***Seeing social events: The visual specialization for dyadic human-
human interactions***

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Abstract

Detection and recognition of social interactions unfolding in the surroundings is as vital as detection and recognition of faces, bodies, and animate entities in general. We have demonstrated that the visual system is particularly sensitive to a configuration with two bodies facing each other as if interacting. In four experiments using backward masking on healthy adults, we investigated the properties of this dyadic visual representation. We measured the inversion effect (IE), the cost on recognition, of seeing bodies upside-down as opposed to upright, as an index of visual sensitivity: the greater the visual sensitivity, the greater the IE. The IE was increased for facing (vs. nonfacing) dyads, whether the head/face direction was visible or not, which implies that visual sensitivity concerns two bodies, not just two faces/heads. Moreover, the difference in IE for facing vs. nonfacing dyads disappeared when one body was replaced by another object. This implies selective sensitivity to a body facing another body, as opposed to a body facing *anything*. Finally, the IE was reduced when reciprocity was eliminated (one body faced another but the latter faced away). Thus, the visual system is sensitive selectively to dyadic configurations that approximate a prototypical social exchange with two bodies spatially close and mutually accessible to one another. These findings reveal visual configural representations encompassing multiple objects, which could provide fast and automatic parsing of complex relationships beyond individual faces or bodies.

Keywords: body perception, event perception, scene perception, social cognition, configural processing, body-inversion effect.

Public Significance Statement

This study shows that human vision is particularly sensitive to stimuli and scenes with high social value. In particular, we provide evidence for the existence of an internal visual representation that approximates a prototypical social exchange, where two spatially close bodies appear to engage in a reciprocal action. This multi-body representation may constitute the intermediate step between body perception and domain-specific inferential processes that lead to social action understanding.

Introduction

In the last decades, research in vision and cognitive science has demonstrated that the human attentional/perceptual system is attuned to detect and recognize visual stimuli with high social value, most notably the conspecifics' faces and bodies (Bindemann, Scheepers, Ferguson, & Burton, 2010; Downing, Bray, Rogers, & Childs, 2004; New, Cosmides, & Tooby, 2007; Ro, Russell, & Lavie, 2001; Stein, Sterzer, & Peelen, 2012). Thus, in complex, cluttered scenes, a human body is detected with the highest priority. Such benefit is thought to be mediated by perceptual mechanisms that can rapidly access the global configuration of multi-part objects such as bodies and faces, without prior part-by-part analysis (Diamond & Carey, 1986; Rhodes, Brennan, & Carey, 1987; Maurer, Le Grand, & Mondloch, 2002).

As important as recognition of bodies is recognition of unfolding social exchanges. Third-party interactions may require the observer to rapidly activate adaptive responses (e.g., for defense or assistance) and inferences on social roles and norms (Quadflieg & Koldewyn, 2017). Thus, perceptual adaptations, similar to those for face and body perception, might have evolved to favor detection and recognition of social interactions.

Previous research has shown that spatial relations among objects affect object recognition (Green & Hummel, 2006; see also Baeck, Wagemans, & Op de Beeck, 2013; Kim & Biederman, 2010; Roberts & Humphreys, 2010). In particular, two objects are recognized more accurately when they appear to interact in a functional way (a pitcher tilted toward a glass as if pouring into it),

than when they are presented as independent, unrelated items (e.g., a pitcher tilted away from a glass; Green & Hummel, 2006).

Those findings encouraged the hypothesis that spatial relations among bodies could affect body perception; particularly, bodies in spatial relations that cue social interaction could be processed more efficiently than in other types of configurations. A recent study has offered initial support to this hypothesis (Papeo, Stein & Soto-Faraco, 2017). In that study, recognition performance was disproportionately impacted by inversion (i.e., the presentation of stimuli upside-down) for two bodies facing each other as if interacting, and significantly less so for two bodies facing away from each other.

The cost of inversion, or inversion effect (IE), is significantly higher for single bodies (and faces) than for other object classes (Bruyer, 2011; Reed, Stone, Bozova, & Tanaka, 2003; Stein et al., 2012; Yin, 1969). This phenomenon has been linked to specialized perceptual mechanisms that rapidly access the global configuration of multi-part objects based on the spatial relations between parts, without prior part-by-part analysis (Diamond & Carey, 1986; Rhodes et al., 1987; Maurer et al., 2002). Whether this specialization is selective to certain object classes (Kanwisher, McDermott, & Chun, 1997; Rezlescu, Barton, Pitcher, & Duchaine, 2014), or reflects a type of particularly efficient processing that can apply to any well-experienced object class (Ashworth III, Vuong, Rossion, & Tarr, 2008; Gauthier, Skudlarski, Gore, & Anderson, 2000; Richler, Mack, Palmeri, & Gauthier, 2011; Sekuler, Gaspar, Gold, & Bennett, 2004), is debated. Beyond multiple, open debates, the implication for the IE remains that the perceptual system is particularly sensitive to (i.e. is particularly efficient at processing) the

shape of the stimulus in its canonical (upright) appearance, as defined by parts and, more importantly, relations among parts.

