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Similarity of Actions Depends on the Functionality of Previously Observed Actions

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People have a tendency to imitate the behavior of others, sometimes even automatically. And yet, evidence suggests that many of our actions are controlled, mediated by current goals and careful considerations. Here, we investigated whether the observation and evaluation of previous actions of another person modulates the similarity of actions between people in present trials. We manipulated the functionality of a confederate's actions and the interactive context in 2 behavioral tasks, which consisted of games that participants played against a confederate or a virtual computer opponent. To measure effects of working memory load on imitation rates, participants additionally performed an easy or difficult auditory *n*-back task in parallel to the tasks. We show that participants occasionally produced rather bizarre and dysfunctional behavior when the confederate had done so as well. Even more importantly, results from both tasks show that participants most likely copied dysfunctional behavior in the present trial when the confederate performed functional actions in the previous trial. Thus, the positive evaluation of action consequences in previous trials increases the probability of similarity between the participant's and confederate's actions in present trials despite a chance to copy improper actions. Furthermore, we found a trend of increased action similarities when participants were under high working memory load in Experiment 1 but not in Experiment 2. These results suggest that copying an observed action is an efficient and effortless behavioral and social strategy to achieve similar goals as others, though with an increased risk of maladaptive behavior.

Keywords: imitation, mimicry, action compatibility, action evaluation, trial order effects

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Excluding basic muscle reflexes such as breathing, much of people's actions are learned by watching others. Imitative behavior is indeed an easy and efficient way to get acquainted with useful actions. Copying an action from another person may seem well planned and under autonomous control of people themselves. However, the contrary is often the case and there is numerous evidence suggesting that much of the imitative behaviors are involuntary (Bargh & Ferguson, 2000). For instance, humans tend to automatically imitate the behavior (Chartrand & Lakin, 2013; Fadiga, Craighero, & Olivier, 2005; Heyes, 2011; van Baaren, Janssen, Chartrand, & Dijksterhuis, 2009) and take into consideration actions of others (Sebanz, Knoblich, & Prinz, 2003). Everyday examples are the contagious effects of yawning or the unconscious copying of a neighbor's posture in a lecture hall. Thus, humans sometimes mimic other people with little control over their own actions.

Recent evidence supports the idea that humans have limited control over their imitative behavior because imitation occurs even if the consequences of the action are not useful (Belot, Crawford, & Heyes, 2013; Cook, Bird, Lünser, Huck, & Heyes, 2012) or counteractive to the task's goals (Naber, Vaziri Pashkam, & Nakayama, 2013). The tendency to imitate might be rooted in the evolutionary advantage of a close connection between perception (of others) and action, which has been argued to result in a strong dependency between perception and action behavior (Dijksterhuis & Bargh, 2001). Indeed, there is strong behavioral (Hommel, Müsseler, Aschersleben, & Prinz, 2001) and neural (Bekkering et al., 2009; di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992) evidence for a strong interconnection of perceptual and action-planning processes, which can account for phenomena of seemingly automatic perception-induced action tendencies. Human ancestors are likely to have benefited from social

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interaction and imitative skills could have been a prerequisite to learn actions from others. In a similar vein, people's reflexive drive to imitate may help to develop coherent communicative languages across group members. Thus, the intimate relation between perception and action (Hommel et al., 2001; Sperry, 1952) permits useful functions, even though it may sometimes lead to the mimicking of dysfunctional behavior (Naber et al., 2013).

Learning is suggested to be crucial to the strength of the relationship between perception and action (Catmur, Walsh, & Heyes, 2009). The associative sequence learning theory describes that children learn to associate observed self-movement with the paired motor program independent of whether the observed actions are self-produced or by someone else (Ray & Heyes, 2011). The brain automatically strengthens the connections between areas that code the motoric response program and the visual movement, either produced by the agent or a model. Imitation is explained as follows in this perspective: The observation of someone else performing a similar movement activates the associated motor code causing the observer to move a like. This type of learning associations are shown to have comparable properties as Pavlovian conditioning, including dependency on experience (Heyes, Bird, Johnson, & Haggard, 2005) and the context in which actions are learned (Cook, Dickinson, & Heyes, 2012). Imitation is in this sense a byproduct—though a useful one—of an innate disability to disentangle the self from others when it comes to coding the visual representation.

Luckily, people have some control over their imitative tendencies. For one, even under conditions that induce particular response tendencies, people are often able to suppress them to a degree that overt behavior is not affected (Cross, Torrisi, Reynolds Losin, & Iacoboni, 2013; Knight, Staines, Swick, & Chao, 1999), especially if they are in conflict with current goals (van Schie, van Waterschoot, & Bekkering, 2008). For instance, in a study by Van Leeuwen, van Baaren, Martin, Dijksterhuis, and Bekkering (2009) participants were subjected to a (primary) behavioral imitation task and a (secondary) working memory task with either low or high cognitive load. Participants imitated more while performing the more demanding secondary task, suggesting that people can suppress automatic response tendencies when and to the degree that sufficient resources for cognitive control are available (Baddeley, 2003; Brass, Derrfuss, Matthes-von Cramon, & von Cramon, 2003; Brass, Derrfuss, & von Cramon, 2005; Brass, Zysset, & von Cramon, 2001).

While the inhibition of imitative tendencies is more of a control mechanism of motoric output, attention is a factor that shapes the magnitude of imitation by modulating the input strength of visual information (Heyes, 2011; Kornblum, Hasbroucq, & Osman, 1990). When an observer's attention has been drawn to a model's body part in action (e.g., by an exogenous cue), the participant will have less difficulty producing the same action or an action with the same body part as compared to when attention is drawn away to an irrelevant part (Bach, Peatfield, & Tipper, 2007; Chong, Cunnington, Williams, & Mattingley, 2009). These studies provide evidence that when observed actions or the associated body parts fall within the focus of attention, observers' own action schemes become more easily activated, facilitating the production of similar actions.

