, they were surprised by a question asking them to report the color of the irrelevant inner circle. Although participants exhibited nearly perfect performance in identifying the color of the relevant outer circle, their performance in identifying the color of the irrelevant inner circle was no different than guessing. This result suggests that because the stimulus of the inner circle was not relevant, it did not activate any representation, semantic or otherwise, leaving the observer without any reportable-knowledge of its nature. Chen et al. (2016) reported a similar finding, participants who watched a video showing a ball being passed were able to report how many times the ball was passed but were unable to indicate its color. Similarly, when participants are primed with a specific task set, task-relevant stimuli caused a larger Stroop interference effect than did irrelevant stimuli (Spruyt et al., 2018).

ROAR can also help explain why unintentional learning processes are sensitive to the task relevance of stimuli. For example, implicit learning is assumed to be largely automatic in that participants learn an artificial grammar incidentally, without being instructed that there is any underlying grammar controlling the stream of stimuli and often without being aware of what they have learned (Pothos, 2007; Rowland & Shanks, 2006). In one study (Eitam et al., 2009; see also Eitam et al., 2013) participants were shown strings of letters on top of color patches. They were unaware that the letter sequences and the color order were governed by two distinct finite grammars. In response to surprise tests on the grammar underlying the dimension that was task-relevant for them, participants were able to discern novel grammatical and agrammatical strings. Conversely, participants were asked to do the same for novel strings generated by the grammar underlying the task-irrelevant dimension performed at the chance level.

While task relevance usually confers transient relevance and according to ROAR also confers transient activation of representations by stimuli, the above mechanism has also been proposed to explain what is known as chronic accessibility (e.g., Andersen et al., 1995; Higgins & Brendl, 1995). The influence of task-irrelevant information—often in the context of social categorization—was initially explained by repeated activation of the currently irrelevant representations in similar contexts, making them easily activated by less appropriate stimulation across contexts. In contrast, according to ROAR, rather than being explained by passive chronic activation or accessibility, the chronicity of a representation's activation occurs due to its high computed relevance across situations, e.g., when a representation serves long-term goals or a motor program is effective across situations. As shown above (e.g., Chen et al., 2016), the influence of short-term, transient goals can be demonstrated under a specific induction or information processing task set. In contrast, chronic or long-term goals can also influence the processing of incoming stimuli. For

example, Moskowitz, Gollwitzer, Wasel, and Schaal (1999) showed evidence of facilitated recognition of briefly presented adjectives matching participants' stereotypes regarding different groups. The facilitation was assumed to be unintentional, as under longer presentation times participants attempted to respond more slowly instead of displaying opinions that were not politically correct. Other examples include chronic pain patients who have a bias to pain-related stimuli (Schoth et al., 2012), bias for food stimuli among those trying to control their weight (Kleiman, Trope, & Amodio, 2016), and the bias towards rewards (Hickey et al., 2010). Thus, chronic or cross-situational mental activation may stem, passively, from a state of chronic accessibility due to a history of repeated activation (Higgins, 1996; Higgins & Brendl, 1995) or, according to ROAR, actively: as the result of the transiently computed relevance of a representation being stable across situations when information is perceived as relevant across them.

The current study

As described above, according to the ROAR framework, incoming information is available for mental processes given its relevance to the current task performed by the individual. Indeed, Brass et al. (2000) claimed that in an imitation-inhibition task the distractor hand stimuli are *task-irrelevant*, as participants are required to attend to the symbolic cue. In contrast, we claim that the distractors in the imitation-inhibition task are *task-relevant* because they are required to perform the task (i.e., execute them on alternating trials). Because the actions whose the participants are instructed to execute are task relevant and they should be activated by appropriate stimulation (Buetti et al., 2014). This makes the distractors sufficiently potent to influence behavior, through response selection, leading to effects such as the incompatibility effect observed for incompatible distractors.

Contra to Brass and colleagues' statement above, here we test whether imitation occurs *only* in the case of task-relevant stimuli. The imitation-inhibition task (Brass et al., 2000)

includes a *compatible* and an *incompatible* condition, according to which the response cue and the observed distractor action are respectively matched or mismatched. These conditions are compared to a *baseline* condition in which no action takes place. To test our hypothesis, we added a novel *response-irrelevant* condition such that on each trial, participants viewed an additional distractor along with the symbolic cue. This distractor took the form of a finger that is not part of the response set (e.g., lifting the middle finger as opposed to the index and ring fingers used for responding to the cues). To reiterate our aim of the current study, we ask whether automatic imitation is conditional on the task relevance of the observed action. Here task relevance is manipulated as the inclusion or exclusion of an action in the current task-set.

As noted above, both ASL- and TEC-driven explanations for conditional automatic imitation predict an incompatibility effect for the irrelevant distractor condition, similar to the incompatibility effect usually found in the incompatible condition. Based on ASL prediction, the irrelevant distractor is a highly familiar action, such that the strong sensorimotor association between seeing a finger being lifted and lifting that finger is not extinguished, even following extended practice. Based on TEC prediction, the finger movement will activate the existing event file, potentiating the motor code responsible for executing the observed action.

In contrast, ROAR posits that although the representation of the task-irrelevant finger is not part of the task set, it may be stimulated. Nevertheless, given its insufficient task relevance it will not be activated, will not affect action selection, and will not lead to any incompatibility effect (similar to the baseline condition). The assumption here is that the participants' goal is to respond to the symbolic cues rather than to imitate or avoid imitation of the observed actions. There are good reasons to believe this is the case (see General Discussion).

As in previous studies that used an imitation-inhibition task (e.g., Brass et al., 2000), our key dependent variable is response speed. We predict that comparing the mean response time in each condition to the response time in the baseline condition will replicate the pattern found using this paradigm:

- (a) Shorter RTs in the compatible condition compared with baseline.
- (b) Longer RTs in the incompatible condition compared with baseline.
- (c) No difference in RTs in the irrelevant condition compared with baseline.

Note that although accuracy is another variable used to measure automatic imitation, it may not be a good indicator of a covert process that entails action selection as well as response time (see Heyes, 2011). As accuracy is a secondary measure, we include its analysis in the Supplementary Materials section.

Additionally, as we are interested in testing a boundary condition for automatic imitation (i.e., predicting a null result for the irrelevant condition), we used customary methods for testing such a statistical hypothesis. Using a within-subject design, we collected relatively large samples to reach conclusive results in the frequency analyses. We also used Bayesian relative strength of evidence (BF) and parameter estimations, which allow us to quantify the evidence in favor of the predicted null result. All of the above are also consistent with recent recommendations specific to the study of automatic imitation (Ramsey, 2018).

Experiment 1

Method

Participants

Fifty-six participants were recruited using the SONA system of the Department of Psychology, University of Haifa, Israel. Seventy-three percent were female, ages 18-39 ($M = 24.26$, $SD = 4.77$); demographic data for ten participants were not collected due to

experimenter error. Participants were eligible for participation if they reported they were right-handed and did not have any neurological medical conditions. All participants received either course credit or ~\$6.50 for their participation.

No prior power analysis was conducted for the study. A recent meta-analysis (Cracco et al., 2018) found that on average, the difference between the compatible and incompatible conditions in studies using the imitation-inhibition task is about $g_z = 0.95$ (yielding Cohen's d of 0.96 given our $N = 56$; Borenstein et al., 2011; Hedges, 1981). Note that our sample is quite large compared to the samples in the meta-analysis, where about 80% of the studies had 25 or fewer participants. We were interested in comparing the baseline condition to all other conditions rather than in a comparison between the compatible and incompatible conditions, which is expected to yield a larger effect size. Therefore, we analyzed the power of our sample to detect a smaller effect. Experiment 1 has sufficient power to detect an effect that is less than half of the mean effect found in the meta-analysis ($d = 0.4$, $1 - \beta = 0.9$). In comparing the compatible and incompatible conditions to the baseline condition, Brass's seminal study yielded significant compatibility and incompatibility effects (Cohen's d larger than 1.4) with $n = 8$ (Brass et al., 2000).

Apparatus

The experiment was programmed in PsychoPy2 Version 1.82 (Peirce et al., 2019) and run on HP COMPAQ ELITE 8200 MT. Stimuli were shown on a BENQ XL2420T screen, set to 120Hz. Responses were collected using a standard PC mouse.

Task and stimuli

Figure 1A depicts a trial. On each trial, a pronated hand was shown for 560 milliseconds (ms), followed by a distractor action: either the index, middle, or ring finger raised for ~170ms, or nothing occurring for the same time period (baseline condition). The final frame of the movement sequence remained on the screen for an additional ~790ms and

then disappeared. The next trial began after another ~1840ms. The symbolic cue (the digit 1 or 2 in white font) was shown from movement onset until the hand stimulus disappeared.