The study by Papeo et al. (2017) showed that specialized mechanisms, as indexed by the IE, could apply to the perception of two interacting bodies as well as faces and bodies. The authors proposed that, by virtue of their relative positioning cuing an interaction, two facing bodies could be processed as a structured unit, to which the visual system is particularly sensitive. More precisely, under the hypothesis that the IE reflects the extent to which object recognition relies on the spatial relations among its parts, the analysis of spatial relations could be particularly central for scenes in which parts are perceived as belonging to the same structure (e.g., facing dyads).

The hypothesis that there are perceptual adaptations for detection and recognition of social interaction implies that the visual sensitivity to dyadic configurations is: a) category-specific, in the sense that it applies to body dyads as opposed to any pair of seemingly related objects (i.e., body-object or object-object pairs); and 2) domain-specific, in the sense that it concerns representations of social interaction as opposed to any action-mediated relation. The current study speaks to these issues.

First, we asked what physical stimulus evokes visual sensitivity. In body perception, the head is processed with higher priority relative to other body parts (Bindemann et al., 2010). Moreover, in discriminating individual body postures, the face-area could account on its own for the cost of body inversion on performance (Brandman & Yovel, 2012; Yovel, Pelc, & Lubetzky, 2010). Thus, the visual sensitivity captured by the two-body IE (Papeo et al., 2017) could concern

two facing heads/faces rather than two facing bodies. Recasting this issue, we asked what happens to the two-body IE when the information about head positioning was made unavailable (Experiment 1). Second, we asked whether the visual sensitivity to dyadic configurations is triggered by the perception of a body in a relation with another body, or a body in a relation with *anything*. To address this, we measured the IE for facing and nonfacing dyads, and compared it with the IE obtained for pairs involving a body facing toward *versus* away from a non-body object (Experiments 2-3). Finally, under the hypothesis that human visual perception is particularly sensitive to two bodies in a relation, we investigated whether visual perception is sensitive to dyadic configurations with bodies in any action-mediated relation, or to mutually accessible bodies, seemingly engaging in a reciprocal exchange –i.e., the prototype of social interaction. We compared the magnitude of IE for dyads with two bodies facing one other *versus* dyads where one body faced the other but the latter faced away. In the latter condition, the two bodies enjoy a unidirectional relation, where one acts over the other, with no reciprocity (Experiment 4).

Across all the experiments, we evoked the IE in a visual-categorization task, with stimuli presented for a short time (30 ms). Short stimulus presentation and backward masking were used to reduce stimulus visibility and emphasize the cost of inversion. Critical comparisons were performed between stimulus groups that were matched for all visual features except the relative positioning. That is, for each facing pair involving two given items, there was a nonfacing pair involving the same two items. We expected the difference between facing and nonfacing conditions to be driven by a different performance with inverted trials, which reflects the cost of inversion.

To allow the categorization task, trials involving bodies were interleaved with trials involving non-body objects. We recorded response accuracy and reaction times (RTs), and measured the IE as an index of visual sensitivity.

Methods

Experiment 1

Experiment 1 investigated whether the two-body IE was modulated by the positioning of two bodies in a dyad (facing/nonfacing), when positioning was determined by the full body *versus* the body-minus-head. If the heads alone triggers the two-body IE, the difference in the IE for facing *versus* nonfacing dyads should be reduced or abolished in the latter condition.

Participants

Thirty-one healthy adults with normal or corrected-to-normal vision (18 female, mean age 22.22 years $\pm$ 2.04) participated as paid volunteers. All participants in this and the following studies signed a consent form approved by the local ethics committee. Experiment 1 was exploratory with respect to the sample size. Sensitivity power analysis (*GPower* 3.1) estimated a minimum detectable effect (i.e., the smallest true effect, which would be statistically significant with *alpha* 0.05, and *power* β 0.80) of $\eta_p^2 = 0.06$ for the category by positioning by orientation interaction in a within-subjects design with a sample size of 31. The actual effect size of this interaction in Experiment 1 was used to evaluate the appropriateness of the sample size to obtain a similar effect size in the following experiments.