For another, the probability that a particular response tendency is established at all depends on the social circumstances and, in particular, on the relationship between imitated model and imitator. For example, the amount of mimicry of mannerisms between individuals correlates with how much they like and trust each other (Chartrand & Bargh, 1999; Over, Carpenter, Spears, & Gattis, 2013; Stel, Rispens, Leliveld, & Lokhorst, 2011; Stel et al., 2010). Along the same lines, individuals with more ego-centric attitudes are less likely to engage in imitative behavior (van Baaren, Maddux, Chartrand, de Bouter, & van Knippenberg, 2003) and people who do not belong to the mimicker's social group are imitated less (Bourgeois & Hess, 2008; Buttelmann, Zmyj, Daum, & Carpenter, 2013). These so-called chameleon effects have been interpreted as facilitating social bonding and group-building (Lakin, Jefferis, Cheng, & Chartrand, 2003).

While the studies outlined above demonstrate that spontaneous imitation is modulated by long-term learning and several rather static situational aspects, the more dynamic role of the experiences with a model's actions have so far not been taken into account by imitation theories. The aim of the present study was to investigate how the tendency to imitate might emerge from trial to trial. In particular, we focused on what one may consider the functionality of an action, which we operationalized by manipulating the type and therewith the consequences of the model's behavior. It seems obvious that it would make more sense to imitate a model showing functional behavior than a model showing dysfunctional behavior. Indeed, it is shown that imitation can be inhibited depending on the task's goal (Poljac, van Schie, & Bekkering, 2009; van Schie, et al., 2008) and that the observation of incorrect actions recruits specialized cognitive mechanisms to evaluate action functionality (van Elk, van Schie, & Bekkering, 2008). However, on the fly evaluation of a model's present actions is demanding especially when action imitation is fast and dynamic. Furthermore, the automatic tendency to imitate may overrule rational evaluations of the perceived actions (Paulus, Hunnius, Vissers, & Bekkering, 2011). Imitators may simply judge whether some induced response tendency is sufficiently goal-related and if this is not the case, as with dysfunctional movements, this tendency is discounted or suppressed in subsequent trials. More informative with regard to the imitation in the context of functionality are past actions: Having experienced a model performing a functional action might render that model more useful and thus increase the impact of the model's behavior in the next trial. This suggests an interesting interaction: while functional actions of models might be considered more likely in general (thus having a stronger impact on the imitator's performance in the present Trial n), having just experienced a functional action of this model (in Trial $n - 1$) may also allow for some impact of a currently (Trial n) dysfunctional behavior of that model.

In our experiments, the functionality of the action that the model showed varied randomly from trial to trial, so that some trials followed a functional action of the model while others followed a dysfunctional action of the model. As explained above, we expected that evidence for similar actions among an observers and model would be stronger after functional than after dysfunctional action of the model. To counteract possible strategies and metacognitive influences (which were not very likely already given the trial-to-trial manipulation), we assessed action similarity in a demanding situation. Furthermore, we did not test whether participants would imitate a particular action but, rather, looked into similarities between the action of the model and the action of the participant. Accordingly, spontaneous imitation or spatial compatibility would be reflected in greater similarity between these two actions. We additionally vary working memory load with a secondary *n*-back task to test for effects of cognitive control on action similarity.

Experiment 1

Material and Method

Participants. Thirty-six individuals participated (age M = 19.66, SD = 1.02; five male and 31 female). All participants were right-handed students, received study credit or money for participation, had normal or corrected-to-normal vision, were naïve to the purpose of the experiment, gave informed written consent before the experiment, and were debriefed after the experiment. The experiments conformed to the ethical principles of the Declaration of Helsinki and were approved by the local ethics commission of Leiden University.

Each participant performed the experiment together with one of two confederates (author A. S. H. and a psychology student). The confederates were trained to rapidly produce gestures in advance of the participants. Confederates had memorized all actions in advance and were instructed to act the same in all experiments. In multiple practice sessions the confederates received feedback on their posture, gaze, and actions, with the goal to minimize variability in these factors across trials and experiments.

Apparatus. Stimuli were generated on an Asus Vivobook (ASUSTeK Computer Inc., Taipei, Taiwan) laptop computer with Microsoft Windows 8 operating system, using MatLab (Mathworks) and the Psychophysics toolbox extension (Brainard, 1997). The presentation monitor displayed 1366 by 768 pixels at a 60-Hz refresh rate. Screen size was 26 cm in width and 17 cm in height, and the participant's viewing distance to the screen was approximately half a meter. In Experiment 1, the participants and confederate were seated opposite across a square table at approximately one meter distance from each other (Figure 1A). Two keyboards were positioned below the table to allow the participant and confederate to respond to the second auditory task (see below) with their right foot while their hands remained available for gestures. Auditory stimuli were presented to the confederates and participants with Sennheiser HD201 (Sennheiser Electronic GmbH, Wedemark, Germany) headphones. All actions by both the participants and confederates were recorded on video by a Sony HD camera.

Stimuli and procedure. Participant and confederate were to produce actions or gestures in response to visual pictures displayed on the monitor. As shown in Figure 1B, a picture displayed an object that could be associated with a specific movement. Participant and confederate had 3 s to think up and produce an action until the following trial started. Each picture was preceded by a red screen presented for 2 s to indicate that the picture was about to be shown. After the 1-s presentation of the picture, a black screen was shown for 2 s to indicate that an action had to be made.

Participants were naïve to the role of the confederate; they were deceived by being told that we invited pairs of participants (of which one was the confederate) to more efficiently collect data. The confederate produced either a dysfunctional, uncommon action or a functional, stereotypical action in advance of the participant. For example, a dysfunctional action in response to a picture of a hairbrush (Figure 1B) would be that the confederate picks it up and puts it to her ear as if it is a phone. Alternatively, a functional gesture would be the same action after seeing the picture of a phone. A total of 160 pictures were presented; all 160 associated confederate actions can be found in the Supplementary Materials. Pictures were collected from the Internet and scaled to 800 × 600 pixels (16 × 11 cm).

