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ARTICLE

The impact of response type on affordance and spatial compatibility effects in human and object interactions

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Abstract

Everyday social interactions or goal-directed actions towards objects activate action plans appropriate to their affordances. The spatial compatibility of a stimulus and a response might interfere with the activation of these action plans. In the present study, we examined how framing of interactions affects the interplay between affordance and spatial compatibility effects towards humans and objects in two separate experiments. In a motor priming task designed to simultaneously assess these two effects, participants were presented with interactive hand gestures and objects with a single handle. Participants responded either with their left or right hand according to the colour mask of the stimulus, regardless of the spatial position or the affordance-related orientation of the stimulus. In Experiment 1, when responses were given by keypresses, we found independent affordance and spatial compatibility effects towards objects. Surprisingly, interactive hand gestures induced a reversed affordance effect, that is, imitative action tendencies. Changing the responses from keypresses to the performance of grasping actions in Experiment 2 drastically altered these findings, resulting in the enhancement of affordance and the elimination of spatial compatibility effects for both human and object interactions. These findings highlight the importance of contextual influences on the emergence of automatic action tendencies.

KEYWORDS

affordances, interactive gestures, motor priming, perception-action, spatial compatibility

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BACKGROUND

Perceptual processes triggered by different cues in our environment generate a variety of automatic action tendencies. When we see an object falling on our right side, we try to catch it with our spatially compatible right hand. When we see a mug with a handle pointing towards the right or someone extending their right hand for a handshake, we again use our right hand, but this time because this action is what the object or the social agent affords. In the present study, we conducted a systematic investigation of these automatic action tendencies by specifically focusing on the dynamic interplay between the spatial compatibility effect and the object and social affordance effects in different responding contexts.

The spatial compatibility effect refers to the automatic facilitation of responses that are spatially compatible with the location of a stimulus in our visual field. It is typically manifested as faster reaction times for spatially compatible than incompatible stimulus–response mappings in tasks in which the choice of the response side is based completely on a spatially irrelevant stimulus characteristic such as shape, colour (Craft & Simon, 1970), or auditory pitch (Simon & Small, 1969). Although this effect has been predominantly studied in typical responding contexts where the right hand is used to press a right keyboard key and the left hand is used to press a left keyboard key, it has been consistently reported that the effect is also prominent when the response hands are crossed to the contralateral sides of the body (Craft & Simon, 1970; Nicoletti et al., 1982; Roswarski & Proctor, 2000) or when unimanual responses using the index and middle fingers of the same hand are used (Heister et al., 1986; Katz, 1981). These critical findings indicate that it is not the correspondence between the location of the stimulus and the anatomical hand, but the sharing of the spatial code between the stimulus location and the response side in a given responding context, which is the critical determinant in the emergence of the spatial compatibility effect.

The object affordance effect, another well-established stimulus–response compatibility effect, is grounded in the more general concept of affordances proposed by Gibson (1979), who argued that perception of objects or events activates the action representations provided by their functional features. Gibson's hypothesis on such a link between perception and action was empirically supported by Tucker and Ellis (1998; see also Ellis & Tucker, 2000) using a stimulus–response compatibility paradigm, in which the participants were presented with normal or vertically-oriented versions of everyday graspable objects with single handles (e.g. teapot) and gave left- and right-hand button press responses based on the vertical orientation of the objects. The right (left) hand responses were faster when the object's graspable end was oriented towards the right (left), compared to the trials in which the object's handle was towards the left (right), which was interpreted as providing support for the object affordance effect. Nevertheless, the behavioural facilitation effect reported in object affordance studies is highly debated as to whether this effect is produced due specifically to the action possibilities afforded by the object properties or whether it is inherently related to a more general process of spatial stimulus–response compatibility. Addressing this question, Tucker and Ellis's (1998) second experiment supported the former account, revealing that when the responses were given with different fingers of a single hand, the behavioural facilitation effect was diminished, unlike what has been shown for the spatial compatibility effect (Heister et al., 1986; Katz, 1981). However, other researchers observed affordance-compatible response facilitation effects in crossed hand or foot responses (Phillips & Ward, 2002; Symes et al., 2005; but see Janyan & Slavcheva, 2012) or unimanual responses (Cho & Proctor, 2010, 2011), which has been taken as evidence supporting the accounts that argue for the spatial overlap of stimulus–response coding, rather than object affordances, as the process underlying these findings. Yet, other studies independently manipulating the spatial- and affordance-related features of objects reported that the two effects were distinct from each other; however, which effect would be more dominant at any time point was affected by a variety of factors. For instance, Pappas (2014) reported that while silhouettes of objects are sufficient to produce spatial compatibility effects, internal visual details of objects, such as depth information in photographs, are necessary to induce affordance effects. In addition, attentional demands of the task were shown to be critical, as attention to the low-level features of the objects, such as their colour, only elicited spatial compatibility effects, whereas attention to the high-level

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object features, such as their functional category (e.g. kitchen vs. garage) or orientation, also produced affordance effects (Saccone et al., 2016; Symes et al., 2005). Regarding the role of response type, Iani et al. (2011) reported that both effects could be observed simultaneously; however, the interaction between the effects was related to how the responses were executed. Specifically, the two effects did not interact with each other when responses were performed as keypresses, whereas there was a significant interaction between them when responses were performed as reaching actions, indicating the different response selection processes responsible for these effects. In parallel with this study, we examined the spatial compatibility and object affordance effects simultaneously in different responding contexts.

Social affordances, a separate notion also grounded in the more general concept of affordances, refers to the interactive action opportunities between two social agents (Carvalho, 2020). One critical difference distinguishing social affordances from object affordances is that, during social interactions, one is required to reciprocate the other individual's action (e.g. extending their right hand for a handshake) not with the spatially compatible response (the left hand), but with the hand that complements (the right hand) the interaction partner's action. Curioni et al. (2020) used images of individuals performing either interactive (e.g. handshake) or communicative (e.g. thumbs up) gestures with either the right hand, which was located on the left side of the screen since the body of the individual was centred, or the left hand, which was located on the right side of the screen. The spatial compatibility effect that resulted from the location of the gesture hand on the screen was found to be lower in the communicative than in the interactive gesture condition, which indicated that interactive gestures led to a slight facilitation of the spatially incompatible but affordance-compatible hand. In a similar vein, Liepelt et al. (2010) investigated affordance-related behavioural facilitation towards communicative (e.g. handshake), transitive (e.g. grasping an apple) and intransitive (e.g. closed hand) actions produced by human and non-human (i.e. a wooden hand model) agents. In line with social affordance accounts, the participants initiated affordance-compatible complementary responses faster for communicative gestures performed by humans than by nonsocial agents. Faber et al. (2016) further elaborated on the role of interactive possibilities and showed that the perceived reachability via manipulation of the distance or the presence of a physical barrier did not modulate faster complementary hand responses towards interactive (i.e. handshake) gestures compared to non-interactive (i.e. fist) gestures. Furthermore, to address the possible modulatory role of spatial stimulus–response compatibilities for affordance-related behavioural facilitation towards interactive gestures, Flach et al. (2010) investigated responses towards left or right hands performing a handshake gesture and arrows directed towards the left or the right, all presented on the left or right side of the screen. They revealed that although both stimulus types produced strong spatial compatibility effects, the directional compatibility effect, which was in line with social affordances, occurred only for the handshake gestures. It is important to note that the type of response administration might be a critical factor in the emergence of the social affordance effect, since faster complementary hand responses were observed in studies using key release as responses (Faber et al., 2016; Farmer et al., 2021; Flach et al., 2010; Liepelt et al., 2010), whereas the only study that used keypress responses reported the opposite pattern, showing faster responses for the spatially compatible but affordance-incompatible hand responses (Curioni et al., 2020).

Social affordance studies examine complementary behaviours in scenarios where two people interact with each other, yet these are not the only action tendencies triggered by the observation of social agents. Behavioural studies consistently show that observing a particular action (e.g. finger tapping) facilitates the execution of the same action in the observer, which is referred to as imitative compatibility or automatic imitation (Brass et al., 2000, 2001; Craighero et al., 2002; Stürmer et al., 2000). In interactive social contexts (e.g. someone extending their right hand for a handshake), the complementary (our right hand) and the mirror-congruent imitative (our left hand) action tendencies might often conflict with each other. The facilitation of appropriate actions upon perceiving a social agent might not only be affected by the characteristics of the perceived action itself but also be heavily influenced by the intentions of the observer in a given context. Nevertheless, the critical factors that lead us to engage in imitative or complementary behaviours in social interactions remain unknown.