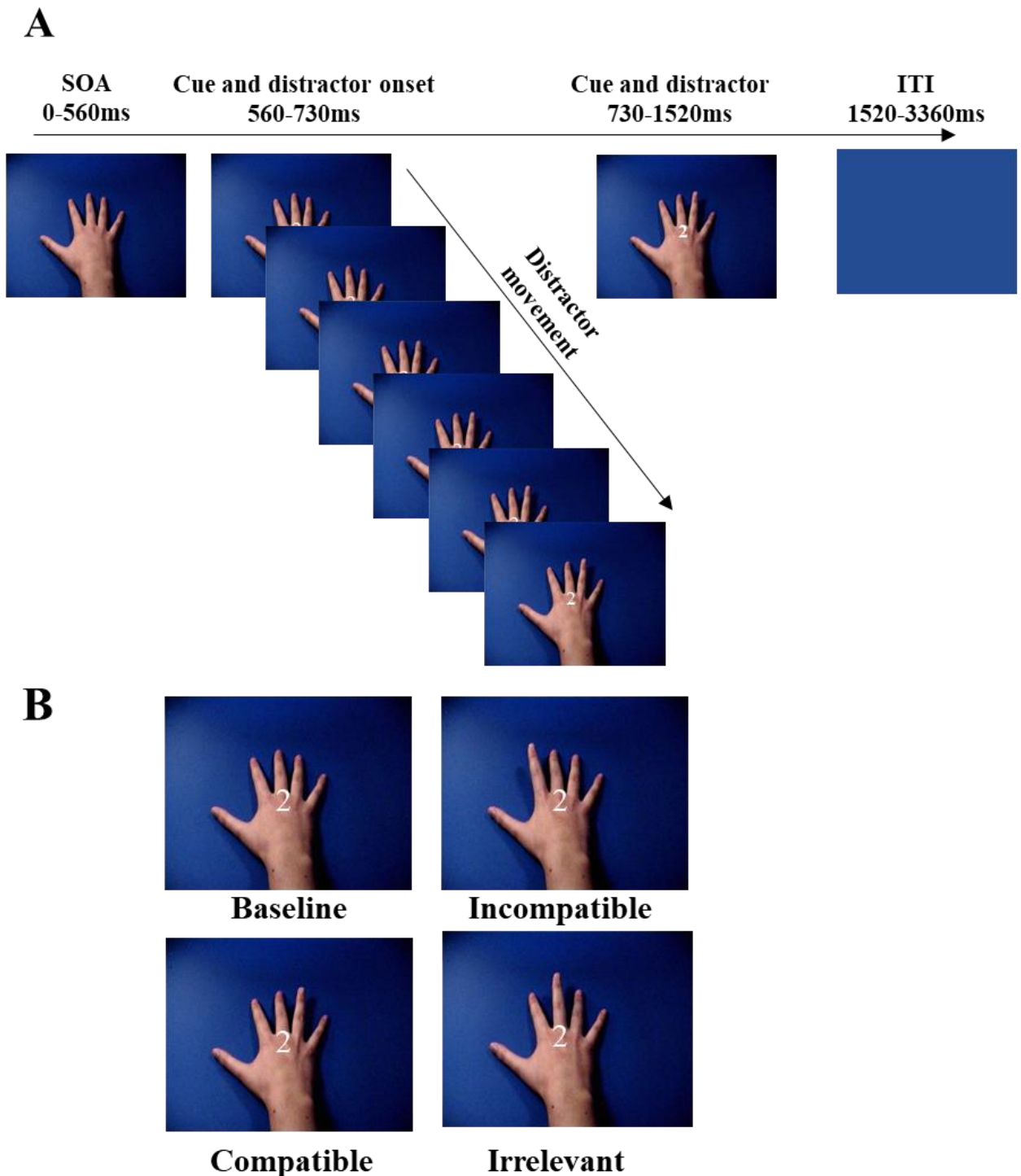


Figure 1: Depiction of method used in Experiment 1. (A) Compatible trial timeline, cued to respond using the ring finger. (B) The final frame of the distractor movement, given four possible experimental conditions, and a cue indicating response with the ring finger.

The viewing distance was not tightly controlled, but the hand stimulus was positioned in the middle of the screen and occupied $\sim 6^\circ$ of the visual angle horizontally. The cue occupied $\sim 1.5^\circ$ of the visual angle vertically and appeared on the intermediate phalange of the middle finger when the hand was resting, about $\sim 2.2^\circ$ above the center of the screen. The distractor stimuli were used in a previous study (De Coster et al., 2013)¹.

At all times except during breaks, participants were instructed to press the left and right buttons of the computer mouse respectively using the index and ring fingers of their right hand and to refrain from pressing the scroll wheel with their middle finger. They were told to respond to the digits 1 or 2 by respectively lifting either their index or ring finger and then pressing the button once again. Response latency was recorded as the time of the release of the mouse button. Participants were instructed to respond to the cue as quickly and as accurately possible and to ignore all information other than the cue. Finally, participants were asked not to move any finger except when prompted by the cue.

Design and Procedure

The experiment included four *within-subject* conditions, depicted in Figure 1B:

(a) Compatible - the cue indicated the same action shown by the distractor; (b) Incompatible - the cue indicated the response not shown by the distractor; (c) Irrelevant - the distractor action was not part of the response set; and (d) Baseline - no distractor action. The experiment included a total of 120 experimental trials arranged in three 40-trial blocks separated by self-paced breaks. Each block was composed of five 8-trial cycles, with each cycle containing one repetition of all possible combinations of the experimental conditions

¹ We thank Dr. Lize De Coster for sharing the set of stimuli from her research (De Coster et al., 2013).

(baseline, compatible, incompatible, and irrelevant) and two response fingers (index and ring) shown in random order. Before the experimental blocks, participants performed one 8-trial cycle as practice.

Participants signaled their agreement to participate in the experiment by signing an informed consent form and were then seated in a soundproof room. They were given instructions and verbal feedback by the experimenter during the 8-trial practice cycle. The experimenter then left the room, leaving the participants to perform the three experimental blocks. Following the task, participants completed a demographic and debriefing questionnaire, were thanked, and were compensated with course credit or cash. Each experimental session lasted about 15 minutes. The study was approved by the Ethics Committee of the University of Haifa (Approval No. 426/18).

Results

Pre-Processing

Throughout the study, we analyzed only valid trials obtained in the experimental blocks. See Supplementary Materials for matching unfiltered analyses. The major exclusion criteria were based on previous studies employing the imitation-inhibition task. These criteria usually include filtering responses that are incorrect, faster than 100-150ms or slower than 900-1000ms (e.g., Ainley et al., 2014; Catmur & Heyes, 2011; Cracco et al., 2015; Genschow et al., 2019; Leighton et al., 2010). Moreover, we filtered trials in which the response keys were not pressed at the beginning of the trial, as specified below. Finally, all valid trials from participants who had a low proportion of valid trials (<60%) were also labeled invalid, as their valid trials would amount to less than 18 observations per condition (60% of 30 trials) and would not allow us to produce a reliable aggregation of each condition's mean RT. The threshold of 18 valid trials arbitrarily serves as a rule of thumb, and about 20 data points per aggregated mean is commonly recommended (see Simmons,

Nelson, & Simonsohn, 2011). Note that trials may be deemed invalid based upon multiple criteria (e.g., a participant may respond slowly and incorrectly).

After the 8-trial practice cycle was discarded, each participant had 30 potential data points for each of the four experimental conditions (a total of 120 trials) before data screening began. Discarded (invalid) trials included incorrect or omitted responses (8.39%), slow responses ($>950\text{ms}$, 0.98%), fast responses ($<150\text{ms}$, 3.5%; including RTs $< 0\text{ms}$ occurring when a participant responded before the appearance of the cue and distractor), and trials in which participants did not press the buttons correctly at the beginning of the trial (6.85%). Incorrect pressing means that the buttons were in any state that differed from holding down the left and right button at the same time while the scroll wheel is not pressed. Finally, all the data from four participants who had $<60\%$ valid trials (7.14% of 56) were removed. Total filtration amounted to 16.8%. The remaining valid trials for each participant were aggregated into means for each experimental condition.

Analyses

Data were analyzed using R, mainly with the *afex* and *BaysFactor* packages (Morey et al., 2015; Singmann et al., 2015). Individual means and group estimated marginal means for the difference between each condition and the Baseline condition (including 95%-CI) are plotted in Figure 2A. For Bayesian estimation and inference plots see Figure 1 B-C. For descriptive statistics see Figure 1D.

A repeated-measures ANOVA revealed a significant effect of experimental condition on mean response time [$F(1, 71) = 44.60, p < 0.001$, Partial- η^2 Squared = .47]. Here and in the following experiments, degrees of freedom were corrected using the Greenhouse-Geisser correction and rounded to the nearest integer. We then compared the compatible,

incompatible, and irrelevant conditions to the baseline condition by subtracting each participant's mean RT on each condition from the mean RT on the baseline condition.

The contrasts fully matched our predictions. Replicating previous studies using this task, RT was significantly lower for the compatible condition [Lower-tail $t(51) = -4.26$, $p < 0.001$, mean response time change -16.50ms , Cohen's $d = -0.60$ 95%-CI $(-0.89, -0.30)$, $\text{BF}_{1:0} = 507.600$] and significantly higher for the incompatible condition [Upper-tail $t(51) = 5.48$, $p < 0.001$, mean response time change 23.27ms , Cohen's $d = 0.77$ 95%-CI $(0.45, 1.07)$, $\text{BF}_{1:0} = 24707.550$]. We also found evidence showing no difference between the irrelevant and baseline conditions [Two-tail $t(51) = 0.01$, $p = 0.994$, mean response time change 0.03ms , Cohen's $d = 0.00$ 95%-CI $(-0.27, 0.27)$, $\text{BF}_{1:0} = 0.150$]. Bayesian estimation of the RT change (shown in Figure 2B) supports the frequentist analysis, showing faster response speed on the compatible condition compared with baseline, slower response speed on the incompatible condition and no difference for the irrelevant condition (i.e., no effect on RT; see Figure 2B). Finally, a sequential analysis² of the Bayes factor for each contrast confirmed the robustness of the pattern (Figure 2C).

² Simply put, a sequential analysis is a statistical test (e.g., t-test) that is performed iteratively as data accumulates (for example, every five additional participants). It is often used in Bayesian statistics as there is no threat of Type-I error inflation as in frequency statistics. A sequential analysis plot as used here displays the strength of the evidence for H_1 vs. H_0 (i.e., Bayes factor) at any point during data collection. Thorough information and recommendations can be found elsewhere (Marsman & Wagenmakers, 2017; van Doorn et al., 2019).