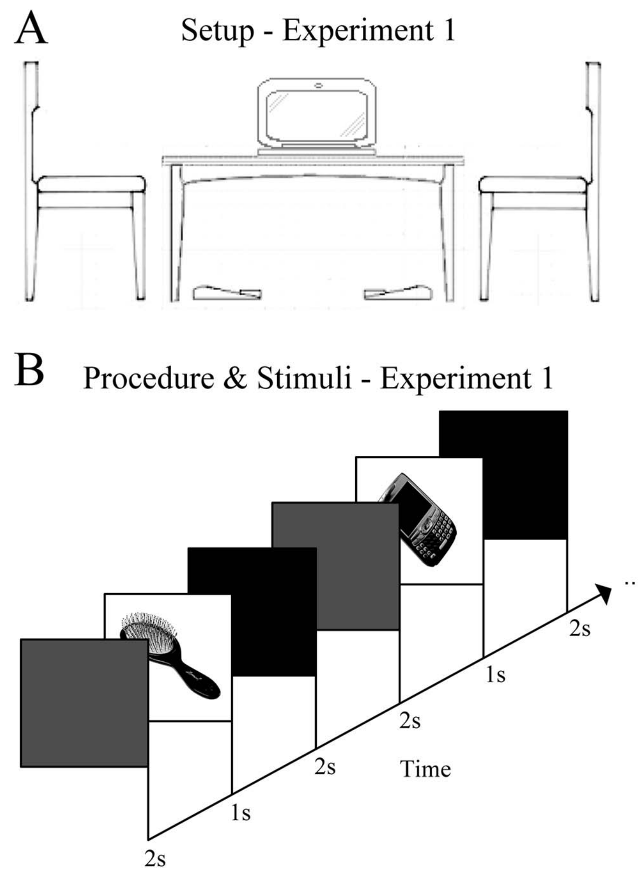

Figure 1. Apparatus, stimuli, and procedure of pantomime Experiment 1. (A) Schematic drawing of apparatus. Confederate and participant sat opposite of each other while watching the pictures presented on a laptop. Keyboards for responses to the auditory *n*-back task were positioned below the table. (B) Schematic drawing of the procedure. Participants were presented a red screen for 2 s and an object for 1 s, followed by a black screen for 2 s to indicate that the action had to be produced. The presentation of a brush was associated with an unlikely and dysfunctional action by the confederate. In this case the confederate would pick up the brush and put it to her ear as if it was a phone. The phone picture was accompanied with the same action and thus stereotypical and functional action. Note that presentation order was randomized and the likelihood that two objects with similar actions repeated each other was minimal. Both pictures closely correspond to the actual pictures presented during the experiment, which are here not displayed here for copyright reasons.

In parallel to the behavioral task, participants performed an additional auditory version of the *n*-back task (Kirchner, 1958) to facilitate imitation (van Leeuwen, et al., 2009). The idea was that the *n*-back task increased task load therewith depleting the participants of working memory resources that are normally used to prevent participants from blindly imitating the confederates actions and produce self-initiated actions. The task consisted of an ongoing presentation of a number sequence by a computer voice and participants indicated when a similar number was repeated with a distance of one or two

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numbers ($n = 1$ or $n = 2$) between the current and preceding number. For example, the participants should have responded to the second number 2 or the second number 9 for the sequence [. . . 4 8 2 2 9 1 9 3 . . .]. Participant's performed the one-back or two-back task in blocks of 40 pantomime trials. Half of the participants started with the one-back task and the other half with the two-back task. The *n*-back numbers were presented every second and *n*-back repetitions occurred approximately every 5 s, once for each pantomime trial on average. Participants were instructed to balance their effort between the *n*-back task and the pantomime task.

Analysis. To determine the degree of action similarity, two authors (A. B. and another psychology student) rated the similarity between the actions of participant and confederate on a scale of 1 to 10, with 10 representing identical actions. Both raters were naïve to the action functionality conditions across stimulus pictures and the ratings of both raters correlated significantly across participants ($r = .81$, $SD = .04$). The timing of the confederate's action in comparison to the participant's actions was crucial. Actions of the participant that started before the confederate's action ($M = 2\%$, $SD = 4\%$) were removed from the analysis because no imitation could have been taken place. We also wanted actions to be spontaneous and therefore excluded the trials from the analysis in which the timing of the participant's action was delayed and performed after the deadline had passed ($M = 6\%$, $SD = 4\%$). Actions were also not analyzed when raters bared no consensus (a difference larger than 5 points) on the degree of similarity between the participant's and confederate's action ($M = 2\%$, $SD = 2\%$). Eventually, 90% of the actions ($SD = 6\%$) across participants were considered in the analysis. In all these trials, the confederates made no errors during the performance of the action.

To ensure that the trained gestures of the confederates were indeed experienced as functional and dysfunctional actions by the participants, we invited four additional individuals to rate the actions on a scale of functionality between 0 and 100 (100 is fully functional). These raters were presented with all 160 objects together with a text describing the confederate's action response. Note that the confederates used these objects and texts to memorize and produce the actions in the experiment. Raters could rate the functionality of these actions by clicking on a digital slider scale with a computer mouse pointer (see Supplementary Figure 1). Functional actions were indeed rated significantly more functional as dysfunctional actions (functional: $M = 80$, $SD = 16$; dysfunctional: $M = 41$, $SD = 7$), $t(3) = 4.29$, $p = .02$.

The amount of hits and false alarms were assessed for the *n*-back task. Differences in performance between de one-back and two-back task were expressed as d' a measure derived from signal detection theory, and calculated as z scores of the percentage hits minus z scores of the number of false alarms (Stanislaw & Todorov, 1999) per one-back and two-back condition.