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In light of the above discussions, we conducted the present study, which compares the object and social affordance effects with the spatial compatibility effect in a single task design. In two experiments, we used a motor priming paradigm in which spatial and affordance-related information were conveyed simultaneously but independently. Specifically, in different trials, participants were shown images of either graspable objects (e.g. cups) or interactive gestures (e.g. handshakes). The handles of the objects were oriented either towards the left or the right, and the hands performing the gestures were either the right or the left hands, designed to elicit left- or right-hand affordances in the participant. These images were also presented either on the left or the right half of the screen in different trials to assess spatial compatibility effects. The task was to respond with either the left- or right-hand responses based on the colour masks applied to the stimuli, which were unrelated to their affordance- and spatial-compatibility-related features. Critically, the response type was different between the two experiments. In the first experiment, responses were administered by simple keypresses using the left and right hands. Based on the literature, we hypothesized that the spatial compatibility and the affordance effects would be of equivalent strengths for objects. On the other hand, we predicted that the social affordance effect would be stronger than the spatial compatibility effect for gestures, given their interactive nature, which was expected to override the influence of their spatial compatibility. In the second experiment, we changed the responses to more interactive ones, asking participants to make key releases followed by grasping gestures performed towards the computer screen. Here, we predicted that framing the task in a more interactive context would lead to stronger object and social affordance effects, but weaker spatial compatibility effects, compared to those seen in the first experiment with keypress responses. Earlier reports did not reveal any differences between the facilitation of left- and right-hand motor action plans in response to interactive gestures or actions (Curioni et al., 2020; Faber et al., 2016; Sartori et al., 2014); thus, we hypothesized that the spatial compatibility and the affordance effects would be comparable for the left- and right-hand responses.

MATERIALS AND METHODS

Experiment 1

Participants

Sixty participants with normal or corrected-to-normal vision were recruited to participate in Experiment 1 either voluntarily or in exchange for course credits. Eight were excluded due to not being right-handed as measured by the Edinburgh Handedness Inventory (Oldfield, 1971), and another participant was excluded due to inadequate performance in the behavioural task (see Data Analysis for details). Thus, all analyses were performed on the final sample of 51 participants aged between 19 and 53 ($M = 23.41$, $SD = 6.07$; female/male = 37/14). None of the participants in the final sample reported a diagnosis of colour blindness or a psychological or neurological disorder associated with social cognition deficits in the last three years. All procedures were approved by the Koç University Committee on Human Research (2022.410.IRB3.188), and each participant read and signed a written informed consent according to the Declaration of Helsinki before participating in the study.

Stimuli

The experimental stimulus set consisted of images depicting either human models performing interactive gestures with one hand or everyday objects with single handles through which they can be manipulated with one hand. For human images, photographs of three different types of interactive gestures—handshake, request and arm-wrestling handshake (for the naming of gestures, see the validation study reported below)—performed by a female and a male model wearing grey crewneck sweaters and

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sitting behind a white table against a dark grey background were taken (Figure 1a). All gestures were performed with the right hand, while the left hand was positioned naturally on the left side of the model. The heads of the models were excluded from the images, and there were no visible markings (tattoos, nail polish, scars, etc.) on the models' hands. The models were asked to perform these gestures towards the centre of their body as much as possible. A few photographs of each gesture were taken one by one. The major reason why certain detailed characteristics of our stimuli might differ between the models and gestures is that we wanted the gestures to be performed by the models as naturally as possible, without much intervention. For object stimuli, photographs of two different versions of three objects with single handles—mug, teapot and watering pot—were taken on the same white table against the same dark grey background (Figure 1a). The colour of all the objects was either white or light cream to keep their colour as similar as possible to human hands. Objects were positioned such that their handles were directed towards the left from the viewpoint of the camera. All photographs were edited using Adobe Photoshop (version 24.0.0) to ensure that the midpoints of the hands in human images and the handles

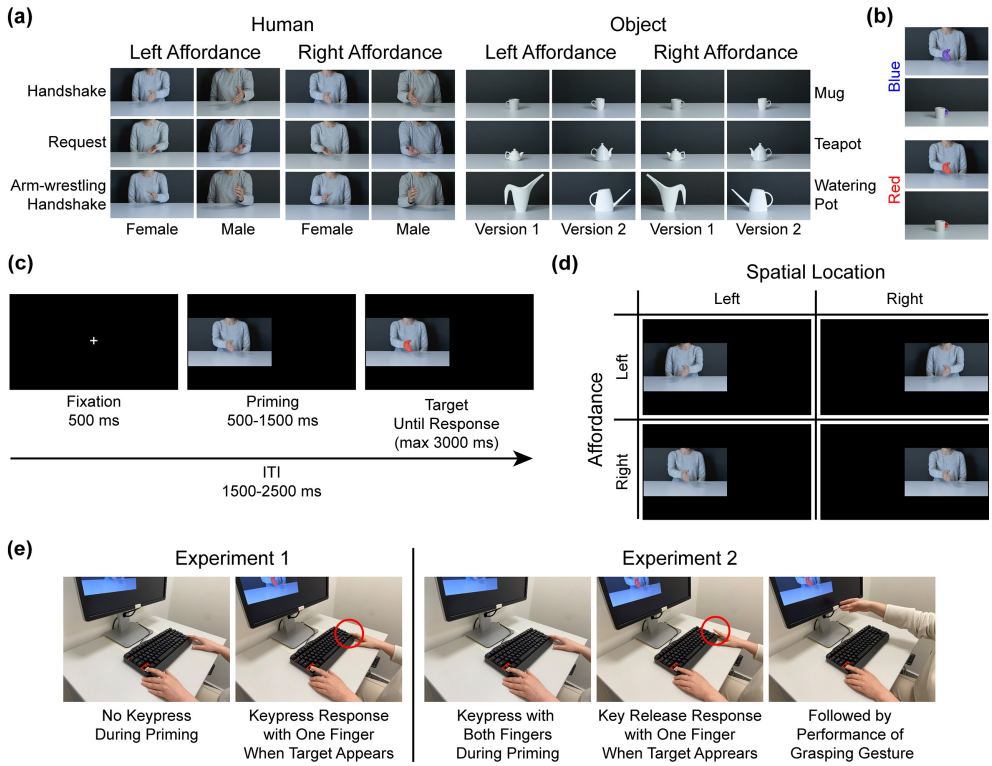


FIGURE 1 Stimuli and task design. (a) The images used in both experiments consisted of handshake, request and arm-wrestling handshake gestures performed by a female and a male model and two different versions of mug, teapot and watering pot objects. (b) Blue and red colour masks applied to the hands of the models and the handles of the objects were used as task-relevant features to which participants responded in both experiments. (c) Each trial started with a fixation of 500 ms, followed by the presentation of the motor priming image for a variable duration between 500 and 1500 ms. Then, the target image, which was the colour mask applied version of the priming image, was shown until a response was registered within 3000 ms. The intertrial interval was randomly selected from the 1500–2500 ms range. (d) The images were presented in four different ways according to the 2 spatial location (left, right) × 2 affordance (left, right) design. An image presented in the left (right) half of the screen was expected to facilitate the left (right) hand of the participant according to the spatial compatibility effect. A gesture image, in which the model extends their anatomical left (right) hand for a handshake, or an object image, the handle of which is directed towards the left (right) of the screen, was expected to facilitate the left (right) hand of the participant according to social and object affordance effects, respectively. (e) In Experiment 1, participants responded with simple keypresses. In Experiment 2, each trial started with participants holding down on both keys, and responses to the target image were given as key releases, followed by the performance of grasping gestures towards the centre of the screen.

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in object images were positioned at the centre of the image horizontally and the table appeared at the same level vertically. All images were downsampled to 1868 × 1080 pixels.

The original set of 12 images was horizontally flipped to also create versions of the human images depicting the hand gesture performed with the left hand and the object images depicting the handles of the objects directed towards the right of the image. Finally, two additional versions of each image, in which the hand of the model or the handle of the object was overlaid with blue or red masks to be used as target stimuli in the behavioural task, were generated (see Procedure for details; Figure 1b). The average RGB values were [95,68,168] and [186,59,54] for blue and red masked areas, respectively. Although there were no differences in any of the RGB values between the hand and the handle masked areas in the images with blue masks, all $t(10) \leq 0.311$, $p \geq .762$, $BF_{10} \leq 0.482$, the RGB values of the hand masked areas were slightly higher than those of the handle masked areas in the images with red masks, all $t(10) \geq 2.381$, $p \leq .039$, $BF_{10} \geq 2.140$.