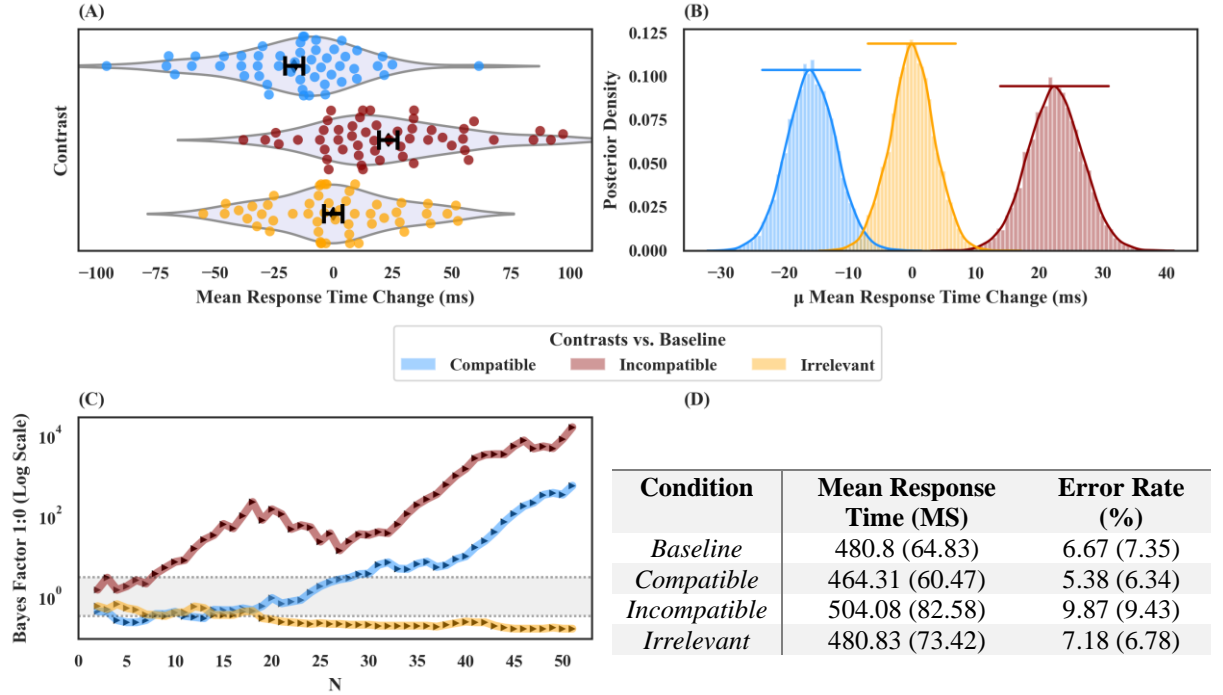


Figure 2: Results of Experiment 1 - Compatible movement accelerated response speed (blue; all panels), incompatible movement slowed down response speed (red), while irrelevant movement did not affect response speed (orange). (A) Estimated marginal means (X-Axis), 95%-CI and violin-plots of RT change on each condition compared with baseline (Y-Axis); (B) Bayesian estimation of posterior distributions of RT change (X-Axis) on the different experimental conditions (color); stacked horizontal lines indicate 95%-HDI of the posterior distribution; (C) sequential analysis of Bayes factor (Y-Axis, Log-scaled) for contrasting each condition and the baseline condition (color); shaded area indicates inconclusiveness region ($1/3 < BF_{1:0} < 3$). (D) Means (SD) of response speed and error rate for the different experimental conditions in Experiment 1.

These results were not influenced by the preprocessing described above. Indeed, after filtering out only incorrect responses, responses occurring before the cue or participants whose accuracy was below 50% on one of the conditions, the results remained qualitatively the same (for unfiltered data analyses see Supplementary Materials section).

Discussion

Experiment 1 fully replicated the standard conditions of automatic imitation: imitation of compatible and incompatible distractor actions compared with baseline inaction. As predicted, we found no incompatibility effect for the key condition of task-irrelevant distractors – actions which not part of the response set.

Note that this finding cannot be easily explained by modulation via selective attention, as participants processed and imitated the finger movements straddling the irrelevant finger and the response cue, which was shown at the same location at which the irrelevant actions were performed (i.e., the middle finger).

Experiment 2

Experiment 2 had two goals. First, we aimed to replicate the pattern of results from Experiment 1 (aside from an additional, pre-registered replication of Experiment 1, shown in the Supplementary Materials section as Experiment 4). Second, we applied a computational model to recover the latent parameters that led to the incompatibility and compatibility effects in the case of incompatible and compatible conditions, respectively, and to compare these to the irrelevant condition that did not exhibit imitation.

Method

Experiment 2 was identical to Experiment 1 with the following exceptions:

- (a) To increase generalization, we modified the set of responses and distractors, such that the irrelevant finger was the ring finger rather than the middle finger and the response fingers were the index and middle fingers.
- (b) Unlike Experiment 1, the trial began with a variable SOA of 500-2500ms during which the baseline image was displayed, followed by a cue and a distractor movement (6 frames over ~170ms). Rather than the blank blue frame from Experiment 1, the cue and the final frame remained on the screen for 670ms. These were then replaced by the baseline image without the cue, which remained for another 500ms, until the next SOA. The variable SOA duration included a constant of 500ms plus a random value sampled from an exponential distribution (scale parameter set to 0.33), truncated at 2 seconds to avoid very long SOAs. Based on other studies using the imitation-inhibition task (e.g., Press,

Gillmeister, & Heyes, 2007), we used SOAs to prevent participants from pre-planning their response times.

- (c) By increasing the number of trials in Experiment 2, we were able to improve response speed and accuracy estimates, as required for the modeling procedure. Note, however, that the selected model can also be used for rather small data sets, as outlined in the Computational Modeling section.
- (d) The experiment consisted of five experimental blocks, interwoven with self-paced breaks. Each block included ten repetitions of the 8-trial cycle of two response cues (ring finger, middle finger) under four conditions (compatible, incompatible, irrelevant, and baseline). Excluding the 8-trial practice cycle, the experiment resulted in a total of 400 trials over five blocks of 80 trials each.
- (e) Unlike Experiment 1, participants responded by holding down the left, down, and right arrow keys on a standard PC keyboard rather than by pressing the left and right mouse buttons. They were instructed to lift only the cued finger. Response latency was defined at the point at which one of the keys was released. In view of the variable SOA, the response was time-locked to the cue and distractor movement.
- (f) Unlike Experiment 1 and to maximize the use of our participant pool, left-handed participants were also recruited. For left-handed participants, all distractor action stimuli and illustrations on instructions slides were horizontally inverted, and participants responded using the left hand rather than the right hand.

Participants

Twenty-seven participants were recruited via the participant recruiting system of the Psychology Department, University of Haifa, Israel. Sixty-three percent were female, ages 19-39 ($M = 25.74$, $SD = 5.41$). None of the participants participated in the other experiments.

Two were left-handed. One participant was excluded prior to all pre-processing as she chose to quit the experiment prior to completion of the last experimental block.³

Results

Pre-Processing

Similar to Experiment 1, we screened out invalid trials. Invalid trials included incorrect or omitted responses (9.86%), slow responses (>950ms, 1.95%) and fast responses (<150ms, 1.23%), including the release of any keyboard keys before the cue appeared (i.e., RT < 0ms, given the variable SOA period). Finally, all data from two participants (<60% valid trials, 7.69% of 26) were removed. Total filtration amounted to 13.96% of raw data. The remaining valid trials for each participant were aggregated as condition means for each participant.

Analyses

For descriptive statistics and inferential plots of the data see Figure 3. A repeated-measures ANOVA shows that the effect of experimental condition on mean response time is significant [$F(2, 36) = 25.82, p < 0.001$, Partial- $\eta^2 = .53$]. We continued by comparing the compatible, incompatible, and irrelevant conditions to the baseline condition.

The post-hoc contrasts replicated the pattern found in Experiment 1 and in the pre-registered replication (Experiment 4, see Supplementary Materials). Response time was significantly lower in the compatible condition [Lower-tail $t(23) = -5.15, p < 0.001$, mean

³ We did not conduct an a-priori power analysis, yet the experiment has the power of 0.65 to detect a small effect size of 0.4 (a conservative estimate). Note that if the effect sizes for compatibility and incompatibility effects detected in Experiment 1 are used, Experiment 2 has sufficient power (>0.9). Also note that this sample is larger than ~80% of the studies in a recent meta-analysis of automatic imitation (Cracco et al., 2018).

response time change -18.10ms, Cohen's $d = -1.07$ 95%-CI (-1.57, -0.56), $BF_{1:0} = 1487.170$], significantly higher in the incompatible condition [Upper-tail $t(23) = 2.56$, $p = 0.009$, mean response time change 10.94ms, Cohen's $d = 0.53$ 95%-CI (0.10, 0.96), $BF_{1:0} = 5.980$], and no different in the irrelevant condition [Two-tail $t(23) = -0.25$, $p = 0.805$, mean response time change -0.71ms, Cohen's $d = -0.05$ 95%-CI (-0.45, 0.35), $BF_{1:0} = 0.220$].

Bayesian estimation of the RT change supports the frequentist analysis (see Figure 3B). Finally, a sequential analysis of the Bayes factor for each contrast confirms the robustness of the pattern (Figure 3C). As in Experiment 1, the pattern of results was virtually identical even when we employed very little preprocessing.