Results and Discussion

Action similarity. We investigated to what degree the participants' actions were influenced by the confederate's actions. To answer this, we analyzed the similarity between the participant's actions and the confederate's action depending on the functionality of the confederate's action in the *present* trial (trial *n*). Results show that actions were more similar when the confederate performed functional rather than dysfunctional actions (Figure 2A; functional: $M = 6.7$, $SD = 0.5$; dysfunctional: $M = 3.3$, $SD = 0.6$), $t(35) = 47.70$, $p < .001$. For example, 97% of the participants displayed similar behavior as the confederate by picking up a fictional item and putting it to the ear after seeing a picture of a phone. This is not surprising because these types of actions were stereotypical. However, participants also produced actions that were less functional but still similar to the confederate's actions. For example, 65% of the participants put a fictional phone to their ear if the confederate did this (similarity ratings equal or larger than 5) in response to the presentation of a brush. Participants sometimes produced rather bizarre behavior that was remarkably similar to that of the confederate (see Supplementary Movies 1 and 2), including actions such as eating fireworks (43% of the participants) or putting a thumbtack in the eye (15% of the participants). More importantly for our purposes, we also analyzed the similarity between the participant's actions and the confederate's action depending on the functionality of the confederate's action in the *previous* trial or trials (Trials $n - 1$, $n - 2$, etc.). Supporting the notion that the participants sometimes produced similar actions as the confederate, action similarity in any given trial correlated with the action similarity scores in the last three preceding trials (Figure 2B). This suggests that the mechanism that biases participants to produce similar actions as the confederate fluctuates in the order of at least three trials over time. As shown in Figure 2C, functional actions were more likely to be reproduced by the participants when preceded by functional actions of the confederate (previous functional: $M = 7.0$, $SD = 0.6$; previous dysfunctional: $M = 6.8$, $SD = 0.5$), $t(35) = 2.21$, $p = .03$. The same applied to dysfunctional actions (previous functional: $M = 3.4$, $SD = 0.8$; previous dysfunctional: $M = 3.2$, $SD = 0.7$), $t(35) = 2.09$, $p = .04$, indicating that even a dysfunctional action of the confederate was likely to be similar to the participant's action when the preceding action was functional. In other words, watching the confederate perform a functional action in a preceding trial promoted action similarity in the present trial,[1] independent of the present functionality of the confederate's action. The positive effect of a previous functional trial on action similarity in the present trial did not interact between present functional and dysfunctional actions, $t(35) = 0.54$, $p = .59$.

During post hoc debriefing only one of the 36 participants indicated to have the feeling that the experiment was designed to measure interactions with the other participant (i.e., the confederate). None indicated that they were aware of an explicit tendency to imitate the other person. This suggests that the findings do not reflect a particular strategy. To sum up the results, participants are less likely to produce the same action as the confederate when they observed a dysfunctional rather than a functional actions but action similarity increases when the previously observed actions were functional.

***n*-Back working memory.** Participants performed an easy one-back or difficult two-back task in parallel to the gesture task in

[1] A post hoc analysis was performed to test whether imitation rates not only depended on the confederate's action functionality in preceding trials, but also whether the functionality of the actions produced by the participants themselves was affected by the action functionality of their preceding actions (i.e., independent of the confederate's actions). After all actions of the first 30 participants were rated for functionality, we found no trial-to-trial effects of functionality per participants. Actions preceded by less functional actions (i.e., functionality score <8.25) were rated as functional ($M = 8.236$, $SD = 0.292$) as actions preceded by more functional actions (>8.25; $M = 8.278$, $SD = 0.232$), $t(29) = 1.13$, $p = .27$.

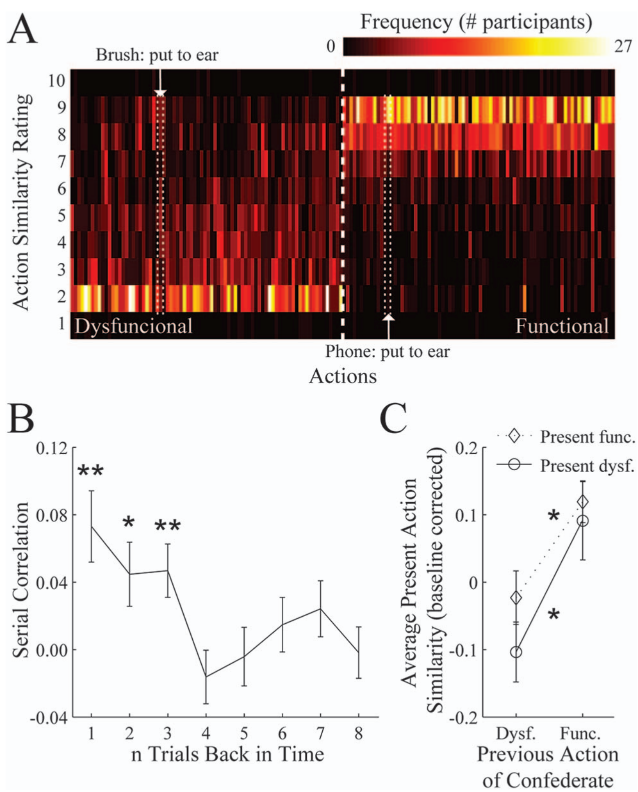

Figure 2. Action similarities between confederates and participants. (A) A heat map of histograms of action similarity rates (*y*-axis) per performed action (*x*-axis). Brighter colors display which actions were very similar. The confederate's dysfunctional (dysf.) and functional (func.) actions are located left and right from the dashed vertical line and produced dissimilar and similar actions by the participant, respectively. The example objects from Figure 1 are highlighted with the dotted vertical lines. (B) The average serial correlation across participants between action similarity of present trials and *n* trials back in time. The lines that connect data points across categories in Figures 2B and 2C do not represent continuous data but merely serve to ease comparisons across conditions. (C) The participant's action similarity in present trials as a function of confederate's action functionality in previous trials. To ease comparison with the results of Experiment 2 (see Figure 4C), action similarity rates were baseline corrected by subtracting average similarity rate per functionality condition (see text for average uncorrected similarity rates). See the online article for the color version of this figure.

Experiment 1. Results show that the total amount of hits and false alarms across blocks for the two-back task was smaller and bigger than the one-back task, respectively (percentage hits: one-back: $M = 64\%$, $SD = 14\%$; two-back: $M = 46\%$, $SD = 15\%$; number of false alarms: one-back: $M = 29$, $SD = 24$; two-back: $M = 35$, $SD = 22$; difference in d': $M = 1.35$, $SD = 1.12$), $t(35) = 7.22$, $p < .001$. This difference suggests that participants' performance dropped in the two-back task as compared to the one-back task because working memory resources were depleted more (Baddeley, 2003; Conway et al., 2005; Owen, McMillan, Laird, & Bullmore, 2005). As demonstrated in the following analyses, we predicted that the depletion of working memory capacity during the two-back affected the similarity in behavior between confederates and participants.