We conducted a qualitative online study via Qualtrics (Qualtrics, Provo, UT) with 30 naïve participants aged between 20 and 25 years old ($M = 21.55$, $SD = 1.38$, female/male = 23/7) who did not participate in the main experiments to assess how participants would spontaneously describe the gestures we used in the present study. Participants were shown images depicting seven different gestures, three of which were the ones used in the present study (Figure 1a). The other four were making a fist as if fist-bumping another individual, the thumbs-up gesture, the okay sign as performed by joining the thumb and the index finger in a circle and the peace sign as performed by holding up the index and middle fingers in a V form. The latter three gestures were included as communicative gestures with little to no physical interactive purpose, while the fist gesture was included as a potentially ambiguous stimulus that might or might not be considered interactive. All gestures were performed by the same two models. Participants were shown the images depicting these gestures, and for each, they were asked the question "How would you describe the action shown in this photograph in a few words?" To collect the responses of the participants as naturally as possible, the participants were not given any other information or instructions regarding gestures, and they were free to write as much as they pleased. The seven gestures described above performed by the two models were shown once in their original, right-hand version and once in their horizontally flipped, left-hand version, for a total of 28 images presented in a shuffled order. Verbs and related action words in participants' responses were coded, and the percentages of the top five words were used to summarize how participants freely described these gestures. The gestures shown in the first row of Figure 1a were described with the verbs 'to shake hands' (36%), 'to greet' (19%), 'to meet' (18%), 'to extend hand' (10%) and 'to agree' (7%; total = 91%). The gestures shown in the second row of Figure 1a were described with the verbs 'to request' (20%), 'to give' (14%), 'to extend hand' (11%), 'to take' (10%) and 'to cadge' (7%; total = 62%). The gestures shown in the third row of Figure 1a were described somewhat differently between the male and female models. Specifically, the most frequent description for the male model was "to arm-wrestle" (43%), which was never used to describe the gesture performed by the female model. For the female model, the most frequent response was 'to shake hands' (19%), which was also the third most frequent response for the male model (11%), right after 'to greet' (13%). Overall, the top five responses across the models were 'to arm-wrestle' (22%), 'to shake hands' (14%), 'to greet' (10%), 'to hold' (8%) and 'to extend hand' (8%; total = 63%). Although the same gesture was described as two different actions ('to arm-wrestle' vs. 'to shake hands' or 'to greet'), which would definitely have an impact on the semantic processing of these gestures, the fact that both of these actions are generally performed to elicit physical interactions and specifically require the same complementary hand actions from the observers gave us confidence that the perception-action mechanisms that we explored in the present study would have been minimally affected by these differences. Based on these findings, we labeled the gestures we used in the present study as handshakes, requests and arm-wrestling handshakes.

We conducted another online validation study on a separate sample of 32 participants aged between 19 and 25 years old ($M = 21.69$, $SD = 1.53$, female/male/other = 24/7/1) to assess whether the gestures we used in the present study were indeed explicitly evaluated to be interactive. For this second validation study, we used the same 28 images as described above for the first validation study. This time, for each

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gesture, the participants were given two statements and asked to report how much they agreed with each of them on a 5-point scale (strongly disagree, disagree, neither disagree nor agree, agree, strongly agree). The two prompts were: "The hand action shown in the photograph is an interactive gesture. (He/she aims to have a physical interaction with me.)" and "The hand action shown in the photograph is a communicative gesture. (He/she aims to express something to me.)" Responses were coded from 1—strongly disagree to 5—strongly agree. The average of the three emblem gestures—peace, okay, thumbs up—were rated to be more communicative than interactive, $F(1, 31) = 78.173$, $p = 6 \times 10^{-10}$, $\eta_p^2 = 0.716$, $BF_{inc} = 6 \times 10^6$, with no effect or interaction of the gender of the model. Thus, we calculated the average of all these six sets of ratings (3 gestures × 2 models), to which the gestures used in the present study were compared. All three gestures used in the main experiments produced by both the female and male models were found to be dramatically more interactive than the emblem gestures, all $t(31) \geq 8.333$, $p \leq 2 \times 10^{-9}$, $d \geq 1.473$, $BF_{10} \geq 6 \times 10^6$. On the other hand, only the handshake gestures performed by the female and male models and the arm-wrestling handshake gesture performed by the male model received communicativeness ratings that were significantly lower than both their own corresponding interactiveness ratings and the communicativeness ratings of the emblem gestures, all $t(31) \geq 2.255$, $p \leq .031$, $d \geq 0.399$, $BF_{10} \geq 1.701$. Thus, although all three gestures used in the main experiments were found to be highly interactive, some of them were also perceived to be communicative, underlining their dual nature.

Procedure

The motor priming task was programmed in PsychoPy (version 2023.2.1; Peirce et al., 2019). Visual stimuli were presented through a computer screen (Dell P2214Hb, 22 inches, 1920 × 1080 pixels resolution, 60-Hz refresh rate) at a viewing distance of ~75 cm, and the responses were collected through a mechanical keyboard (Zalman ZM-K500) positioned in perfect horizontal alignment with the screen. The left ctrl and right arrow keys of the keyboard were labelled as 'A' and 'B', respectively, and used as the response keys in the motor priming task since they were placed in the leftmost and rightmost bottom corners of the keyboard.

The motor priming task was designed to simultaneously assess the effects of spatial compatibility and affordances on motor responses in human and object interactions. Each trial started with the presentation of a central fixation cross for 500 ms, followed by a motor priming phase in which the unmasked versions of human or object images could be presented in four different ways (Figure 1c). To test spatial compatibility effects, each image could be shown such that the horizontal middle point of the hands in the human images and handles in the object images were positioned exactly in the centre of the left or right half of the screen, priming the left- or right-hand responses of the participants, respectively (Figure 1d). To test affordance effects, for both of these two possible positions on the screens, each image could also be shown in two different ways, affording either the left or the right hand. Specifically, in one condition, the interactive gestures were performed by the anatomically left hand of the model, and the handles of the objects were directed towards the left of the screen, both of which afforded the left-hand responses of the participants. In contrast, right-handed gestures and right-directed handles afforded the right-hand responses of the participants. This priming phase lasted for a random duration between 500 and 1500 ms to assess whether priming duration affects subsequent motor activity. Following the priming phase, either the blue or red masked version of the priming image was shown as the target stimulus for 3000 ms or until the participant pressed a response key according to the instructions they received at the beginning of each block (Figure 1e). No feedback was given to participants about their responses. An intertrial interval of a randomly selected duration between 1500 and 2500 ms separated subsequent trials from each other.

The allocation of target stimulus colour masks to response keys was manipulated across two blocks. Participants were instructed to press 'A', which was actually the left ctrl button on the keyboard, with their left index finger when they detected a colour change to blue in the stimulus, and press 'B', which was actually the right arrow key on the keyboard, with their right index finger when they detected a

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colour change to red in the stimulus in one block and vice versa in the other block. The order of the two blocks was counterbalanced across participants. Before the beginning of experimental trials in each block, participants underwent a short practice block to learn the colour-response mappings of that particular block instruction. During these practice blocks, participants were given feedback about the accuracy of their responses after each trial and were required to respond correctly in a minimum of 12 out of 16 trials to proceed to the experimental trials of that particular block.

The entire task consisted of 2 instruction blocks (Blue-A & Red-B, Blue-B & Red-A) ×2 spatial location (Left, Right) ×2 affordance (Left, Right) ×2 stimulus category (Human, Object) ×3 stimulus type (for Humans: Handshake, Request, Arm-wrestling Handshake; for Objects: Mug, Teapot, Watering pot) ×2 stimulus version (for Humans: Female, Male; for Objects: two different exemplars of each object) ×2 colour masks (Blue, Red) ×4 repetitions = 768 trials. In each instruction block, there were four small blocks with self-paced resting periods in between. In each small block, stimuli were presented in a pseudo-randomized order, which restricted successive presentations of more than five identical spatial location, affordance, stimulus category and colour mask trials. The experiment lasted approximately one hour. After the motor priming task, participants filled out the Edinburgh Handedness Inventory (Oldfield, 1971) and a demographic questionnaire. Participants who scored less than 50 on the Edinburgh Handedness Inventory were classified as non-right-handed and excluded from statistical analyses.

Data analysis

Data were prepared for analyses using MATLAB (version R2022b) and analysed in JASP (version 0.16.4; JASP Team, 2022). The minimum accuracy threshold for inclusion in statistical analyses was determined a priori as 85% based on the average minimum number of accurate trials we aimed to have for each condition to calculate reliable reaction times. Specifically, the total number of trials in Experiment 2 (see below) was 576, and we aimed to have, on average, at least 30 accurate trials for each of our $2 \times 2 \times 2 \times 2 = 16$ conditions. The 85% of 576 corresponds to $489.6/16 = 30.6$ trials per condition; thus, the accuracy above 85% was chosen as an inclusion criterion for both experiments. The overall accuracy levels of all participants were above 85% ($M = 97.31\%$, $SD = 2.31\%$), except for one participant (83%), who was excluded from statistical analyses. Reaction times were estimated starting from the onset of the presentation of the target images with colour masks. For the analysis of reaction times, trials in which the responses were not accurate and responses in which the reaction times were less than 200 ms were initially excluded. Then, for each participant, outlier reaction times were detected. To do this, due to the positively skewed nature of reaction time distributions, the raw reaction times were first log-transformed, and then any value that was above or below 3 standard deviations from the mean of these log-transformed values was excluded. The percentages of trials that were excluded due to the combination of these three criteria were between 0.52% and 20.18% across participants ($M = 5.14\%$, $SD = 4.07\%$). Finally, for each specific combination of the relevant conditions for a given statistical analysis, the average of the log-transformed reaction times within those trials was calculated and then transformed back to the linear scale to be used in subsequent statistical analyses.