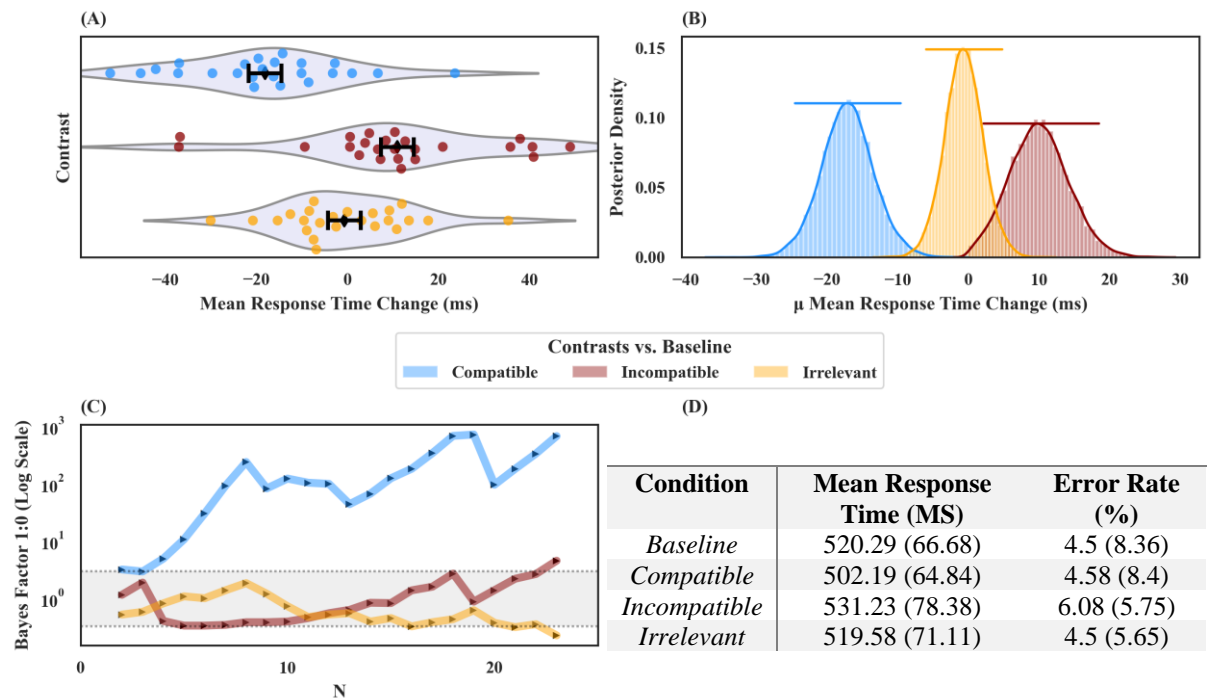


Figure 3: Results of Experiment 2 – A compatible distractor accelerated response speed (blue; all panels), an incompatible distractor slowed down response speed (red) and an irrelevant distractor did not affect response speed (orange). (A) Estimated marginal means (X-Axis), 95%-CI and violin-plots of RT change on each condition compared with baseline (Y-Axis); (B) Bayesian estimation of posterior distributions for RT change (X-Axis) on the different experimental conditions (color); stacked horizontal lines indicate 95%-HDI of the posterior distribution; (C) Sequential analysis of Bayes factor (Y-Axis, Log-scaled) for contrasting each condition and the baseline condition (color); shading indicates the region of insensitivity ($1/3 < BF_{1:0} < 3$). (D) Means (SDs) of response speed and error rate on the different experimental conditions in Experiment 2.

Discussion

In Experiment 2 and in a pre-registered replication (Experiment 4, see Supplementary Materials), we replicated the pattern observed in Experiment 1, reflecting the incompatibility and compatibility effects previously documented for compatible and incompatible distractors, respectively. Note that this pattern occurs only for distractors that are part of the task set, while there is no incompatibility effect for the irrelevant condition. Computational modeling of the behavioral data from Experiment 2 is discussed after Experiment 3.

Experiment 3

Method

Like Experiment 2, Experiment 3 was designed to replicate the findings of Experiment 1 and generalize the results to other responses. Experiment 3 was identical to Experiment 1, except that the irrelevant stimulus was the index rather than the middle finger. Participants were asked to place the middle and ring fingers of their right hand on the left and right buttons of a PC mouse and keep only these keys pressed at all times. They were instructed not to place their index finger on the mouse buttons. The appropriate responses to the ‘1’ and ‘2’ cues were to lift and press the middle and ring fingers, respectively. As in Experiment 1, response time was defined as the point at which one of the pressed mouse buttons was released, time-locked to cue and distractor onset.

Participants

Seventy-one participants were recruited via the participant recruitment system of the Department of Psychology, University of Haifa, Israel. Seventy-four percent were female, ages 18-33 ($M = 22.66$, $SD = 3.35$); demographic data for eight participants were not collected due to experimenter error. Given the small number of left-handed participants, only

right-handed participants were recruited. None participated in any of the other experiments. All participants received either course credit or ~\$6.50 for their participation.⁴

Results

Pre-Processing

As in Experiment 1, we analyzed only valid trials. Invalid trials included incorrect or omitted responses (12.51%), slow responses (>950ms, 2.2%), fast responses (<150ms, 4.63%), and trials in which participants did not press the buttons down at the beginning of the trial (8.07%). Finally, all data from eight participants (<60% valid trials, 11.27% of 71) were removed. Total filtration amounted to 21.71%. The remaining valid trials for each participant were aggregated as condition means.

Analysis

For descriptive statistics and inferential plots of the data see Figure 4. A repeated-measures ANOVA found a significant effect of experimental condition on mean response time [$F(2, 122) = 37.13, p < 0.001$, Partial- $\eta^2 = .37$]. We continued by comparing the compatible, incompatible, and irrelevant conditions to the baseline condition.

As in the previous experiments, RT was significantly lower in the compatible condition [Lower-tail $t(62) = -5.06, p < 0.001$, mean response time change -19.08ms, Cohen's $d = -0.64$ 95%-CI (-0.91, -0.37), $BF_{1:0} = 8516.000$] and significantly higher in the incompatible condition [Upper-tail $t(62) = 3.57, p < 0.001$, mean response time change 11.57ms, Cohen's $d = 0.45$ 95%-CI (0.19, 0.71), $BF_{1:0} = 73.460$]. Yet, unlike the previous experiments, the RT in

⁴ We did not conduct an a-priori power analysis, but the experiment has sufficient power for detecting a small effect size of Cohen's $d = 0.4$ (~0.95; note that in both Experiments 1 and 2 our effect sizes were substantially larger than 0.4).

the irrelevant condition (here, observed index finger movement) was significantly higher compared with the baseline condition [Two-tail $t(62) = 2.63$, $p = 0.01$, mean response time change 9.52ms, Cohen's $d = 0.33$ 95%-CI (0.08, 0.59), $BF_{1:0} = 3.24$]. Given that the Bayesian estimation of the change in RT supports the frequentist analysis (Figure 4B) and that the sequential analysis of the Bayes factor for each contrast confirmed the robustness of the pattern (Figure 4C), we do not treat it as a fluke and discuss it further in the General Discussion. Finally, the pattern of results remained the same even when considering invalid trials (see Supplementary Materials).

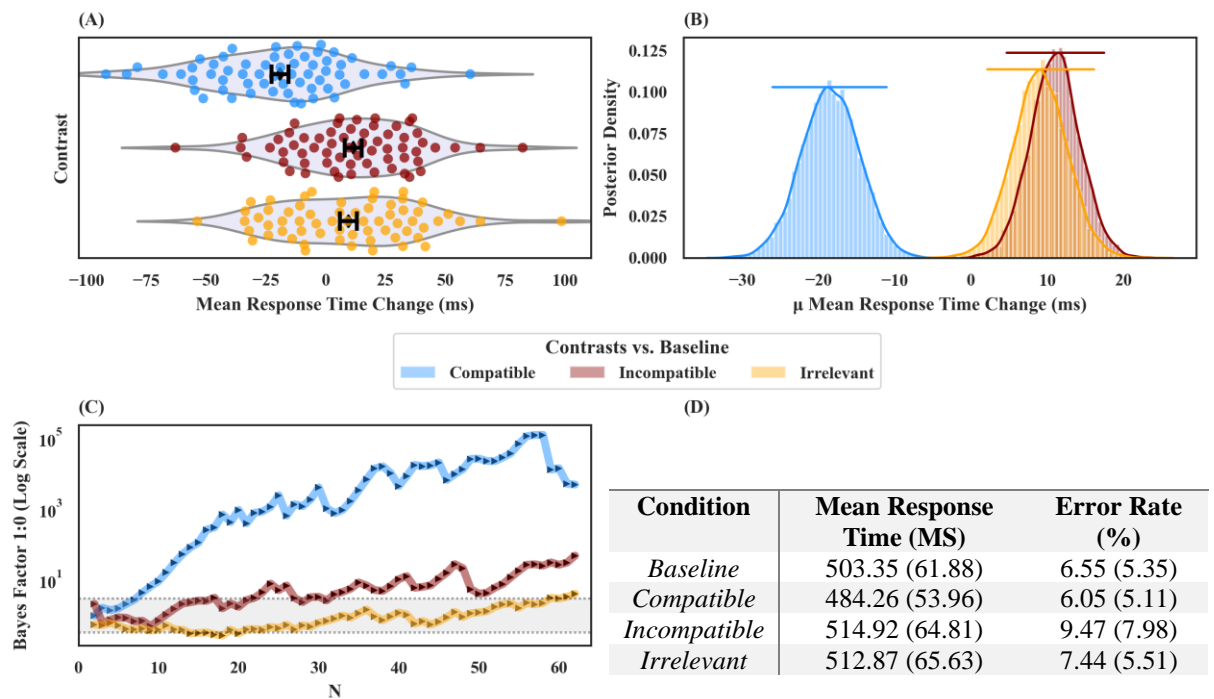


Figure 4: Results of Experiment 3 replicated the finding that the compatible distractors accelerated response time (blue; all panels), and the incompatible distractors slowed down response time (red). Yet in contrast to the other three experiments, the irrelevant movement of an index finger slowed down response time (orange). (A) Estimated marginal means (X-Axis), 95%-CI and violin-plots of RT change on each condition compared with baseline (Y-Axis); (B) Bayesian estimation of posterior distributions for RT change (X-Axis) on the different experimental conditions (color); stacked horizontal lines indicate 95%-HDI of the posterior distribution; (C) Sequential analysis of Bayes factor (Y-Axis, Log-scaled) for contrasting each condition and the baseline condition (color); shaded area indicates an inconclusive region ($1/3 < BF_{1:0} < 3$). (D) Means (SDs) of response speed and error rate on the different experimental conditions in Experiment 3.

Computational Modeling

Past research on automatic imitation has largely focused on behavioral measures (mainly response speed and accuracy) or on neurophysiological evidence (Darda & Ramsey, 2019). Another technique that was used to study automatic imitation is computational modeling which such modeling can enrich research through revealing underlying processes in observed behavior (Farrell & Lewandowsky, 2010). To better understand the underlying processes in automatic imitation, we present here the analyses of parameters obtained by a computational model fitted to the behavioral data.

A prominent class of computational models for cognitive processes are drift-diffusion models (Ratcliff & Rouder, 1998). These models implement a random-walk process based on observed behavior (error rate, response speed) and provide estimates of latent parameters as outputs, these are seen as explanations for the observed distributions of response accuracy and latency. In essence, the different variations on the original drift-diffusion model use the same logic: a simulated agent samples information from the environment in favor of one of the response alternatives with a given *rate of accumulating information* (drift-rate). The information is accumulated until it reaches a *decision threshold* in favor of either response (boundary) and a specific response is selected. Given that the most frequent form of the model uses two decision thresholds (i.e., two different response alternatives), drift-diffusion models are highly suitable for analyzing two-alternative forced-choice tasks, similarly to the imitation-inhibition task.