Action similarity per *n*-back working memory condition. Last, we analyzed whether participants copied the confederates' actions more when under high working memory load as compared to low load. A data trend suggested that participants' actions were rated as more similar to the confederates' actions during the two-back task ($M = 5.0$, $SD = 0.7$) compared to the one-back task ($M = 5.2$, $SD = 0.5$) although this effect just touched the significance level of an alpha of 0.05, $t(35) = 2.00$, $p = .05$. The effect of load-induced increases on action similarity did not differ between functional and dysfunctional trials, $t(35) = 0.20$, $p = .84$. The magnitude of increases in action similarity in present trials after preceding observing functional actions of the confederate was neither affected by working memory load for present functional trials, $t(35) = 1.09$, $p = .28$, nor for present dysfunctional trials, $t(35) = 0.57$, $p = .57$. These results suggest that increased working memory load may increase the urge to produce similar actions as the confederate independent of previous trials.

Taken altogether, the results suggest that participants do not only consider the functionality of the currently observed action of another person when engaging in the production of similar actions. Rather, they also consider the functionality of previous actions of this person, with the effect that previously experienced functionality of the model action increases the tendency to reproduce the current model action. Before considering the wider implications of this observation, we report the outcome of the second experiment, that aimed to conceptually generalize the findings with a setup that allowed us to assess the degree of action similarity more objectively (i.e., without subjective ratings) and to fully control the behavior of the (now virtual) confederate.

Experiment 2

In Experiment 2 we sought to investigate trial-to-trial effects of action functionality on action similarity between participants and a confederate in a rather different, and technically more efficient setting. Participants were provided more time than in Experiment 1 to observe the "confederates" actions, which now consisted of (function or dysfunctional) moves in a Tetris-like game. This allowed the participant to more closely follow and evaluate the observed model actions and potentially adapt his or her own actions depending on their opponent's success.

Material and Method

Participants. A separate group of 37 individuals participated (age $M = 19.22$, $SD = 4.62$; 20 male and 17 female), together with a virtual confederate (the computer). Participants sat alone at the table and used the laptop's keyboard for responses.

Stimuli and procedure. Participants played an adapted version of the popular computer game Tetris (Alexey Pajitnov, Dorodnicyn Computer Centre, Moscow, Russia) against a confederate. The participants met the confederate (same as in Experiment 1) in a separate room right before the experiment started. The participants were told that the confederate will play the Tetris game in a separate room but that his or her game screen will be visible to them. The original Tetris game is a two dimensional single-player game in which players try to efficiently fill an empty container space (i.e., a Tetris field) with a sequence of blocks that fall from the ceiling at random locations (Figure 3A). Players can rotate and move the blocks to the correct positions with the goal to leave no empty spaces at the bottom of the field. When a horizontal row of cells in the field is fully filled with blocks, the participant gains

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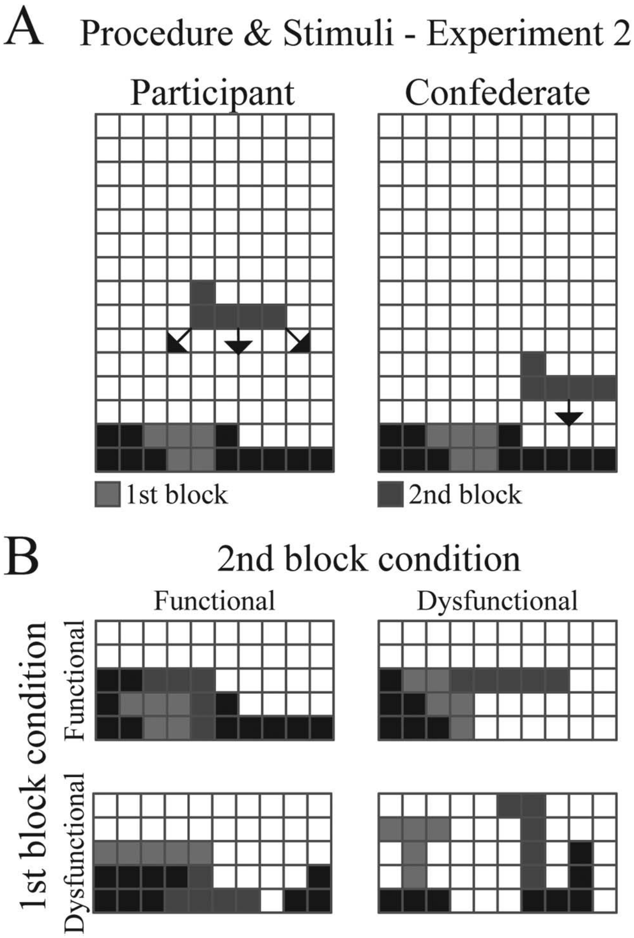

Figure 3. Apparatus, stimuli, and procedure of Experiment 2. (A) Schematic drawing of the Tetris game stimuli. The left and right Tetris fields were controlled by the participant and the computer confederate, respectively. Two blocks (gray) had to be placed on the bottom of the field per trial with the goal to create an as flat base surface (black) without empty cells (white). A block slowly appeared at the top of the field and fell one cell per second until it hit the base field or an already placed block. Participants could control the blocks by moving them to either the left or right at a rate of one cell per second. Participants were also able to see the confederate's actions in advance to enable action evaluation and to potentially adapt their own actions when necessary. Alternative to the current figure, blocks were colored red and green, the background was gray, and field raster lines were not visible in the actual experiment (see Supplementary Movie 3). (B) The placement of a block by the computer confederate was either functional (i.e., producing a flat base surface) or dysfunctional with regard to the task's requirements (i.e., eventually a bumpy rather than flat field). A trial consisted of two consecutive blocks that were placed either both functional (top left), functional followed by dysfunctional (top right), dysfunctional followed by functional (bottom left), or both dysfunctional (bottom right). The blocks received the same color as the base field during the experiment but are here shown in light and dark gray to indicate the order of the first and second block, respectively. Arrows and text were also not part of the experimental design but are added for clarification. Reported outcomes are based on two-tailed *t* tests or Pearson correlations. Asterisks in the plots indicate the alpha significance level for statistical comparisons (* $p < .05$, ** $p < .01$, *** $p < .001$). Error bars indicate the standard errors of the mean.