We also calculated the Spatial Compatibility Effect (SCE) and Affordance Compatibility Effect (ACE) indices separately by first taking the average of all reaction times in trials in which the response hand and the spatial compatibility or affordance compatibility conditions were compatible with each other and another average of trials in which they were incompatible with each other. Then, the average reaction times in incompatible trials were subtracted from those in compatible trials for SCE and ACE indices separately. Higher values of these indices indicate stronger effects.

Finally, a quintile analysis was performed on reaction times as described in Catmur and Heyes (2011) to examine whether the magnitude of spatial compatibility and affordance effects were modulated by responding speed. Specifically, each participant's raw reaction times were divided into 5 equal-length bins based on their ranking from the fastest to the slowest. For each of these quintiles (quintiles 1–5 having

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the fastest to slowest reaction times), the average of the log-transformed reaction times was taken and then transformed back to the linear scale to be used in subsequent statistical analyses. Note that these quintiles were constructed within the specific reaction time distribution of each participant separately. Thus, the same quintile might correspond to fairly different absolute reaction times across participants.

The details of the statistical models are described below, specifically for each analysis. The alpha level was set to .05 and Bonferroni-corrected for multiple comparisons as indicated specifically for each analysis. Greenhouse–Geisser-corrected p values were used for evaluation of statistical significance when sphericity assumptions were violated, as indicated by significant Mauchly's tests of sphericity. For significant effects, effect sizes were reported as Cohen's d for paired-samples and one-sample t-tests and as partial eta-squared (η_p^2) for ANOVAs. When possible, frequentist analyses were supplemented with Bayesian statistical analyses. BF_{10} stands for the Bayes factor that quantifies the ratio of the evidence in support of H_1 to the evidence for H_0 in paired-sample and one-sample Bayesian t-tests, and BF_{inc} indicates the Bayes factor that quantifies the ratio of the evidence when a factor is included compared to the evidence when it is excluded from the model in repeated-measures Bayesian ANOVAs. The significance of BF values was evaluated using the conventional cut-off points of 3 and 1/3, indicating significant evidence in favour of H_1 and H_0, respectively (Keysers et al., 2020). Thus, a BF_{10} or a BF_{inc} value below 1/3 indicates evidence for the absence of an effect, which is a conclusion that is not possible to arrive at in traditional frequentist statistical analyses.

Experiment 2

Participants

Thirty-five participants with normal or corrected-to-normal vision were recruited to participate in Experiment 2 in exchange for course credits. Five were excluded due to not being right-handed and another three were excluded due to inadequate performance in the behavioural task as described in Experiment 1. All analyses were performed on the final sample of 27 participants aged between 18 and 24 ($M = 21.41$, $SD = 1.53$; female/male = 17/10). As in Experiment 1, none of the participants in the final sample reported a diagnosis of colour blindness or a psychological or neurological disorder associated with social cognition deficits in the last three years. All procedures were approved by the Koç University Committee on Human Research (2022.410.IRB3.188), and each participant read and signed a written informed consent according to the Declaration of Helsinki before participating in the study.

Procedure

The experimental stimuli, the testing setup, and the motor priming task were exactly as in Experiment 1, except for one critical difference. In this experiment, the participants were required to give their responses not by pressing the 'A' or 'B' keys on the keyboard but by releasing the response hand from one of these keys and performing a grasping gesture towards the centre of the computer screen (Figure 1e). Each trial started with a text message instructing the participant to press and hold down the 'A' and 'B' keys simultaneously with their left and right index fingers, respectively. When both buttons were held down, the fixation cross, the priming stimulus and the target stimulus were presented with the same parameters as in Experiment 1. In two separate instruction blocks, participants were asked to release either one of their index fingers according to the colour mask of the target stimuli. After releasing the relevant hand, participants were required to make a grasping action towards a marked area in the centre of the bottom of the computer screen frame as if they were going to hold the object handle or the human hand depicted on the screen. The responses were instructed to be performed towards the centre of the screen, instead of towards the handle or the hand specifically shown in each trial, since we did not want to induce systematic differences between different spatial compatibility conditions, which would

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potentially create a confounding factor hindering our efforts to assess spatial compatibility effects as validly as possible. In addition, we used simulation of grasping actions as responses, instead of real actions performed on a real object or a plastic hand, since doing the latter would require the gesture and object effects to be tested in different blocks with different visual characteristics, which could potentially lead to confounding factors when comparing the two stimulus categories. Responses were video recorded during the experiment, and trials in which the participants did not perform the reaching action were removed from analysis. The rigour with which the grasping gestures were performed varied among participants. Some participants performed grasping gestures that specifically matched the different interactive gestures presented, while others used more general grasping gestures for all the stimuli. These variations in grasping gestures were not coded or quantified.

In Experiment 2, each unique stimulus-condition combination was repeated three times, instead of four times as in Experiment 1, which yielded a total of 576 trials. All other procedures were identical to Experiment 1.

Data analysis

The data were processed and analysed exactly as in Experiment 1. The trials in which the participant performed a key release not only with the required response hand but also with the non-response hand were coded as inaccurate and thus were not included in reaction time calculations. The accuracy levels of the three participants were below 85%, thus they were excluded from statistical analyses. The overall accuracy levels of the included participants were very high ($M = 96.02\%$, $SD = 2.66\%$). The percentages of excluded trials due to all rejection criteria were between 1.56% and 12.15% ($M = 4.79\%$, $SD = 2.70\%$), similar to Experiment 1.

RESULTS

Experiment 1

We first analysed the entire dataset of reaction times in a 2 stimulus category (Human, Object) × 2 spatial location (Left, Right) × 2 affordance (Left, Right) × 2 response hand (Left, Right) repeated-measures ANOVA (for descriptive statistics, see Table S1). This analysis revealed significant main effects of stimulus category, $F(1, 50) = 67.266$, $p = 8 \times 10^{-11}$, $\eta_p^2 = .574$, $BF_{inc} = 4 \times 10^7$, indicating faster responses for Humans compared to Objects, and response hand, $F(1, 50) = 9.943$, $p = .003$, $\eta_p^2 = .166$, $BF_{inc} = 15.818$, indicating faster responses for the dominant Right hand compared to the Left hand. There were also significant interaction effects of spatial location × response hand, $F(1, 50) = 45.033$, $p = 2 \times 10^{-8}$, $\eta_p^2 = .474$, $BF_{inc} = 6 \times 10^5$, Figure 2a, affordance × response hand, $F(1, 50) = 5.935$, $p = .018$, $\eta_p^2 = .106$, $BF_{inc} = 1.637$, Figure 2b, and stimulus category × affordance × response hand, $F(1, 50) = 40.145$, $p = 7 \times 10^{-8}$, $\eta_p^2 = .445$, $BF_{inc} = 2 \times 10^5$. In order to examine the spatial location and affordance effects further, planned comparisons between their corresponding Left and Right compatibility conditions for Humans and Objects and for Left and Right response hands were conducted separately via four separate paired-samples *t*-tests with Bonferroni-corrected alpha values of $0.05/4 = 0.0125$. We found significant spatial location effects, that is, faster responses in spatially compatible compared to spatially incompatible trials, for both Humans and Objects while responding with both Left and Right hands (Table 1). The analysis of affordance effects, on the other hand, revealed dramatically different results for Humans and Objects. While there were significant affordance effects, that is, faster responses for affordance-compatible compared to affordance-incompatible trials, for Objects for both Left and Right response hands, for Humans, there was a significant reverse-affordance effect for the Left-hand responses and a similar, but not significant, trend for the Right-hand responses (Table 1). These patterns suggest that, in this task,

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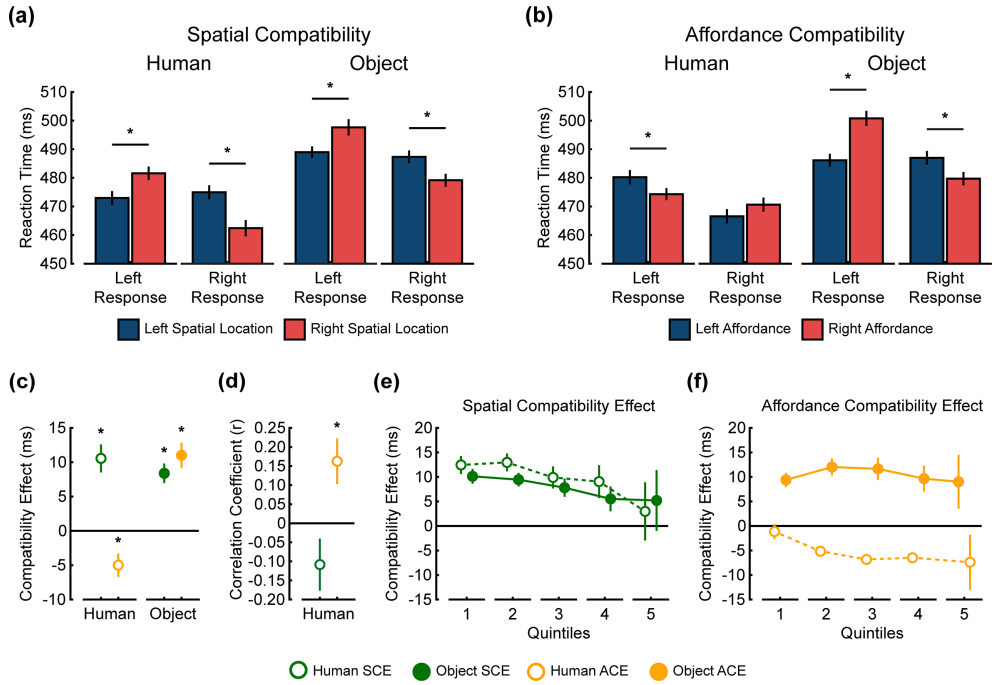