From of the existing versions of the drift-diffusion model, we chose to use the EZ-Diffusion model (Wagenmakers et al., 2007) for several reasons. This model provides a minimalist yet powerful version of the full diffusion model and was shown to perform well even for relatively small data sets. Moreover, it is relatively easy to comprehend and hence can be used communicate the results of the model to non-experts (van Ravenzwaaij et al.,

2017; Wagenmakers et al., 2007). A third reason is that while all forms of the drift-diffusion models are fitted based on response speed and response accuracy, the input for EZ-Diffusion model are summary statistics computed for each participant. Unlike other models, it provides an analytical solution of the entered input rather than a time-consuming fitting routine. An important offshoot is that the model will always provide the same output for a given input (as there is no estimation, only direct calculation). Finally, the EZ-Diffusion model has been recently used in the context of automatic imitation and thus offers a point of reference to our findings (Gordon et al., 2020). .

As described above, the input for the model are summary statistics for each participant, specifically, the proportion of correct responses, the mean and the variance of response speed. The model output are three values that denote parameters of the latent process that are explanations of why the observed response speed and accuracy were obtained. The first recovered parameter is *Drift Rate* (also termed v)—the rate at which the (random-walk) process of information gathering is drifting in favor of a response. This rate reflects the speed of information processing, such that a higher drift rate indicates faster evidence accumulation. It also indirectly reflects the ease of processing the stimuli and perhaps the activation of the mental representations involved as well and as such related to theories that include mental activation as part of their explanandum, such as ROAR. The second parameter is *Boundary Separation* (also termed a)—which denotes the amount of information required to reach a decision. It reflects the conservativeness of the response selection process, such that a higher result indicates a more conservative process, in the context of the current study changes in this parameter can be construed as an alternative to mental activation-based explanations. The third parameter is *Nondecision Time* (also termed S or Ter)—an estimate of the time used by processes that are thought to be unrelated to reaching a decision, such as neural conduction, motor planning, and execution. As nondecision time is assumed not to

reflect meaningful mental processes, this parameter usually receives little to no attention and its epistemic status can be compared to that of a constant in a regression model.

To characterize the action-selection process, the EZ-Diffusion model assumes that a single process represents the accumulation of evidence in favor of one of the responses until the process reaches an activation level that crosses one of the thresholds and the corresponding response is selected. To illustrate, in the current study the evidence accumulation process dictates whether the participant will select the response associated with the shown symbolic cue or the alternative response. Because this is a simplified model, it does not assume fluctuations in drift rate along with the task and does not implement a mechanism for modeling a bias in favor of either response or of other features that are implemented by more sophisticated models. Correspondingly it requires significantly fewer data compared to the above, computationally heavy, fitting routines. Figure 5 illustrates how the model depicts the input parameters (drift rate, boundary separation, and non-decision time) among the distributions of response speed and accuracy using the data from Experiment 2. A discussion of the mathematical implementation of the model is beyond the scope of this paper, but can be found elsewhere (Wagenmakers et al., 2007).

A recent study by Gordon et al. (2020) provides an example of what can be learned about human cognition by using a computational model. In this study, the EZ-Diffusion model was used to analyze the response pattern of individuals diagnosed with Autistic Spectrum Disorder (ASD) on a version of the imitation-inhibition task. ASD individuals exhibited slower response speed and higher error rate compared with the control group. Yet their estimated drift rate and boundary separation did not differ from those of neurotypical individuals. This finding is taken as evidence that the mental process responsible for automatic imitation did not qualitatively differ between the groups, although the observed performance measure did.

Like Gordon et al. (2020), in the current study we were interested in the drift rate parameter, as drift rate represents the speed at which information is processed in favor of a response and the neural/mental activation of this response's representation (Ratcliff, Cherian, & Segraves, 2003). Thus, drift rate is relevant to the ROAR prediction that task-relevant information will be activated but task-irrelevant information will not. Drift rate is also well suited for testing conditions with different difficulty levels, such as compatible and incompatible distractors. Specifically, given an *incompatible* distractor, representation of the incorrect response is activated, making selection of the appropriate response difficult. The conflict between the symbolically cued correct responses and the distractor-cued incorrect responses should result in a slower drift rate. Likewise, we should also expect a faster drift rate for the *compatible* condition, as both the distractor action and the symbolic cue promote the accumulation of evidence in favor of the same response. Note that we hypothesized that the drift rate for the *irrelevant* condition would be similar to the rate for the *baseline* condition. That is, since from a functional perspective no representation competes with the one activated by the symbolic cue, there is no conflict. We were less interested in the boundary separation parameter as we assumed our participants would be equally vigilant when faced with distractors of all types. We also did not predict any differences on the non-decision parameter, consistent with the assumption that this parameter does not capture any meaningful mental processes, in the current context.

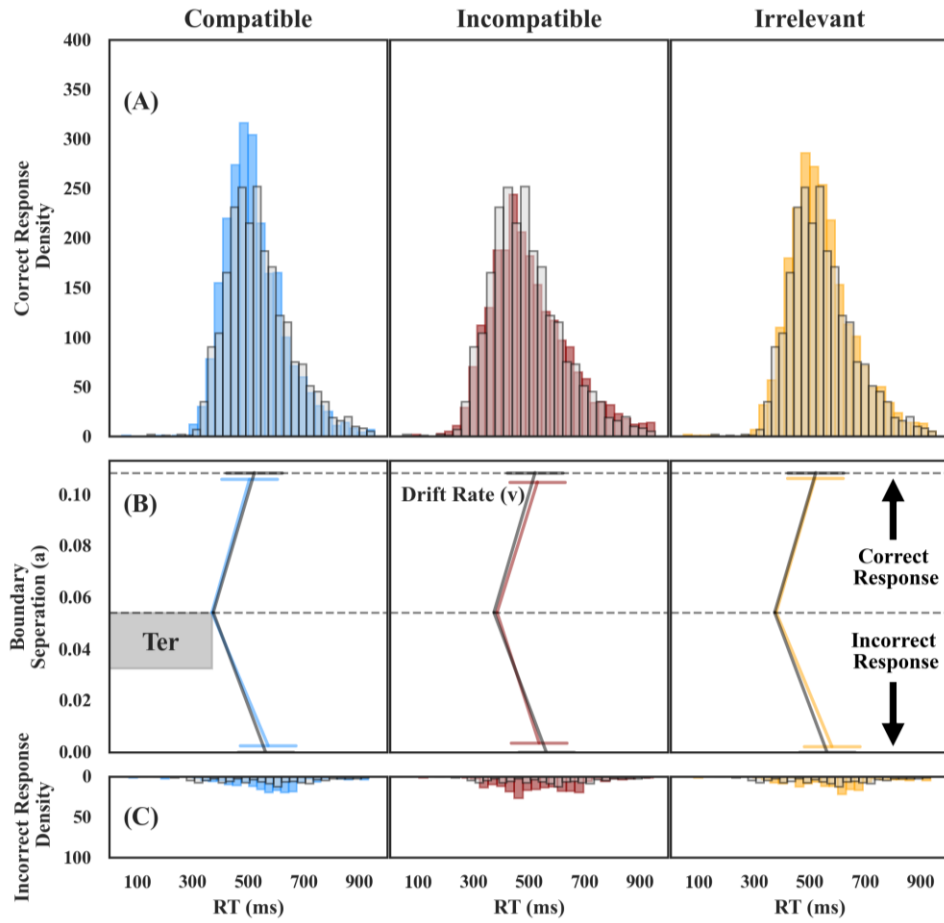
Before presenting the results of the model, we reiterate that the input fed into the model is based both on response speed and on error rate. As response accuracy serves as a secondary measure of automatic imitation (Heyes, 2011), we did not include it in the main text, but rather in the Supplementary Materials section (save for descriptive statistics shown in Tables 1-3).

Modeling data from Experiment 2

The model was implemented in Python based on the original R implementation of Wagenmakers et al. (2007). See the Supplementary Materials for implementation validation. In our analysis, we used the filtered data set used for RT analyses in Experiment 2. In line with the frequency and Bayesian analyses of response speed presented above, we first calculated the parameter estimates for each participant on all conditions. We then subtracted the parameter estimates for the *compatible*, *incompatible*, and *irrelevant* conditions from the *baseline* condition. Figure 5 includes the means and standard deviations of the parameters obtained from the model.

Analysis of the drift rate *parameter*, which was our variable of interest, was similar to the above analyses of response speed. A repeated-measures ANOVA yielded a significant effect of condition on drift rate [$F(1, 27) = 6.71, p = 0.01$, Partial- $\eta^2 = .23$]. Compared with the baseline condition, drift rate was not significantly different for the compatible condition [Upper-tail $t(23) = 1.27, p = 0.108$, drift rate change $0.0132v$, Cohen's $d = 0.27$ 95%-CI (-0.14, 0.67), $BF_{1:0} = 0.770$], yet note the inconclusive Bayes factor, which did not support either the alternative or the null hypotheses. For the incompatible condition, drift rate was significantly slower compared with baseline [Lower-tail $t(23) = -2.17, p = 0.020$, drift rate change $-0.0332v$, Cohen's $d = -0.45$ 95%-CI (-0.87, -0.03), $BF_{1:0} = 2.980$]. Hence, the data support the prediction that drift rate did not differ for the baseline and irrelevant conditions [Two-tail $t(23) = -0.16, p = 0.875$, Drift Rate Change $-0.0015v$, Cohen's $d = -0.03$ 95%-CI (-0.43, 0.37), $BF_{1:0} = 0.220$]. Note that here the BF provides support for the null hypothesis.

A depiction of the Drift-Diffusion model usually outlines relations between the recovered model parameters (drift rate, boundary separation, and non-decision time) and the observed behavior parameters (error rate and response speed). Figure 5 depicts the model using the data from Experiment 2.