points, the row disappears, the entire field is lowered, and the speed at which the blocks fall down is sped up. To simplify our adapted version of Tetris, only two blocks fell down per trial, blocks could not be rotated, rows of cells did not disappear when fully filled, and the speed of the moving blocks was kept at a steady and slow pace of one cell per second across trials (Supplementary Movie 3). The Tetris field consisted of 15 by 10 cells and each block was made out of five cells.

In our version of Tetris, an additional field of a virtual confederate was depicted to create a context in which imitation was possible (see right in Figure 3A). The blocks of the confederate fell 3 s ahead of participants' blocks such that the participant could evaluate the confederate's block trajectories. These trajectories were preprogrammed to ensure identical trials across participants. The trajectories consisted of movements from a random position at the ceiling to the final location at the field's base. Participants controlled the placement of their own blocks by moving each block to the left or right for one cell per second by using the arrow keys on the computer's keyboard. The participants were naïve to the confederate as they were told that the other field was controlled by a participant that sat in an adjacent room in the lab.

We instructed participants to minimize the amount of "damage" points by keeping the base field as flat and filled as possible. They received one damage point for each block sticking out of the base field (i.e., one point per increase or decrease in height across the field) and four damage points for each empty cell below filled cells. Importantly, the confederate dropped each of the two blocks per trial in either a functional manner causing few damage points or dysfunctional manner causing many damage points (Figure 3B). This resulted in four possible conditions per trial: functional/functional, dysfunctional/functional, functional/dysfunctional, and dysfunctional/dysfunctional. Each condition was repeated for five trials to enhance the apparent persistence of the confederate's action types. All participants played the same 80 trials (160 blocks) in random orders and the layout of each field and the two blocks varied across the trials (for more examples, see Supplementary Figure 2).

As in Experiment 1, participants performed an auditory *n*-back task simultaneously with the Tetris game. A one- or two-back repetition was presented approximately three times every trial.

Analysis. The design of the Tetris game allowed objective measures of action similarity rates by calculating the horizontal distance between the participants' and confederate's final block positions per trial (a larger distance meant less action similarity).

Results and Discussion

Action similarity. Despite considerable differences in the setup and the task, the outcome was very similar as in Experiment 1: functional actions of the model were more likely to be imitated than dysfunctional actions (Figure 4A; functional: $M = 8.9$, $SD = 0.3$; dysfunctional: $M = 7.6$, $SD = 0.3$), $t(36) = 20.51$, $p < .001$. Also, preceding action similarities correlated with subsequent action similarities (Figure 4B), indicating that a history of action resonance promoted more resonance in the present trial. Especially previous functional model actions enhanced the participants' tendency to produce similar actions in the present trial (Figure 4C). This effect was highly significant for present functional (previous functional: $M = 9.2$, $SD = 0.5$;

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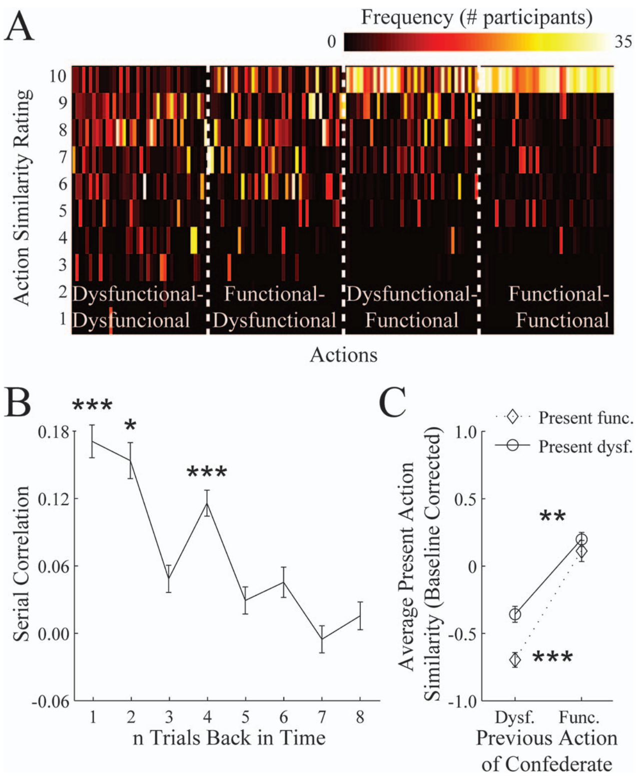

Figure 4. Action similarities. (A) Same results as in Figure 2 but now for Experiment 2. The terms at the bottom of the figure indicate the type of action for Block 1 – Block 2. (B) Present trial action similarity correlated with action similarity up to $n = 4$ preceding trials, indicating that short changes in the tendency to imitate lingered on to subsequent trials. (C) Participants were again more likely to imitate actions when the confederate performed a functional action in the previous trial. Dysf. = dysfunctional; Func. = functional. See the online article for the color version of this figure.

previous dysfunctional: $M = 8.4$, $SD = 0.3$), $t(36) = 10.37$, $p < .001$, and current dysfunctional model actions (previous functional: $M = 7.6$, $SD = 0.3$; previous dysfunctional: $M = 7.1$, $SD = 0.4$), $t(36) = 6.98$, $p < .001$. A significant interaction shows that the size of the effect of previous trials on action similarity in present trials is stronger for present functional than dysfunctional actions, $t(36) = 2.16$, $p = .04$. The latter result indicates that a sequence of a dysfunctional-to-functional trial causes a larger change in action similarity than a dysfunctional-to-dysfunctional trial.