FIGURE 2 Spatial compatibility and affordance effects in Experiment 1. Average reaction times for human and object stimuli for left- and right-hand responses in left and right spatial compatibility (a) and left and right affordance compatibility (b) conditions. Asterisks in (a) and (b) denote statistically significant paired-samples *t*-tests at a Bonferroni-corrected alpha level of .0125 (Table 1). (c) Average Spatial Compatibility Effect (SCE) and Affordance Compatibility Effect (ACE) indices for human and object stimuli. Higher positive values indicate stronger compatibility effects. Asterisks in (c) denote statistically significant one-sample *t*-tests with a Bonferroni-corrected alpha level of .0125. (d) Average correlation coefficients between the Interactiveness-Communicativeness indices of the gestures and the SCE and ACE indices. Asterisks in (d) denote statistically significant one-sample *t*-tests with a Bonferroni-corrected alpha level of .025. Average SCE (e) and ACE (f) indices for human and object stimuli across quintiles. Error bars in all panels depict standard errors of the means.

there were imitative, mirror-compatible, as opposed to social affordance-compatible, responses towards human interactive gestures.

In the analysis described above, we did not find any interaction between spatial compatibility and affordance compatibility effects, suggesting that they can be examined independently from each other. To make a more direct comparison of the magnitudes of these effects for Humans and Objects, we calculated the Spatial Compatibility Effect (SCE) and Affordance Compatibility Effect (ACE) indices (see Data Analysis for details) and analysed them in a 2 effect type (SCE, ACE) × 2 stimulus category (Human, Object) repeated-measures ANOVA. There were significant main effects of effect type, $F(1, 50) = 18.197$, $p = 9 \times 10^{-5}$, $\eta_p^2 = .267$, $BF_{inc} = 36.971$, and stimulus category, $F(1, 50) = 16.012$, $p = 2 \times 10^{-4}$, $\eta_p^2 = .243$, $BF_{inc} = 47.959$, and more importantly, a significant interaction between effect type and stimulus category, $F(1, 50) = 34.487$, $p = 4 \times 10^{-7}$, $\eta_p^2 = .408$, $BF_{inc} = 10^7$, Figure 2c. Further investigation of this interaction via six planned comparisons with Bonferroni-corrected alpha values of $0.05/6 = 0.0083$ revealed that SCE for Humans and Objects and ACE for Objects did not significantly differ from each other, all $t(50) \leq 1.218$, $p \geq .229$, $BF_{10} \leq 0.185$, and they were all significantly greater than ACE for Humans, all $t(50) \geq 6.336$, $p \leq 7 \times 10^{-8}$, $d \geq 0.887$, $BF_{10} \geq 2 \times 10^5$. We also assessed these indices by comparing them to 0 via four separate one-sample tests with a Bonferroni-corrected alpha level of $0.05/4 = 0.0125$. These comparisons provided further support for the above findings, indicating significantly positive SCE indices for both Humans, $t(50) = 5.195$, $p = 4 \times 10^{-6}$, $d = 0.727$, $BF_{10} = 5 \times 10^3$, and Objects, $t(50) = 5.866$, $p = 4 \times 10^{-7}$, $d = 0.821$, $BF_{10} = 4 \times 10^4$. ACE indices were also significantly greater than 0 for Objects, $t(50) = 6.033$, $p = 2 \times 10^{-7}$, $d = 0.845$, $BF_{10} = 8 \times 10^4$; however, the same indices were

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TABLE 1 Descriptive statistics and the results of planned comparisons.

Experiment	Effect	Stimulus	Response	Compatibility		t	p	Cohen's d	BF_{10}
				Left	Right				
1	Spatial compatibility	Human	Left	473 ± 10	482 ± 11	−3.309	.002	−0.463	17.268
			Right	475 ± 11	462 ± 11	4.546	4×10^{-5}	0.637	599.976
		Object	Left	489 ± 11	498 ± 12	−2.971	.005	−0.416	7.376
			Right	487 ± 11	479 ± 12	3.587	8×10^{-4}	0.502	36.231
	Affordance compatibility	Human	Left	480 ± 11	474 ± 10	2.592	.012	0.363	3.086
			Right	467 ± 11	471 ± 11	−1.911	.062	−0.268	0.819
		Object	Left	486 ± 11	501 ± 12	−5.051	6×10^{-6}	−0.707	3×10^{3}
			Right	487 ± 11	480 ± 12	2.710	.009	0.379	4.007
2	Spatial compatibility	Human	Left	612 ± 27	617 ± 28	−0.896	.378	−0.173	0.294
			Right	619 ± 30	621 ± 32	−0.330	.744	−0.063	0.214
		Object	Left	621 ± 25	627 ± 25	−0.997	.328	−0.192	0.320
			Right	631 ± 29	638 ± 30	−1.547	.134	−0.298	0.586
	Affordance compatibility	Human	Left	598 ± 24	632 ± 32	−3.196	.004	−0.615	11.057
			Right	643 ± 36	599 ± 28	3.246	.003	0.625	12.300
		Object	Left	607 ± 24	642 ± 27	−3.623	.001	−0.697	28.177
			Right	662 ± 34	609 ± 26	4.005	5×10^{-4}	0.771	4×10^{-4}

Note: The left and right compatibility columns contain the mean ± standard error of the mean reaction time values in milliseconds. The degrees of freedom of the t-tests are 50 and 26 for Experiments 1 and 2, respectively.

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significantly lower than zero for Humans, $t(50) = 2.927$, $p = .005$, $d = 0.410$, $BF_{10} = 6.649$. These findings demonstrate that there are spatial compatibility and affordance compatibility effects of similar magnitude for object interactions, and spatial compatibility effects for human interactions are also of similar magnitude. Nevertheless, the ACE is reversed for human interactions, indicating the tendency to initiate imitative movements rather than complementary movements that social affordances would dictate.

Since we used three different interactive gestures and three different objects in our stimulus set, we also assessed whether the SCE and ACE indices differed among these different stimulus types. For Humans and Objects separately, we conducted a 2 effect type (SCE, ACE) × 3 stimulus type (for Humans: Handshake, Request, Arm-wrestling Handshake; for Objects: Mug, Teapot, Watering Pot) repeated-measures ANOVA. Stimulus type neither showed a main effect nor an interaction with effect type, Humans: all $F \leq 0.917$, $p \geq .403$, $BF_{inc} \leq 0.195$; Objects: all $F \leq 1.075$, $p \geq .345$, $BF_{inc} \leq 0.251$, Figure S1a, suggesting that the spatial compatibility and affordance effects were not influenced by different interactive gesture or object types. Having found different degrees of interactiveness versus communicativeness ratings among the gestures in a validation study, we performed additional analyses to assess the relationship between the perceived interactiveness versus communicativeness of the observed gestures and the strength of the SCE and the ACE indices they elicit. Specifically, for each subject, we calculated the SCE and ACE indices separately for each of the Female—Handshake, Female—Request, Female—Arm-wrestling Handshake, Male—Handshake, Male—Request and Male—Arm-wrestling Handshake gestures. We also calculated the Interactiveness-Communicativeness (I-C) indices of each gesture by subtracting the average communicativeness ratings from the average interactiveness ratings in the second validation study. We then calculated, for each participant, the correlation coefficient between these two sets of six values, separately for SCE and ACE. These two sets of correlation coefficient values were then tested against zero via two separate one-sample *t*-tests at the group level. These analyses showed that the correlation coefficients between the I-C and the ACE indices were significantly greater than zero, $t(50) = 2.719$, $p = .009$, $d = 0.381$, $BF_{10} = 4.092$, whereas no such effect was observed for the SCE indices, $t(50) = 1.589$, $p = .118$, $BF_{10} = 0.493$, Figure 2d. This finding indicates that gestures that were perceived to be more interactive than communicative elicited less strong reverse-affordance compatibility, that is, imitative effects.

Additionally, we tested whether the duration of the motor priming stimuli affected the magnitudes of the SCE and ACE indices. For this analysis, trials were separated into short (500–1000 ms) and long (1000–1500 ms) priming duration categories. A 2 effect type (SCE, ACE) × 2 stimulus category (Human, Object) × 2 priming duration (Short, Long) repeated-measures ANOVA showed that priming duration did not have a main effect or significantly interacted with any of the other variables, all $F \leq 1.581$, $p \geq .214$, $BF_{inc} \leq 0.324$, Figure S1b, suggesting that spatial compatibility and affordance effects were comparable across different priming durations.