(D)			
Condition	Drift Rate (v)	Boundary Separation (a)	Non-decision Time (Ter)
Baseline	0.348 (0.099)	0.108 (0.015)	373.83 (57.89)
Compatible	0.362 (0.101)	0.103 (0.017)	369.12 (53.34)
Incompatible	0.315 (0.089)	0.101 (0.017)	384.71 (68.21)
Irrelevant	0.347 (0.088)	0.104 (0.015)	379.21 (60.96)

Figure 5: Experiment 2 – depiction of the drift-diffusion process recovered by the EZ-Diffusion model. Plots (A) and (C) depict RTs of all response times for correct and incorrect responses, respectively. Translucent grey bars represent data from the baseline condition and colored bars depict data from the compatible, incompatible, or irrelevant condition. (B) Depiction of latent parameters: Following the non-decision period (Ter , grey rectangle), the evidence accumulates in favor either of a correct or of an incorrect response until it crosses the decision threshold (boundary separation: The top and bottom horizontal lines in the middle row indicate the mean a and $\frac{a}{2}$, respectively for the baseline condition, with slightly narrower bounds for all other conditions (hence colored diagonal lines are shorter). The diagonal lines indicate the drift rate, with a faster drift-diffusion rate resulting in a steeper line (here plotted as connecting mean non-decision time and mean of correct and incorrect responses, per condition). (D) Means (and SD's) of the model's parameters for the different experimental conditions of Experiment 2.

To sum up the drift rate findings for Experiment 2, compared to baseline we found a trend toward a faster drift rate in the compatible condition (consistent with faster response speed), robust evidence for a slower drift rate for the incompatible condition (consistent with lower response speed), and robust evidence for no difference in drift rate for the irrelevant condition (consistent with virtually identical response speeds). The results for the drift rate parameter of the model generally corroborate the key conclusion of the current study—only task-relevant actions unintentionally become accessible to mental processes and further influence response, as a function of their compatibility. As a result, observed irrelevant actions do not influence automatic imitation.

Modeling data from the other experiments

We ran the EZ-Diffusion model for all the experiments and analyzed all recovered parameters. Figure 6 summarizes the findings and plots the effect sizes. In the above discussion, we elaborated on the drift rate parameter obtained in Experiment 2, as this was our variable of interest and the experiment was specifically designed to collect a large amount of data per participant, ensuring reliable modeling results. For all the experiments, the key pattern of differences in the drift rate parameter was similar, and occasionally was more robust than in Experiment 2: faster for the compatible condition, slower for the incompatible condition, and similar for the irrelevant condition. For all four conditions, we found that the boundary separation parameter was lower, albeit insignificantly, than the baseline condition. For an extended summary of the results of the computational model, see Supplementary Materials.

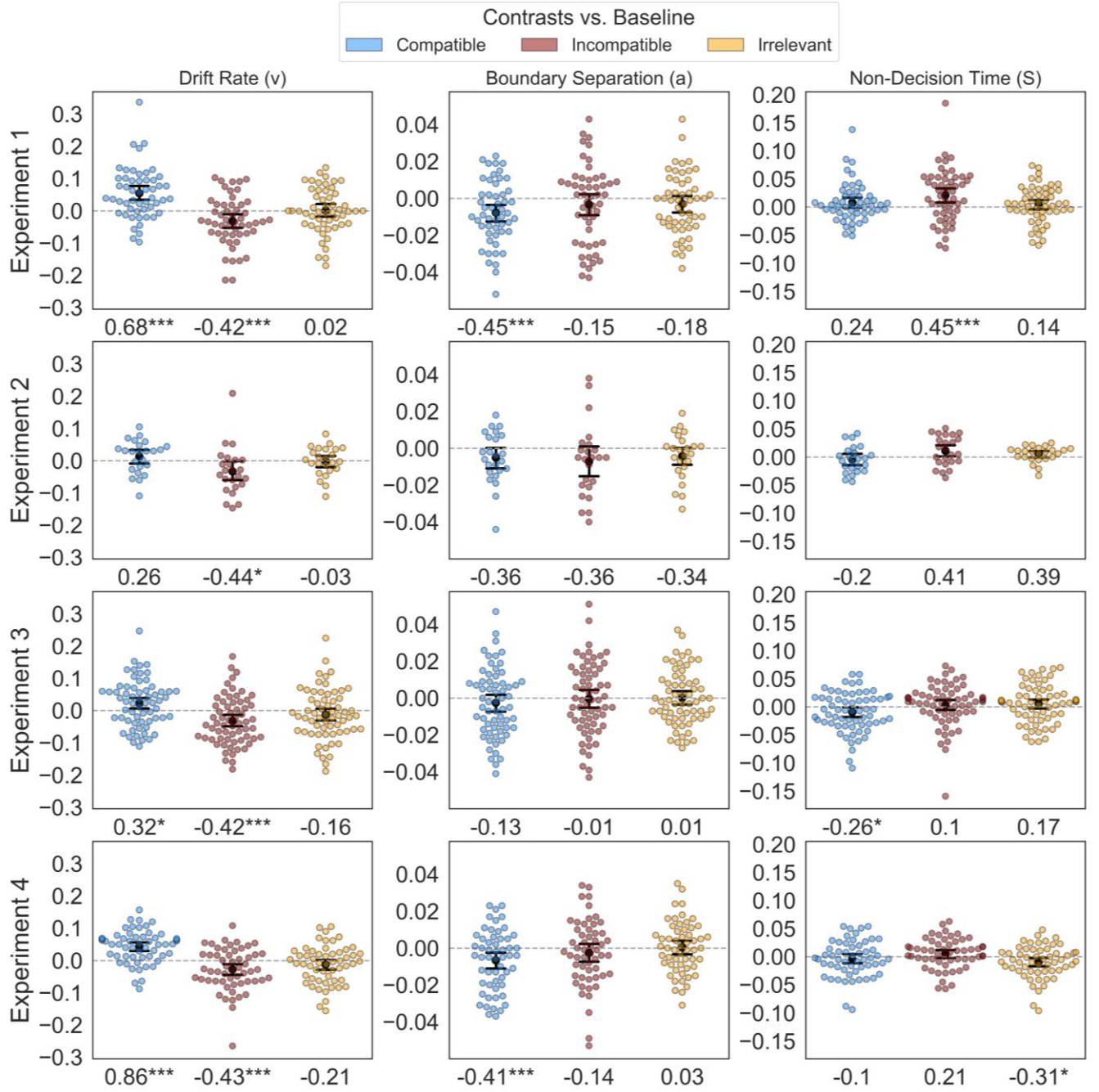


Figure 6: Results of modeling the behavioral data. The key finding is that the drift rate of the irrelevant condition did not differ from the baseline condition in any of the experiments (see yellow scatterplots). The figure shows contrasts between parameter values obtained using the EZ-Diffusion model (Y-axis, figure columns; baseline condition values are subtracted), by experimental condition (X-Axis) and by experiment (figure rows). Error bars indicate bootstrapped 95%-CI. X-Axis values indicate Cohen's d effect size, asterisks denote the statistical significance of a two-tailed one-sample t-test against a population mean of 0 (*<.05, **<.01, *<.005).**

General Discussion

In this study, we used the imitation-inhibition task (Brass et al., 2000) and introduced a novel condition in which the distractor was a finger movement that was not a part of the response set. We postulated that this distractor would be task irrelevant as participants were required to respond using two other responses.

First, we replicated the findings of the original task (i.e., the incompatibility and compatibility effects). Second, our key finding is that in three of the four experiments, we found strong evidence for that no such effects are generated by task irrelevant distractors. Regarding the other behavioral measure, error rate (shown in Tables 1-3 and the Supplementary Materials) we found a pattern of results that was similar to the pattern found for response speed, albeit slightly weaker, as we elaborate. Compared with the *baseline* condition, our participants usually made significantly fewer errors on the *compatible* condition (on experiments 1 and 4), and significantly more errors on the *incompatible* condition (on all experiments except Experiment 2). Finally, in all the experiments, the Bayesian analyses support the conclusion that there is *no* difference in error rate between the Baseline and the Irrelevant conditions, as found for response speed.

In an attempt to identify processing differences between conditions, we ran a computational model on the behavioral data and extracted the latent parameters of drift rate and boundary separation. The EZ-Diffusion model revealed that changes in response speed (and error rate) in the different conditions are due to changes in drift rate. This means that the performance in our task was influenced by the speed at which information is processed until a participant reaches a decision. This in contrast with boundary separation (the conservativeness level of responding) which was quite similar on all conditions compared to the Baseline condition.

The results of the modeling procedure replicate the findings of a recent study (Gordon et al., 2020) that found a faster drift rate for compatible than for incompatible distractors. Our study adds the key finding that the speed of information processing (drift rate) is similar for the Baseline and Irrelevant distractor actions as we reported for response speed. In other words, orthogonally to similarity only task-relevant stimuli (e.g., an incompatible distractor), affect the rate of information accumulation towards a response alternative. In yet other words, observing irrelevant movements did not count as information for action selection, similarly to observing no movement at all (the distractor on the baseline condition). Put succinctly, the modeling part of our paper shows that irrelevant movements do *not* cause automatic imitation, simply because their influence on activation of response representations is negligible.

This study is not the first to show that automatic imitation may be conditional upon the nature of the distractor (e.g., Longo et al., 2008). A notable example comes from a study by Bach, Peatfield, and Tipper (2007), in which participants were required to respond either by pressing a footswitch or a finger key based on the color of a cue located on the model's head, palm or foot. Incompatibility effects were only found when the cue was located near the foot or palm and not near the head. While that study demonstrated how body parts (e.g., the model's head) may or may not lead to a compatibility effect, *the current study is the first to use the movement of distractors that are virtually identical to each other but differ only in their inclusion in the task-set.*

This identity was essential to test whether task-relevance alone is a sufficient condition for modulating automatic imitation which cannot be easily accommodated by theories such as ASL and TEC. As the distractors are considered to be task irrelevant by the conscious agent (i.e. the responding participant) as by the creators of this task – our study demonstrates that

automatic imitation is intrinsically controlled, without the need to stipulate an external executive inhibitory mechanism that is intentionally recruited.