In comparison to Experiment 1, the trial-to-trial effect on action similarity was approximately 4 times stronger, functional: $t(71) = 6.57$, $p < .001$; dysfunctional: $t(71) = 2.95$, $p < .01$. Note that the similarity scale in Experiment 2 represents a different measure than the scale and contains less variance in action similarities than in Experiment 1 (see Figure 4A). z-Score-normalized values nonetheless indicated a stronger effect of preceding functional actions on subsequent action similarities in Experiment 2 than in Experiment 1, functional: $t(71) = 7.66$, $p < .001$; dysfunctional: $t(71) = 3.85$, $p < .001$. It is likely that the design of Experiment 2, including the additional time provided to the participants to evaluate the confederate's actions, strengthened the effect of action functionality in preceding trials on action similarity rates in subsequent trials.

Working memory. Similar to Experiment 1, working memory results show that the total amount of hits and false alarms across blocks for the two-back task was smaller and bigger than the one-back task, respectively (percentage hits: one-back: $M = 58\%$, $SD = 14\%$; two-back: $M = 42\%$, $SD = 14\%$; number of false alarms: one-back: $M = 21$, $SD = 12$; two-back: $M = 36$, $SD = 16$; difference in d': $M = 1.35$, $SD = 1.12$), $t(36) = 8.34$, $p < .001$. In conclusion, the two-back task was more difficult and increased working memory load more than the one-back task.

Action similarity per *n*-back working memory condition. As shown in Experiment 1, the tendency to imitate the confederate increased when participants performed a distracting secondary working memory task in parallel to the first task. However, this effect of task load was absent in Experiment 2 (low load: $M = 8.3$, $SD = 0.2$; high load: $M = 8.3$, $SD = 0.2$), $t(36) = 0.23$, $p = .82$, and the effect size did not differ between functional and dysfunctional trials, $t(36) = 0.70$, $p = .49$. The magnitude of increases in action similarity due to preceding functional actions neither differed between low and high working memory load in present functional trials, $t(36) = 1.06$, $p = .29$, nor in present dysfunctional trials, $t(36) = 0.92$, $p = .37$. These results suggest that increased working memory load had no effect on imitation rates while participants played Tetris. In sum, the effects of working memory load on action similarity in Experiment 1 were not replicated in Experiment 2. The altered design in the Tetris task may have removed a participant's necessity to use working memory resources for adapting the tendency to produce similar actions as the confederate.

General Discussion

The aim of the present study was to see whether people do not only tend to copy behavior of other people they are exposed to, as previous research leads one to expect, but also whether this tendency is sensitive to the functionality of the observed behavior. Our findings show that participants tended to spontaneously copy quite eccentric and inapt behavior of a present human model sitting in front of them (in Experiment 1) or a nonpresent opponent whose actions were displayed spatially next to them on a computer screen (in Experiment 2). This observation is consistent with previous demonstrations of negative consequences due to imitation (Belot et al., 2013; Cook et al., 2012; Naber et al., 2013), and supports the assumption of a close connection between perception and action (Dijksterhuis & Bargh, 2001; Hommel et al., 2001) despite cognitive self-control of actions. Remarkably, we additionally find that a person's actions depend on the history of functionality of actions observed in others. Previous actions of others seem to have a modulatory influence on the preparation of subsequent functional actions.

These results demonstrate a new property of action similarity, namely fluctuations in response similarities across time as a function of the observed action functionality. These effects on behavior linger on from trial to trial. The finding that the magnitude of action similarity correlates across at least three consecutive trials suggests that the degree of overlap between a confederate's and participant's actions is caused by relatively slow action-perception

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dynamics. The phenomenon that the confederate's dysfunctional actions are more likely to be copied by subjects after a functional action may be caused by the same mechanism. However, what might be the mechanism underlying the trial to trial effects on action similarity between agents?

First, supposing that functional behavior makes the observed agent more credible or trustworthy when considering the relevance of that behavior for present action-control purposes, it is tempting to see this relationship as a rudimentary basis of the demonstrated relevance of interpersonal trust for spontaneous imitation and mimicry (Over et al., 2013; Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009). Seeing a person performing a functional action may increase that person's credibility. The instigation of trustworthiness might cause the observer to skip the stage of action evaluation and cognitive control when preparing actions during the observation of the trustee. Recent evidence suggests that at least the reverse is true. In a study by Over and colleagues (2013) children gained more trust for a person that imitated them. The same holds for positive feelings: A priori liking increases rates of imitation (Stel et al., 2010) and high imitation rates cause more liking between interacting partners (Chartrand & Bargh, 1999). Supported by studies showing a link between trust and liking (e.g., Nicholson, Compeau, & Sethi, 2001), it is therefore not unlikely that the factors trustworthiness, positive affect, and imitation are reciprocally coupled.

Second, an agent that produces a surprising, dysfunctional action after a functional action may therewith attract additional attention and consequently facilitate action resonance (Bach et al., 2007). Such an account concurs with a recent identification of modulatory effects on imitation by action visibility (Naber et al., 2013) and the effect of the amount of attention on imitation (Chong et al., 2009; van Schie, et al., 2008). In line with these reports, it is more difficult to control automatic mirroring responses when attention is focused on other's rather than the self (Spengler, Brass, Kühn, & Schütz-Bosbach, 2010). An alternative explanation is that dysfunctional actions do not attract but repel attention in current trials. Attention to the agent may be repelled when the agent's action is irrelevant to the observer. This means that when less or no attention is allocated on the agent, the degree of the perception-action interaction and imitation decreases. Changes in attentional focus from trial to trial as a function of changes in action functionality may thus underlie the fluctuations in action similarity across trials.