Finally, we conducted quintile analyses to assess whether the magnitudes of spatial compatibility and affordance effects were modulated by responding speed (see Data Analysis for details). A 2 effect type (SCE, ACE) × 2 stimulus category (Human, Object) × 5 quintile (1, 2, 3, 4, 5) repeated-measures ANOVA did not show a main effect of quintile or any interaction between quintile and other variables, all $F \leq 2.583$, $p \geq .097$, $BF_{inc} \leq 0.152$, Figure 2e,f, suggesting that the speed of responses did not affect spatial compatibility and affordance effects.

Experiment 2

The analyses were conducted as reported in Experiment 1. A 2 stimulus category (Human, Object) × 2 spatial location (Left, Right) × 2 affordance (Left, Right) × 2 response hand (Left, Right) repeated-measures ANOVA on reaction times (for descriptive statistics, see Table S1) revealed a significant main effect of stimulus category, $F(1, 26) = 7.889$, $p = .009$, $\eta_p^2 = .233$, $BF_{inc} = 5.276$, indicating faster responses for Humans compared to Objects, as in Experiment 1. Surprisingly, in contrast to Experiment 1, there was no significant spatial location × response hand interaction effect, $F(1, 26) = 0.115$, $p = .737$,

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$BF_{inc} = 0.210$, Figure 3a, suggesting that when the responding was changed to releasing a key to make a grasping gesture, the spatial location effects that normally governed the simple keypress responses in Experiment 1 were completely vanished (Table 1). In addition, there was a significant affordance × response hand interaction, $F(1, 26) = 16.286$, $p = 4 \times 10^{-4}$, $\eta_p^2 = .385$, $BF_{inc} = 48.276$, Figure 3b, which was decomposed via planned comparisons comparing Left and Right affordance conditions for both Humans and Objects and for both Left and Right response hands separately. There was a strong affordance effect, that is, affordance-compatible responses were much faster than affordance-incompatible responses, for both Humans and Objects and for both Left and Right response hands (Table 1). We also conducted two separate 2 spatial location/affordance (Left/Right, Right/Left) × 2 response hand (Left, Right) repeated-measures ANOVAs on reaction times, one for Human and one for Object stimulus categories, to assess whether the lack of the spatial compatibility effect we observed could be due to the fact that only half of the trials (left spatial location/right affordance and right spatial location/left affordance) would guarantee a possible interaction with the stimulus since we asked participants to perform their responses towards the centre of the screen. Both of these analyses revealed significant interaction effects, both $F(1, 26) \geq 10.263$, $p \leq .004$, $\eta_p^2 \geq .283$, $BF_{inc} \geq 45.318$, in line with the affordance effect, not the spatial compatibility effect, that is, faster responses with the left hand for spatial right/affordance left compared to the spatial left/affordance right stimuli and the reverse pattern for the right-hand responses, all $t(26) \geq 2.571$, $p \leq .016$, $d \geq 0.495$, $BF_{10} \geq 3.112$, suggesting that the fact that only half of the trials included gestures or objects oriented to the centre of the screen could not explain the absence of the spatial compatibility effects. Taken together, these patterns of results demonstrate that framing the responses in a more interactive context flipped the imitative responses for human gestures

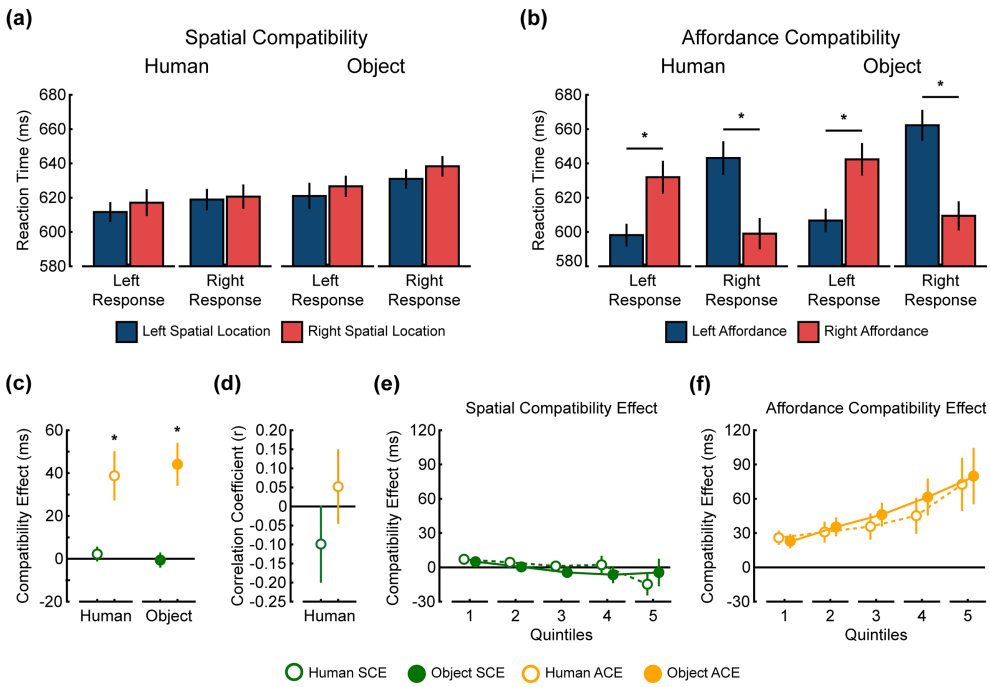


FIGURE 3 Spatial compatibility and affordance effects in Experiment 2. Average reaction times for human and object stimuli for left- and right-hand responses in left and right spatial compatibility (a) and left and right affordance compatibility (b) conditions. Asterisks in (a) and (b) denote statistically significant paired-samples *t*-tests at a Bonferroni-corrected alpha level of .0125 (Table 1). (c) Average Spatial Compatibility Effect (SCE) and Affordance Compatibility Effect (ACE) indices for human and object stimuli. Higher positive values indicate stronger compatibility effects. Asterisks in (c) denote statistically significant one-sample *t*-tests with a Bonferroni-corrected alpha level of .0125. (d) Average correlation coefficients between the Interactiveness-Communicativeness indices of the gestures and the SCE and ACE indices. Average SCE (e) and ACE (f) indices for human and object stimuli across quintiles. Error bars in all panels depict standard errors of the means.

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that were prominent in the simple keypress task of Experiment 1 and yielded strong complementary action tendencies that social affordances elicit.

The analysis of the SCE and ACE indices corroborated the above findings. A 2 effect type (SCE, ACE) × 2 stimulus category (Human, Object) repeated-measures ANOVA showed only a significant main effect of effect type, $F(1, 26) = 15.670$, $p = 5 \times 10^{-4}$, $\eta_p^2 = .376$, $BF_{inc} = 53.485$, Figure 3c. Planned comparisons confirmed these findings by indicating no significant difference between Humans and Objects, either for SCE, $t(26) = 0.561$, $p = .580$, $BF_{10} = 0.235$, or for ACE indices, $t(26) = 0.816$, $p = .422$, $BF_{10} = 0.276$. ACE indices were significantly greater than SCE indices for both stimulus categories, all $t(26) \geq 3.204$, $p \leq .004$, $d \geq 0.617$, $BF_{10} \geq 11.231$. ACE indices were also significantly greater than 0 for both Humans, $t(26) = 3.375$, $p = .002$, $d = 0.649$, $BF_{10} = 16.261$, and Objects, $t(26) = 4.403$ $p = 2 \times 10^{-4}$, $d = 0.847$, $BF_{10} = 171.139$, whereas SCE indices were not, Humans: $t(26) = 0.646$, $p = .524$, $BF_{10} = 0.247$; Objects: $t(26) = 0.173$, $p = .864$, $BF_{10} = 0.207$.

As in Experiment 1, stimulus type did not show a main effect or an interaction with effect type, Humans: all $F \leq 3.537$, $p \geq .054$, $BF_{inc} \leq 2.066$; Objects: all $F \leq 0.934$, $p \geq .399$, $BF_{inc} \leq 0.245$, Figure S1c, suggesting no influence of different interactive gesture or object types on spatial compatibility or affordance effects. The correlations between the perceived interactiveness versus communicativeness of the observed gestures and the strength of the SCE and the ACE indices they elicit were also not significant, SCE: $t(26) = 0.976$, $p = .338$, $BF_{10} = 0.314$; ACE: $t(26) = 0.532$, $p = .599$, $BF_{10} = 0.232$, Figure 3d. The duration of the motor priming stimulus also did not have a main effect or significantly interact with any of the other variables, all $F \leq 3.739$, $p \geq .064$, $BF_{inc} \leq 1.501$, Figure S1d, in line with Experiment 1.