By matching the features and the presentation of all potentially distracting/facilitating movements, the current study maximized the probability of detecting the existence of any blind automatic imitation. The fact that no such imitation was found is strong evidence for the crucial role played by task relevance in modulating this unintentional process. Indeed, this conclusion is in line with other findings showing strong relevance-based control over unintentional processes, such as perceiving (Eitam, Yeshurun, et al., 2013; Eitam et al., 2015) and implicit learning (Eitam et al., 2013b), extending them beyond the semantic or categorization domains to the procedural domain.

The answer to the question of whether automatic imitation, as measured by the imitation task, is conditional on task-relevance. The answer is quite clear – yes, it is, as imitation is all but cancelled for task-irrelevant actions. The key contribution of the current work is in providing evidence that automatic imitation, as measured in this central task, is selective for actions that are in the current response set and does not occur for otherwise simple, familiar yet irrelevant actions.

We continue with discussing whether the findings undercut the dominant interpretation of the empirical effects coming from this paradigm as reflecting automatic (or otherwise) imitation or should be simply related to the general (and not necessarily-social) phenomenon of response compatibility effects.

Theoretical implications

The form of imitation ostensibly captured by the task we used is thought to depend on automatic processes as it shares some features often associated with automatic processes (Moors & De Houwer, 2006). These features include insensitivity to cognitive load (Ramsey

et al., 2019), or to conscious intentions (such as running in opposition to the individual's goals; Belot et al., 2013).

Yet some research shows that automatic imitation may be influenced by top-down control, as in the case of abolishing the incompatibility effect by changing task instructions (Longo et al., 2008). One could argue then that imitation is in fact intentional yet we do not think that this is the case. Rather, we suggest that like other unintentional processes (e.g., perception; implicit learning) automatic imitation can be tightly yet unintentionally controlled. A framework that strives to fully explain automatic imitation must also account for its strong sensitivity to task relevance. Below we first examine the results of the current study through the lens of the ROAR framework (Eitam & Higgins, 2010) and then through ASL (Catmur et al., 2009) and TEC (Hommel et al., 2001), reviewing their merits in view of the current results.

The relevance of a representation

The basic notion of ROAR is that as we perceive information, the relevance of the input to our current goals/tasks is unintentionally evaluated. Goal-relevant information is more accessible to other mental processes (Eitam, Glicksohn, et al., 2013; Eitam, Miele, et al., 2013; Higgins, 1996; see also Usher et al., 2018 and Wyble et al., 2019). As we have no reason to think that participants did not implement the explicit task specified in the instructions (i.e., they responded using the required fingers, and accurately most of the time), it is reasonable to contend that the representations of the two effectors/responses were assigned relevance. Given this task relevance, perceiving one of these two movements activated representations of the matching responses (compatible and incompatible), generating incompatibility or compatibility effects. In contrast, perceiving the irrelevant distractor failed to activate such a representation due to its task irrelevance. The added value of applying the ROAR framework to the current context is that it allows for subpersonal,

automatic yet goal-directed cognition without referring to the somewhat vague concept of intention (Eitam & Higgins, 2010).

Another attractive feature of the ROAR framework is that it is a general-purpose mechanism that was not conceived to explain automatic imitation or the selection of actions for that matter. As noted, ROAR has also been successfully applied in the domain of perception, leading to the discovery of a novel phenomenon known as irrelevance-induced blindness, and as a boundary condition in the unintentional learning of regularities (Eitam et al., 2009, 2014; Eitam, Glicksohn, et al., 2013; but see Glickman & Lamy, 2018).

In line with the generality of ROAR, we show here that the top-down modulation of representations by their (here, task) relevance also applies to eliminating stimulus-response incompatibility effects.

Given the widespread interpretation of the results of the imitation-inhibition task as reflecting automatic imitation, our evidence are cast as evidence for *conditional* automatic imitation. Yet an immediate next question is whether the pattern of results merely reflects S-R compatibility rather than mimicry, controlled by the top-down modulation the task-relevance of the responses.

Regardless of what such research will show, we elaborate below how ROAR's accurate predictions on the lack of imitation of irrelevant distractors are hard to resolve using competing theories such as ASL and TEC.

Associative Sequence Learning

The crux of the ASL explanation for imitation is that sensory input of observed actions is linked to specific motor output patterns through an associative learning process. In the case of automatic imitation, perceiving highly learned action cues activates their corresponding motor programs, making the modeled actions more likely to be selected and executed, i.e., to interfere with selection of the appropriate response that is symbolically cued.

In a study by Leighton and Heyes (2010), participants performed a variation of the imitation-inhibition task where they were instructed on each trial whether to respond using the fingers or the mouth, and whether to respond by opening or closing the effector. The distractors were opening or closing movements, either of the hand or the mouth. The study's key result was that when the effector and distractor mismatched (e.g., responding with a hand movement during a mouth-movement distractor), the compatibility effects of performing the same movement (e.g., hand-opening, while also shown a mouth-opening) were reduced compared to the compatibility effects observed when the required response and the distractor movement were performed by the same effector. The authors interpreted this pattern as evidence that automatic imitation depends partially on the modeled effector (e.g., seeing a hand movement while performing one) as the modeled effector's movement activates the corresponding motor plan (see Introduction). However, the authors continue, such dependence is only partial, as our mind generalizes between similar movement performed by different effectors (e.g., hand-opening and mouth-opening).

Following this logic, ASL must predict that automatic imitation should occur in our task, when both the movement is similar (finger extension) and the effectors (index, ring or middle fingers) are all virtually identical, but our evidence shows that is not the case as we found robust evidence for no incompatibility effect in response to task-irrelevant distractors.

In contrast, ROAR can explain Leighton and Heyes 2010 findings. As both the hand and the mouth were used as effectors during their task, both the hand movement and mouth movement are task-relevant, thus their representations are activated and made available to the action-selection process, thereby creating automatic imitation, although somewhat reduced.

While ASL does not have a mechanism that can explain transient modulation of the activation of highly learned response sequences, this framework can seemingly explain the effect of practice or frequency of activation on the automatic activation of representations

(see Higgins, 1996). ASL was shown to explain how lengthy sensorimotor learning phases can result in inhibitions of the potentiating associations, reducing automatic imitation in some cases (Heyes et al., 2005; Press, Gillmeister, & Heyes, 2007).

In explaining these effects, ROAR uses the somewhat ill-defined notion of chronic relevance (Eitam & Higgins, 2010; see also Eitam et al., 2014). In Experiment 3 we found evidence that the index finger, although not part of the task set (i.e., task-irrelevant), activated response representations. There is evidence to support the notion that substantial neural changes accompany the chronic use of the index finger in everyday tasks (e.g., Cuadra, Falaki, Sainburg, Sarlegna, & Latash, 2019). Similar neural adaptations are found following extensive braille reading practice (Pascual-Leone & Torres, 1993) or finger amputation (Weiss et al., 2000). Evidence also suggests that extensive practice with concurrent feedback may reduce the prominence of the index finger as an effector, though confirming this would require many experimental sessions (Chiang et al., 2004).

Together with the neural implementation-level explanation, ASL could explain why the index finger led to an incompatibility effect although it was not part of the response set. Hypothetically, because practice leads to an oversized cortical representation of the index finger, making it chronically accessible, it is more easily activated mentally and hence can engender incompatibility effects even when it is task irrelevant. As we did not use extensive, multi-session training to manipulate chronic accessibility, this explanation is currently speculative. Yet it is compatible with the ASL framework and as such provides a relevant direction for future testing of this hypothesis.

Theory of event coding (TEC)

ASL and TEC are not mutually exclusive (Brass & Heyes, 2005; Catmur et al., 2009; Heyes, 2005) in that they share the ideomotor or common coding principle. According to that principle, after sufficient co-activation of motor programs and percepts, the mere perception

of a distractor movement should activate the associated motor response, causing either facilitation of the correct response or competition between the current and incorrect responses. Again, this would nicely explain the compatible and incompatible conditions, but not the results for the irrelevant condition. A modification of TEC called intentional weighting (Memelink & Hommel, 2013) may accommodate our null findings on task-irrelevant distractors.

As described in the introduction, TEC refers to event files—stores of perceptual and motor information that can only be retrieved together in a binary manner (e.g., planning to snap your fingers will activate the representation of the sound of the finger-snapping action; Hommel, 1998, 2004). The notion of intentional weighting (Hommel et al., 2001; Memelink & Hommel, 2013) bridges between action and perception by assigning a causal role to intention. Thus, it can extend the concept of an event file in which activation is binary (either active or not), such that the processing of perceptual information is scaled by the degree of intention to act in the associated manner.

The idea that perceptual information relevant to an intended action receives additional weight was tested in a study by Wykowska, Schubö, and Hommel (2009). Their participants were asked to perform two concurrent tasks, one an *intentional* imitation task of either pointing or grasping and the other a visual search for a singleton that was unique either in brightness or size. Given the assumption that each manual action was related to the perceptual dimension (e.g., Tucker & Ellis, 2001), the researchers hypothesized that each action would facilitate the search for the relevant feature. They found that execution of a gripping or a pointing movement facilitated the search for a target unique either in size or brightness, respectively, though only if the target's unique feature was known in advance. Thus the intentional imitation of the action can be thought to increase the salience of corresponding target features (i.e., intentional weighting).

As our participants were instructed to respond using two specific fingers and not the irrelevant one, through the prism of TEC only the representations of the two response-set fingers were intentionally weighted, thus also activating their associated perceptual features. Perceiving the alternative response generated competition as it *further* boosted activation of the alternative motor response, and vice versa in the case of seeing the correct response. In contrast, as the irrelevant finger distractor was not related to any of the appropriate task responses, it received no special weighting, making it unlikely to activate the perceptual or motor commands associated with responding with the irrelevant finger or to elicit incompatibility effect, similar to the baseline condition.

Note that this explanation is somewhat similar to the ROAR explanation for the findings at hand, i.e., that goal relevance is crucial for the activation of automatic processes. Yet ROAR predicts that relevance modulates relatively abstract representations, including actions and semantic representations, but not low level perceptual or motor representations. Hence ROAR provides a different and ostensibly more general domain of application.