Third, the decrease of similarity after the observation of a dysfunctional action may also be the result of increased self-other distinction (Hommel, Colzato, & van den Wildenberg, 2009) and/or the detection of a discrepancy between one's own action scheme and someone else's. This may create, or be the result of, cognitive conflict that triggers additional cognitive control, as observed with experimentally induced cognitive dissonance (Van Veen, Krug, Schooler, & Carter, 2009) or in incongruent trials of a Stroop or Simon task (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton, Coles, & Donchin, 1992). If a conflict in action representations increases the degree of executive functions (Botvinick et al., 2001), top-down cognitive control should be stronger in trials after trials in which the model showed dysfunctional behavior. Given the evidence that more cognitive control reduces the impact of spontaneous response tendencies (van Leeuwen, et al., 2009), this would explain why we found less evidence of spontaneous imitation after dysfunctional than after functional trials. Vice versa, the observation of a functional action may not trigger cognitive control functions, leading to a higher probability of spontaneous imitation of subsequent dysfunctional actions. These three propositions, however, have yet to be established.

In line with previous findings, the results of both experiments provide strong evidence that spontaneous imitation, mimicry, or action compatibility is not a primitive and context-insensitive tendency (Heyes, 2011). Rather, the tendency to copy elements of an observed action is modulated by (a) the present functionality of the observed behavior, with functional behavior being more likely to be reproduced and (b) the functionality of observed behavior in the previous trial. This is in line with recent work indicating that previous experiences are important for imitation to occur (Heyes et al., 2005). The first observation was expected as functional actions are more stereotypical, therewith increasing the probability that a similar action will be performed. However, the second observation is even more interesting for the influence of time on action similarity between agents: Its strength does not just depend on present functionality but also on previous functionality of the model's behavior. In other words, the impact of the other person's behavior on one's own action control seems to depend on the expected usefulness of that behavior.

The role of action control became especially evident in Experiment 1. Participants had to perform a one-back or two-back task in parallel to producing action. The idea was that dual-tasking depletes the participants' executive control functions, therewith decreasing the amount of control of an individual's actions and subsequently facilitating action similarity (van Leeuwen, et al., 2009). As such, adding the *n*-back task was a useful paradigm to prevent that no action would be imitated at all. It also allowed us to replicate—though only in Experiment 1—the previously reported effect of working memory load on the amount of action similarity between agents (van Leeuwen, et al., 2009). Data showed no link between more working memory load and more action similarity in Experiment 2. The low performance on the *n*-back task in Experiment 2 suggests that participants failed to balance attention for the two tasks, perhaps because they focused too much on the Tetris game. Alternatively, the difference in design may underlie the difference in findings between the two experiments. The lacking physical presence of a model in Experiment 2 or the possibility that our Tetris variation may have been too easy to perform could have reduced task demands, therewith reducing impact of the working memory task. While the findings confirm that the physical absence of a person does not prevent participants to reproduce his actions (Krämer, Kopp, Becker-Asano, & Sommer, 2013; Krämer, Simons, & Kopp, 2007; Naber et al., 2013), more research is needed to investigate whether physical human presence and task-difficulty may increase effects of working memory on action similarity. Nonetheless, the fact that behavioral contagion of action schemes is still present when individuals have no direct social interaction with other persons (Naber et al., 2013; Longo & Bertenthal, 2009) suggests that social closeness is not a primary drive of action resonance.

The difference in experimental design and working memory results between Experiment 1 and 2 may raise the question whether action similarity in Experiment 2 is caused by the same mechanism as in Experiment 1, that is, action-evaluation-induced fluctuations in imitation across trials. While the pattern of results

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of Experiment 1 is remarkably comparable to that of Experiment 2, the experiments merely overlap in action context. Namely, imitators can observe the actions of a model—physically present or not—before they produce their own. Perhaps such circumstances are enough to facilitate the evaluation of action functionality and the control of the tendency to imitate in subsequent trials. Alternative to Experiment 1, imitation in Experiment 2 may also be caused by spatial compatibility (Bertenthal, Longo, & Kosobud, 2006; Catmur & Heyes, 2011; Cooper, Catmur, & Heyes, 2013), a mechanism slightly different from automatic imitation (Brass, Bekkering, & Prinz, 2001). Spatial compatibility refers to a similarity in what is done with an object while imitation refers to a similarity in the topographical responses (Heyes, 2011). Imitation is, however, entangled with spatial compatibility in the design of Experiment 2 but it would be interesting for future research to investigate whether spatial compatibility, like automatic imitation, is sensitive to previously observed action functionalities.

Another difference between Experiment 1 and 2 was the composition of the trials. A trial in Experiment 2 included two consecutive actions (i.e., two Tetris blocks falling down) while a trial in Experiment 1 included just one action. The design of Experiment 2 may have caused participant's to assign unequal levels of attention or to experience different changes in trust for the first as compared to the second block. For example, a preceding dysfunctional action may have triggered more distrust in the participant and hence less imitation in the subsequent trial than the amount of trust and increased imitation triggered by a preceding functional action. This explanation supports the interaction between preceding and present action functionality in Experiment 2.

In sum, executive control, social interaction, and the evaluation of actions play modulatory roles in the production of actions. We deem it most plausible that the mapping of the perception of others on self-initialized actions is a primary driver of actions and that executive control, goal evaluation, and social factors are secondary functions that can modulate the degree of action control to some extent. This idea concurs with findings demonstrating that damage to the frontal lobe, a brain area involved in executive control of actions, causes more imitation in patients (Brass, et al., 2003; Lhermitte, Pillon, & Serdaru, 1986). Other factors that may affect imitation are the timing of actions and attentional resources. For instance, very short lags between observed and self-initiated actions may result in less imitation because this weakens the probability to link perception and action (for a discussion, see Aczel, Bago, & Foldes, 2012; Belot et al., 2013). On the other hand, a very long period between action observation and execution may reduce the probability of action mapping because action representations may weaken as time passes. Specific effects of the time between action observation and execution on imitation would be an interesting aspect to study in the near future.

Conclusions

The urge to copy others' behavior presents itself sometimes at rather unusual moments. Our experiments demonstrate how people may adapt their own actions to that of others even when these are maladaptive. Participants occasionally copied strange and atypical behavior, especially after a previous observation of functional behavior, which was probably not the result of a self-initiated action scheme. This demonstrates the complexity of the interaction between people and the brain's tightly linked perception-action mechanisms, source evaluation, and previous experiences with the mimickee.

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