Quintile analyses via a 2 effect type (SCE, ACE) × 2 stimulus category (Human, Object) × 5 quintile (1, 2, 3, 4, 5) repeated-measures ANOVA revealed a significant interaction between effect type and quintile, $F(1.17, 30.46) = 8.550$, $p = .005$, $\eta_p^2 = .247$, $BF_{inc} = 5 \times 10^3$, Figure 3e,f, which was further decomposed via four separate repeated-measures ANOVAs with quintile as the only within-subjects variable. There was no significant effect of quintile on SCE indices for either Humans, $F(2.03, 52.66) = 2.995$, $p = .058$, $BF_{inc} = 1.840$, or Objects, $F(1.79, 46.56) = 0.505$, $p = .586$, $BF_{inc} = 0.054$, whereas the effect of quintile on ACE indices was significant for both Humans, $F(1.32, 34.21) = 5.102$, $p = .022$, $\eta_p^2 = .164$, $BF_{inc} = 32.523$, and Objects, $F(1.34, 34.89) = 5.029$, $p = .022$, $\eta_p^2 = .162$, $BF_{inc} = 30.787$. For both stimulus categories, polynomial contrasts supported linear relationships between quintiles and ACE indices, Humans: $t(104) = 4.157$, $p = 7 \times 10^{-5}$; Objects: $t(104) = 4.459$, $p = 2 \times 10^{-5}$. These findings indicate that affordance effects became stronger as responses to both interactive gestures and objects became slower, an effect that did not occur in Experiment 1.

DISCUSSION

The present study investigated how affordance effects are differentiated from spatial compatibility effects during the initiation of two different response types—keypresses and grasping actions—towards interactive gestures and objects. The strong spatial compatibility effects we observed similarly for both human and object stimuli when responses were given by simply pressing keys on the keyboard in the first experiment completely disappeared when participants were asked to perform key release followed by grasping gestures in the second experiment. In contrast, we found significant object affordance effects, irrespective of the response type used in the two experiments. Facilitation of affordance-compatible complementary responses was only observed when performing grasping actions in the second experiment, while there was a reversed social affordance effect, that is, facilitation of mirror-congruent imitative tendencies, when the responses were simple keypresses in the first experiment. The length of the motor priming period did not modulate these effects.

Our findings regarding strong and independent spatial compatibility and affordance effects in keypress responses further corroborated previous studies testing these two effects simultaneously in similar tasks for objects (Iani et al., 2011, Experiment 1; Symes et al., 2005, Experiment 1). We further revealed, for the first time in the literature, that the magnitude of this spatial compatibility effect

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was comparable for social agents and inanimate objects, which suggests that indeed the position of a stimulus in our visual field, rather than its action capabilities or other complex characteristics, is the critical factor governing the cognitive processes leading to the spatial compatibility effect observed in keypress responses. The complete absence of the spatial compatibility effect for both stimulus categories when responses were switched to performing grasping gestures was surprising, indicating a critical role in how the task is framed and/or responses are performed. Framing the task as a social interaction in which the participants were asked to perform key release followed by handshake gestures towards a manipulandum, which led to the presentation of spatially and directionally compatible or incompatible handshake or arrow stimuli, Flach et al. (2010) reported significant spatial compatibility effects only when the participants could not see their own actions. The absence of the spatial compatibility effect when their responses were visible to themselves is in parallel with the results of our study, in which the participants' responses were also visible. Iani et al. (2011, Experiment 2) reported significant spatial compatibility effects when participants were asked to release a key on the keyboard and reach and touch the ipsilateral touch screen area to respond to everyday objects, yet their analysis revealed significant interactions with object affordance effects, yielding a smaller spatial compatibility effect in affordance-compatible conditions. One methodological difference that might potentially explain the discrepancy between our and Iani et al.'s findings is that we explicitly asked our participants to give their responses as if they were grasping the handle of the objects or the hands of the humans they observed, whereas Iani et al. used a similar reaching response but did not explicitly frame the task as acting on the observed objects. Taken together, these discussions suggest that the framing of the performed action as an interaction, rather than the specific reaching or grasping action that is performed, might be the critical factor that leads to the elimination of the spatial compatibility effect. Nevertheless, it should also be noted that not only how the final responses were given but also the actions that were being performed when the motor priming stimuli were shown differed between the two experiments. That is, in the first experiment, the participants did not actively perform any action during the priming stage, whereas in the second experiment, the participants held down on keyboard keys with both index fingers during the presentation of the motor priming stimulus. Thus, it is possible that the presence of an action already being performed simultaneously in both hemifields might have been responsible for the absence of a spatial compatibility effect in the second experiment. Another methodological factor that might have led us to not find a spatial compatibility effect in the second experiment might be the fact that we asked the participants to perform their responses towards the centre of the screen. It is possible that we would have observed a significant spatial compatibility effect if we were to ask participants to perform their grasping gestures towards where the image was shown—on the left or right side of the screen—in each trial.

Note that, in addition to not observing a spatial compatibility effect, we also did not find a main effect of the response hand in the second experiment, in contrast to the faster right-hand compared to the left-hand responses in the first experiment, as would be expected for right-handed individuals. Can the lack of these two effects be related? We do not hold the opinion that the lack of the spatial compatibility effect could be explained by or can help explain the lack of the main effect of the response hand in the second experiment. This is because clear spatial compatibility effects were revealed for both left- and right-hand responses even when there was a clear main effect of the response hand in the first experiment. Instead of one causing the other one, we believe that the lack of both the spatial compatibility effect and the main effect of response hand in the second experiment might have been caused by a common factor, which is the activation of motor programs related to key releases and/or performing grasping gestures, instead of simple keypresses as in the first experiment. Responses were initiated slower in the second ($M = 635$, $SD = 161$ ms) than in the first experiment ($M = 482$, $SD = 80$ ms). Thus, the dominant right-hand advantage in responding might be revealed strongly only when responses are initiated relatively faster, as in the keypress responses in the first experiment, and this effect might wash out when the responses are initiated relatively later, as in the second experiment. Similarly, relatively late responses might wash out the spatial compatibility effects that would be more strongly observed in faster reactions, which might explain our differential findings in the two experiments.

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The significant object affordance effects we observed not only for grasping but also for simple keypress responses suggest that processing object affordances might be a relatively more basic process that influences our actions irrespective of the nature of the goals of those actions (see Bub & Masson, 2010 for opposing arguments). Several studies showed that the object affordance effect is only seen when the task-relevant cue represents a functional characteristic of the objects, such as their functional category (e.g. kitchen or garage; Saccone et al., 2016, Experiment 1; Symes et al., 2005, Experiment 1), or a feature that affects how the observers would interact with those objects, such as their vertical orientation (Iani et al., 2011; Pellicano et al., 2010, Experiment 2; Saccone et al., 2016, Experiment 3; Tucker & Ellis, 1998). Conversely, when the task-relevant cue is colour, which is generally accepted to be unrelated to the function of the objects or the observers' possible interactions with those objects, the affordance effect is absent (Cho & Proctor, 2010; Pellicano et al., 2010, Experiment 1; Saccone et al., 2016, Experiment 2; Symes et al., 2005, Experiment 3; Tipper et al., 2006; but see Phillips & Ward, 2002). Replicating object affordance effects in two experiments by using colour cues as the task-relevant stimulus characteristic, our findings conflict with these earlier reports. This discrepancy might be due to one critical methodological difference between our study and the other studies reported in the literature. We applied the colour mask to only the affordance-related features, that is, the handles, of the objects, as opposed to the whole object, which might have selectively activated goal-oriented object representations by drawing attention to the affordable object features. In a similar vein, Cho and Proctor (2013) investigated spatial compatibility effects for door handle stimuli by localizing the colour mask to either the tip (the graspable side), the middle, or the base (the non-graspable side) of the handle. Similar to our findings, they found faster keypress responses for the congruent hands when the colour mask was applied to the tip of the door handles. Conversely, they found the opposite behavioural facilitation effects when the colour mask was applied to the base of the door handles, which they interpreted as showing the location of the task-relevant colour cue activates spatial codes, which produce a local spatial compatibility effect within the stimulus, rather than affordance-related effects. It should also be noted that although we found similar affordance compatibility effects in both experiments, the effect was much smaller for keypress responses than for grasping actions, and the quintile analyses revealed dramatically different temporal profiles for the effects in the two experiments. Specifically, only in the second, and not in the first, experiment, we found larger object affordance effects for slower reaction times, in line with other studies reporting an increase in object affordance effect for late responses (Derbyshire et al., 2006; Riggio et al., 2008; Tucker & Ellis, 2001), suggesting the possibility that the two effects we observed in two experiments might have in fact stemmed from different cognitive processes. Considering this set of findings together with Cho and Proctor's (2013) reports, it is possible that the seemingly affordance-compatible findings we revealed for the keypress responses in the first experiment did indeed stem from the colour masks applied to the handles of the objects leading to local spatial compatibility effects (e.g. a coloured right handle of an object facilitating a right-sided response not because of its affordances for the right hand, but because of a local rightward spatial flagging; Cho & Proctor, 2010, 2011, 2013). On the other hand, the behavioural facilitation effects we observed for grasping responses in the second experiment might truly indicate affordance processing. Follow-up studies applying colour masks to the entire object in the same task design might shed further light on these processes.