New questions and future directions

Before turning to the limitations of our study, we discuss a meaningful question related to a distinction between imitation as a covert mental or an overt behavioral phenomenon. This question arose during the course of integrating the reviewers' comments and suggestions.

Automatic imitation is usually measured as a change in response speed. That is, it is assumed to index a covert mental process of conflict between selecting either the cued or the observed movements (Heyes, 2011). In the current study, we found a compatibility effect in the Compatible condition, an incompatibility effect in the Incompatible condition, and no difference between the Irrelevant and Baseline conditions. An identical pattern was observed

for the latent parameter of drift rate. According to this we conclude that automatic imitation is controlled by task-relevance.

Ramsey (2018) recently claimed that response speed does not necessarily index imitative tendencies but possibly indexes domain-general processes, similar to any other S-R compatibility task. An alternative standard for testing imitation is by examining *de facto* imitation in the task, i.e., whether participants perform the displayed distractor action. This will ostensibly result in a lower error rate on the compatible condition and a higher error rate on the incompatible condition (Cracco & Brass, 2019). In examining the covert measure of error rate, we found evidence for an increased error rate in the incompatible condition compared with baseline, a trend toward decreased error rate in the compatible condition, and robust evidence for no difference in error rate between the irrelevant and baseline conditions. Thus it appears that task irrelevance mitigates covert as well as overt imitation.

Another possibility is that task irrelevance does not cancel automatic imitation, but only attenuates it. Based on both the behavioral and the computational modeling data, the current study does not support this alternative. Nevertheless, a future neural imaging study may be able to support or rule out the modulation of imitation through irrelevant distractors. A relevant body of knowledge discusses the neural activation that accompanies intentional inhibition of imitation in tasks similar to ours. Brass, Ruby, and Spengler (Brass et al., 2009) reported findings showing that activation of the anterior fronto-median (aFMC) cortex is higher when participants encounter an incompatible distractor in an imitation-inhibition task. The activation of the aFMC is lower for compatible distractors, likely because there is no need to inhibit the distractor movement. It would be interesting to see whether aFMC activation is increased when viewing irrelevant distractors compared to baseline. The aFMC activation in the irrelevant condition may be similar to that in the baseline condition, somewhere between the baseline and the incompatible condition (hinting at attenuation but

not cancellation of automatic imitation), or even as high as that in the incompatible condition, raising questions regarding the validity of this neural correlate in relation to automatic imitation. Note that according to ROAR no such inhibition is expected, as the irrelevant response representation is not accessible to mental processes in the first place and hence there is nothing to inhibit.

The task relevance of representations can also be tested at the neural level by measuring activity in the amygdala (Cunningham et al., 2004; Cunningham & Brosch, 2012; Sander et al., 2003). A ROAR-based account of our findings would predict that activation of the amygdala is markedly stronger for compatible and incompatible distractors compared with baseline or irrelevant distractors. An even stronger prediction would be that no difference emerges between amygdala activation for the baseline and irrelevant distractors, as irrelevant distractors include movements very similar to the response-set distractors.

Finally, the mirror neuron system is believed to be tightly coupled with the processes that ASL describes (Heyes, 2010). Thus, measuring neural activity in regions associated with ostensive action-mirroring and imitation, such as the inferior frontal gyrus (Bien et al., 2009; Catmur et al., 2009), may also reveal whether irrelevant distractors are processed similarly to incompatible distractors or to baseline distractors, assuming these are not fully filtered out following the process of relevance evaluation attributed to the amygdala.

Limitations

In the current paper, we make claims both about automatic imitation and about automatic processes in general. Accordingly, some of the study's limitations are of interest only to a specialized audience. We therefore moved parts of this section to the Supplemental Materials. Here we cover the most pressing concerns regarding the validity of our findings.

Our basic tenet is that task-relevant actions will be imitated, but task-irrelevant ones will not. Our conclusions rest on the assumption that the participants' responses in the task

are task relevant and hence are imitated when encountered in the compatible or the incompatible conditions. One might argue that our participants had the explicit goal or intention to avoid imitation altogether and hence all distractors are task irrelevant. Yet avoiding imitation altogether does not seem to have been our participants' explicit goal, nor did they selectively fail in attaining it, as the effects of the compatible and incongruent-incompatible cases show. While this possibility cannot currently be empirically ruled out, it is unclear why participants would intentionally avoid imitating a task-irrelevant action but would not avoid imitating one that is incongruent, i.e., an incorrect response on an incompatible condition. Furthermore, if they did try to avoid imitating both the irrelevant and incompatible distractors – one would need an explanation of why they intentionally succeeded only in the case of irrelevant movements.

Another caveat to our key conclusion is the incompatibility effect found in the case in which the index finger played the role of the irrelevant stimulus. This finding suggests that relevance is not the only factor in the activation of mental representations. Specifically, it may suggest that ROAR goes a bit too far in seeking to replace accessibility (Higgins, 1996) with relevance. Specifically, Higgins and Brendl (1995) argued in favor of the role of previous use in modifying the passive *potential* of a representation to be activated, to the degree that even completely irrelevant stimuli low in applicability can activate chronically accessible representations. In ROAR, such chronic cross-situational accessibility was replaced with the notion of active chronic relevance, though this mechanism seems less attractive in the face of the irrelevant index finger. Conversely, it seems that repeated use of the index finger in everyday tasks makes it chronically accessible and hence easily activated, even when irrelevant. Alternatively, extension of the index finger may have a special social cueing role, as pointing is used to indicate important objects in the environment (Ariga &

Watanabe, 2009), thus conferring chronic relevance to mental representation of the index finger. We consider this explanation less attractive than the previous explanation.

Another caveat, one of the reviewers of this paper raised is a possibility that previously evaded us. It seems that the incompatibility effect of the index finger in Experiment 3 occurred when the participant responded using the ring finger but not when using the middle finger. On all other occurrences (i.e., an individual finger out of the pair used on each of the four experiments), there was no incompatibility effect of the irrelevant distractor, regardless of the responding finger. A careful reexamination of the data showed that the identity of the responding finger may affect the pattern of results in the compatible and incompatible conditions as well. For the Compatible condition, we found a compatibility effect on all eight occurrences (i.e., two fingers X four experiments), which was nominally larger when responding using the index finger. For the Incompatible condition, the pattern was less clear cut. On some cases we found no evidence of an incompatibility effect when the participant responded using the index finger but on other we did find such an effect. This could be (post hoc) explained if the index finger's representation is chronically accessible.

Conversely, it could have been expected that if the index finger is chronically accessible than participants would, overall, respond faster using the index finger, but we found no evidence for this suggested post-hoc hypothesis (see Supplementary materials).

Taken together, our findings seem to lend further support to our claims. Nevertheless, due to the length of the manuscript and the fact that this specific conclusion is based on an examination of descriptive rather than inferential statistics, we chose to move a more elaborate discussion of these findings to the Supplementary Materials. Note that when the data are pooled across the different responding fingers, as in most imitation-inhibition studies, the expected incompatibility and compatibility effects emerge for compatible and incompatible distractors. Thus, our key finding that irrelevant movement does not lead to

automatic imitation was detected in all cases but one, even when the identity of the response finger is considered.

A final limitation stems from our rather narrow definition of imitation –automatic imitation as a stimulus-response compatibility effect that is the result of a reactive, unintentional and covert process in which we imitate (or need to inhibit) an observed response, rather than a directed reenactment of peer’s behavior that is based in a social context (Heyes, 2013).

A very different view and conception of imitation is offered by a social-cognition theory of imitation – the Top-Down Response Modulation model (STORM; Wang & Hamilton, 2012). STORM looks at imitation mainly as behavior that is intended to serve the individual by creating affiliation with others for self-advancement. As STORM deals with the effect of social cueing, it is able to explain findings that are external to theories that focus on sensorimotor associations like TEC and ASL. Several studies by Wang and colleagues (Wang, Newport, et al., 2011; Wang, Ramsey, et al., 2011; Wang & Hamilton, 2014) used variations of the imitation-inhibition task where the distractor also includes the upper body and head of the model. In these variations the model looks at the participant or looks away, with the direct gaze resulting in increased compatibility effects compared to when the gaze is directed away (Wang, Newport, et al., 2011).

Note that while it makes sense why social cueing would increase behavior that is compatible with a co-actor’s behavior as this according to the theory should change the attitude of the peer towards the individual, it is unclear why it does not reduce incompatibility effects.

STORM is also informed by studies on intentional imitation (e.g., Krishnan-Barman & Hamilton, 2019). It should be kept in mind that it is unclear whether measures of intentional and unintentional imitation convey the same mental processes (Heyes, 2013; Ramsey, 2018).

Consistent with to STORM we show a top-down modulation of automatic imitation. Yet we use ROAR to claim that our finding on the modulation of automatic imitation for familiar and incompatible yet task-irrelevant movements adds to a general pattern we described in other work (e.g., Eitam, Glicksohn, et al., 2013). In line with a general view of conditional automaticity (Bargh, 1989) While the relevance of a representation may come from a social cognitive judgment and hence modulate activation of representations (Neel & Lassetter, 2019), we make a more general claim – the availability of incoming information to mental processes is conditional on its relevance.

Broader Context

For the past two decades, cognitive scientists have attempted to understand why healthy adults sometimes imitate the movements of others without intending to. In lab settings, this imitation tendency is sometimes studied indirectly. People's task performance is slower and more error prone when they observe an action that conflicts with the one they are asked to execute. Several theories aiming to explain this finding (e.g., *Associative Sequence Learning*) focused mainly on learned sensorimotor associations, claiming that perceiving a familiar action activates the corresponding motor plan and interferes with action selection. Here we apply the theory of *Relevance of Activated Representation*, according to which perceived information is made accessible to mental processes mainly if it is relevant to the individual's current goals. Using several experiments, we show that, in line with our predictions, perceiving familiar actions does not necessarily lead to automatic imitation, but only if these actions are task relevant. In the context of automatic imitation, our findings weaken the sensorimotor-based explanations as well as the link to an ostensive mirror neuron system. More generally, by revealing that imitation depends on relevance, we demonstrate the selectivity of other robust and seemingly automatic processes. We see this as strong evidence for the claim that automatic processes are in a real sense controlled.

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