Stimuli and apparatus

Stimuli involved greyscale renderings of human figures (Table 1; for an illustration of the stimuli, see also Supplementary figure Fig. S1). Using Daz3D (Daz Productions, Salt Lake City, UT) and the Image Processing Toolbox in MATLAB (The MathWorks, Natick, MA), we created thirty facing dyads, each depicting two of eight different bodies (bodies in different poses), and thirty nonfacing dyads, created by swapping the position of the two figures in each facing dyad. The distance between the two bodies in a dyad was matched across facing and nonfacing stimuli. In particular, the centers of the two minimal bounding boxes that contained each figure of a dyad were equally distant from the center of the display, for all dyads (1.8° visual angle), and the distance between the closest points of the two bodies was comparable for facing and nonfacing dyads (1.22° and 1.24° visual angle on average, respectively). By flipping those dyads, we obtained 60 new dyads, for a total of 60 facing and 60 nonfacing dyads. This stimulus set was used across all the experiments, when facing and nonfacing body dyads were included in the design (Experiment 1, 2a, 4; see Table 1). Only for the current Experiment 1, in the flipped versions of the images, the areas around the heads of both figures were blurred using the Gaussian blurring function of the MATLAB Image Processing Toolbox. From the set of original and head-blurred images, inverted stimuli were created rotating each image by 180° .

A similar procedure was used to create 60 facing and 60 nonfacing pairs, each including two of six models of chairs (mean distance from center: 2° visual angle; mean distance between the two closest points: 1.64° visual angle), and

120 pairs of plants, each including two of six renderings of plants (mean distance from center: 1.63° visual angle; mean distance between the two closest points: 0.66° visual angle). All stimuli subtended approximately 6° of visual angle and were shown on a grey background. Masking stimuli were high-contrast Mondrian arrays ($11^\circ \times 10^\circ$) of grey-scale circles (diameter 0.4° - 1.8°). Stimuli were viewed from a distance of 60 cm. They were displayed on a 17-in. CRT monitor (1024 x 768 pixel resolution, 85-Hz refresh rate) controlled with the Psychophysics Toolbox extensions (Brainard, 1997) run on MATLAB. Data analyses were carried out with MATLAB and Statistica (TIBCO Software Inc.).

Procedure

Participants were seated on a height-adjustable chair in front of a computer screen, with their eyes aligned to the center of the screen where stimuli were shown. For each trial, they were instructed to decide whether they had seen bodies, chairs or plants, as accurately and fast as possible. In each trial, they saw a blank display (200 ms), fixation cross (500 ms), blank (200 ms), target-stimulus (30 ms), mask (250 ms) and, finally, blank until a response was given. The next trial began after a variable interval between 500 and 1000 ms.

Participants responded by pressing a key on the computer keyboard in front of them. Half of participants pressed “1” with the index finger for “body” and “2” with the middle finger for “chairs”. The opposite mapping was used for the remaining participants. All pressed a third key (the spacebar) with the left index finger, for “plants”. While bodies and chairs can face/face away from one another, plants do not. Thus, plants were included as fillers to relate the current experiment to the experiments in Papeo et al. (2017), but they were not included

in the factorial design. The task was divided in two runs, each containing the same number of stimuli per condition (720: 240 body dyads, 240 chair pairs, and 240 plant pairs), presented in a random order. Every 30 trials participants were invited to take a break. Two blocks of familiarization were presented before the experiment, to familiarize the participants with stimuli and task. In the first block, four stimuli per condition were shown for 250 ms, so that the participants could see the stimuli clearly. In the second block, eight stimuli per condition were shown for 30 ms, like in the actual experiment. The instructions for the familiarization blocks were identical to those of the actual experiment. The whole experiment lasted about 45 min.

Results

Data from one participant were discarded due to a technical failure during the experimental session. The mean accuracy rates and/or RTs for the remaining 30 participants did not exceed 2.5 *SD* away from the group mean; therefore, they were all included in the final analysis.

Consistent with Papeo et al. (2017), participants' accuracy rates proved more sensitive than RTs, to the experimental manipulations. Across all the experiments, RTs either conformed to the pattern of accuracy data or showed no difference across conditions, which in either case ruled out a speed-accuracy trade-off. Poorer sensitivity of RTs to experimental manipulations, relative to accuracy, could reflect the nature of the task (e.g., fast stimulus presentation could discourage hesitations), and/or it could be a consequence of the relatively high number of errors made by the participants. Indeed, RT values for trials with incorrect responses were discarded (see Supplementary material); this might

have reduced the sensitivity to RT differences across conditions. A full report of the RT descriptive statistics and results is provided as Supplementary material (Tables S1-S3). Here, we focus on accuracy data.

The first analysis sought to test whether a stronger IE for facing than nonfacing pairs was found specifically with body-trials. To this end, accuracy data were entered into a 2 x 2 x 2 repeated-measures ANOVA with factors, category (body, chair), positioning (facing, nonfacing) and orientation (upright, inverted). In this analysis, original and head-blurred bodies were collapsed in the same conditions.