Regarding social affordance effects, contrary to our initial predictions, the keypress responses in the first experiment yielded a clear reversed affordance, that is, the imitative facilitation effect for interactive hand gestures. Furthermore, within the narrow range of interactiveness versus communicativeness of the gestures we used in the present study, less interactive gestures elicited stronger imitative tendencies, suggesting the possibility that a subtle social affordance effect might have acted against the imitative tendencies for strongly interactive gestures in the simple keypress task. These findings are partly in line with the Curioni et al. (2020) study, which reported faster keypress responses when the observed hand gestures were spatially compatible with the response side. Critically, this effect was reduced for interactive gestures (e.g. handshake) compared to communicative gestures (e.g. thumbs-up gesture), indicating slight facilitation of affordance-compatible complementary, not spatially compatible, responses in the interactive context. Nevertheless, we believe that the stimuli and the design used in the Curioni

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et al. study made it impossible to dissociate whether the observed effects stemmed from spatial compatibility or from imitation effects. To be more specific, the bodies of the humans in their stimuli were centrally located such that the hand that was performing the gesture would be on the left and right sides of the screen for the right and left hands, respectively. Thus, for instance, a right hand extended for a handshake might have facilitated left-hand responses due to either its spatial compatibility or its mirror-congruent imitative compatibility, raising a confounding factor in the interpretation of the findings. The stimuli and the task we employed overcame this shortcoming by independently manipulating the spatial and imitative compatibility of the observed gestures, revealing strong and non-interacting spatial compatibility and imitation effects for keypress responses in the first experiment.

In contrast to the imitative action tendencies revealed in the first experiment, when responses were framed in an interactive context, we found strong social affordance effects in the second experiment. Our findings mainly corroborate previous studies revealing similar effects using dynamic handshake responses (Farmer et al., 2021; Flach et al., 2010) or performing (or imitating) the observed gestures (Faber et al., 2016; Liepelt et al., 2010). Taken together, these results underline the pivotal role of active action representations in eliciting social affordance effects, which help explain the absence of social affordance effects for keypress responses in the first experiment. That is, the strong social affordance effects we found in the second experiment are perhaps due to the fact that participants were explicitly requested to execute grasping gestures towards the hands of the individuals they saw on the screen. The fact that no social affordance effect was observed in the first experiment when the responses were not explicitly framed as performing an interactive gesture towards the screen bolsters this argument. Furthermore, by showing social affordance effects using colour as the task-relevant information, we add to the limited number of studies revealing social affordance effects with a variety of task-relevant cues, such as colour (Faber et al., 2016), letter cues (Curioni et al., 2020), numerical cues (Farmer et al., 2021; Liepelt et al., 2010), pre-cued gender (Flach et al., 2010) and stimulus distance (Faber et al., 2016). These reports suggest that, unlike object affordance effects, social affordance effects might be relatively insensitive to the specific task-relevant cue used in a particular study. The temporal profile of the social affordance effect has not previously been analysed via quintile or similar analyses. Few studies investigating the temporal profile of imitation effects revealed that the effects were larger for later responses (Brass et al., 2001; Catmur & Heyes, 2011). In contrast, our quintile analysis revealed uniform imitation effects in the first experiment, whereas the social affordance effect in the second experiment was strongly modulated by the reaction times, revealing larger effects in later responses. This pattern observed for the social affordance effect was identical to the one observed for the object affordance effect in the second experiment and was also in line with other reports regarding object affordance effects (Derbyshire et al., 2006; Riggio et al., 2008; Tucker & Ellis, 2001), suggesting that the object and social affordance effects might be behavioural manifestations of the same underlying cognitive processes, simply elicited by different types of cues. Larger effects for later responses indicate that these behavioural effects are caused by relatively late cognitive processes such as response selection.

The opposing action tendencies we report for different response types during the observation of the same interactive gestures contribute to long-lasting discussions on the emergence of imitative and complementary behaviours in social contexts. These behaviours are often compared with each other to explore how opposing action tendencies can be generated depending on the nature of the goal of the social interactions. Imitation is widely assumed to be an automatic process such that the observation of an action unconsciously lays the ground for the execution of the same action through direct motor mapping (Bertenthal et al., 2006; Brass et al., 2000, 2001; Craighero et al., 2002; Stürmer et al., 2000). Complementary behaviours, on the other hand, emerge in goal-directed social interactions where direct imitation or mirroring of others' behaviours is not functional in accomplishing the goal (Sartori & Betti, 2015). Joint action contexts typically require non-imitative behaviours where two individuals complement each other's actions, such as moving a large table by working together (Sebanz et al., 2006). Accordingly, several studies reported context-related modifications of complementary or identical (imitative) responses towards observed actions in reciprocal contexts (Newman-Norlund et al., 2007; Ocampo & Kritikos, 2010; van Schie et al., 2008). For instance, Ocampo and Kritikos (2010) asked their

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participants to perform identical or complementary actions in response to the observation of another individual holding a wine glass either by the rim or by the stem and showed that identical or opposite action tendencies were enhanced depending on whether the context was imitative or complementary. In the present study, we used interactive gestures, which, in real-life interactions, naturally elicit complementary, rather than imitative, responses. Nevertheless, we showed that the perception of these actions alone was not sufficient to generate complementary response tendencies under all circumstances. Instead, perception of the context as an interaction and/or performance of grasping actions was necessary. Whether imitative processing of others' actions is the default mode of processing that needs to be actively suppressed for complementary actions in interactive contexts or whether one of the two modes of processing does not precede the other but is selected based on the context remains to be examined by future studies.

Can the responses we refer to as complementary instead be anatomically congruent imitative responses? There is an abundance of research converging on the conclusion that natural observation of others' actions from a third-person perspective in the absence of any explicit instructions leads strongly to specular (mirror) rather than anatomical (non-mirror) imitation tendencies both in children (e.g. Bekkering et al., 2000) and adults (Bertenthal et al., 2006). For instance, using a bimanual task in which participants' imitation tendencies were measured between the left and right hands, Franz et al. (2007) revealed a strong natural tendency to imitate in the mirror mode, which could be reversed by altering the sensory information presented to the participants. Furthermore, Koski et al. (2003) showed that the important nodes of the mirror neuron system—bilateral inferior frontal and right posterior parietal cortices—were more active when participants imitated the observed actions in the mirror compared to the anatomical mode. Taken together, given that our stimuli depicted natural hand gestures from the third-person perspective with no additional sensory alteration and that our task did not specifically instruct the participants to imitate the observed actions in the anatomical mode, we strongly believe that the action tendencies we observed in the second experiment were complementary, as opposed to being imitative in the anatomical mode. Nevertheless, a conclusive empirical assessment of these two alternatives would require a study that utilizes either interactive and non-interactive gestures that would enable making differential predictions according to the complementarity and the anatomical imitation hypotheses or interactive actions that would require not identical but a different complementary gesture (e.g. a precision grip in response to a power grip) that would again enable differentiating the two hypotheses from each other.

Although our study provides an in-depth examination of the spatial compatibility and affordance effects of social and object interactions, it is important to acknowledge some limitations that might potentially affect the interpretation of our results. Firstly, our social stimuli were restricted to interactive gestures; the inclusion of non-interactive gestures, which would be expected to elicit imitative but not complementary action tendencies, would have enabled a more detailed examination of the dynamic interplay between these effects. In addition, we only used two different response types—keypress and key release, followed by grasping gestures performed towards the screen as if grasping the handle of the objects or the hands of the individuals. It remains an open empirical question whether the critical determinant of strong affordance effects is framing the context as an interaction or merely requiring the participant to perform a dynamic motor program irrespective of its goal.

CONCLUSION

Our results indicate that perception of objects and human actions trigger behavioural tendencies that are strongly influenced by their spatial location and intrinsic functional characteristics, as well as the type of actions with which we plan to respond. Regarding social interactions, engaging in interactive action plans with others prompts behaviours that complement the actions of others, whereas relatively more passive forms of observation induce mirror-like facilitation of imitative processing. These imitative and complementary behaviours are deeply intertwined into our social interactions, to the

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extent that engaging in one or the other influences people's attitudes and feelings towards each other depending on the context (Hess et al., 1999; Tiedens & Fragale, 2003). Hence, our findings provide significant contributions to the efforts to understand the perceptual, affective and motor processes underlying complex reciprocal and cooperative interactions between individuals.

AUTHOR CONTRIBUTIONS

Pınar Demir: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; software; visualization; writing – original draft; writing – review and editing. **Melda Sandıkçı:** Data curation; investigation; resources; writing – review and editing. **Eda Demir:** Data curation; investigation. **Efe Soyman:** Conceptualization; data curation; formal analysis; methodology; project administration; software; supervision; validation; visualization; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

All authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available at Open Science Framework (https://doi.org/10.17605/OSF.IO/M7YA6).

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