First and foremost, the ANOVA showed a significant three-way interaction between category, positioning and orientation, $F(1, 29) = 33.49, P < 0.001, \eta_p^2 = 0.54$, reflecting a stronger IE for facing than for nonfacing bodies, but no difference between facing and nonfacing chairs (Fig. 1A). The analysis also revealed a main effect of orientation, due to better performance in upright than inverted trials, $F(1,29) = 53.08, P < 0.001, \eta_p^2 = 0.65$; and a category by positioning interaction, $F(1, 29) = 19.20, P < 0.001, \eta_p^2 = 0.40$, showing a larger difference between facing and nonfacing body-dyads than between facing and nonfacing chair-pairs. Finally, there was a significant interaction between category and orientation, $F(1, 29) = 18.64, P < 0.001, \eta_p^2 = 0.39$, and a trend for an interaction between positioning and orientation, $F(1, 29) = 4.01, P = 0.05, \eta_p^2 = 0.12$. These interactions were qualified by the above three-way interaction.

To follow up on the significant three-way interaction, each category was examined separately, with a 2 positioning x 2 orientation repeated-measures ANOVA. The analysis on body-trials showed an effect of positioning, $F(1, 29) =$

13.13, $P = 0.001$, an effect of orientation, $F(1, 29) = 42.81$, $P < 0.001$, and an interaction between the two, $F(1, 29) = 16.92$, $P < 0.001$, $\eta_p^2 = 0.37$. This interaction showed that, although the IE was significant for both facing dyads, $t(29) = 6.77$, $P < 0.001$, and nonfacing dyads, $t(29) = 5.45$, $P < 0.001$, it was significantly larger for the former. As shown in Fig. 1A, the performance was comparable with upright facing and nonfacing dyads. Therefore, the difference in the IE was the result of a higher cost of inversion for facing than for nonfacing dyads.

The same analysis on chair-trials showed an effect of positioning, $F(1, 29) = 8.26$, $P < 0.01$, and of orientation, $F(1, 29) = 22.31$, $P < 0.001$, but no interaction between the two, $F(1, 29) < 1$, *n.s.* That is, in the case of chairs, the relative positioning did not affect the magnitude of the IE.

The second analysis addressed the relationship between the IE for dyads with display of full body *versus* dyads with blurred heads. A 2 body-type (blurred-head vs. full-body) x 2 positioning (facing vs. nonfacing) x 2 orientation (upright vs. inverted) repeated-measures ANOVA showed that the difference in the IE for facing and nonfacing dyads was not modulated by the availability of visual information about head direction. In particular, the analysis revealed a main effect of body-type, $F(1, 29) = 13.13$, $P < 0.01$, $\eta_p^2 = 0.31$, reflecting overall higher accuracy for full-body than for blurred-head trials; a main effect of positioning, $F(1, 29) = 42.81$, $P < 0.001$, $\eta_p^2 = 0.60$, with overall better performance for nonfacing than for facing trials; and a significant interaction between body and positioning, $F(1, 29) = 16.92$, $P < 0.001$, $\eta_p^2 = 0.37$, reflecting a larger difference between facing and nonfacing blurred-head dyads than

between facing and nonfacing full-body dyads. As anticipated above, the three-way interaction was far from significance, $F(1, 29) = 1.02$, $P > 0.25$, which implies that the IE was greater for facing than for nonfacing dyads in both the full-body and the blurred-head condition (Fig. 1B).

Even if conditions with blurred-heads and full-body were not statistically different, the difference with the non-body (chair) trials could have still been driven by full-body dyads. In other words, visual sensitivity might not be higher for bodies without faces relative to other objects. A new analysis ruled out this possibility. We compared the IE for chairs against the inversion effect for bodies with blurred heads only, in a 2 category (blurred-head body or chair) $\times$ 2 positioning (facing or nonfacing) $\times$ 2 orientation (upright or inverted) repeated-measures ANOVA. We found a significant interaction between the three factors, $F(1,29) = 19.76$, $P < 0.001$, $\eta_p^2 = 0.40$, showing that the IE was stronger for facing than for nonfacing blurred-head bodies $t(29) = 2.30$, $P = 0.03$, but did not differ between facing and nonfacing chairs, $t(29) = 0.60$, $P > 0.25$. Notably, the interaction between category and orientation was also significant, $F(1,29) = 19.97$, $P < 0.001$, $\eta_p^2 = 0.41$, demonstrating that the cost of inversion was overall larger for bodies than for chairs, even when heads were blurred. Other significant effects were qualified by the three-way interaction (effect of orientation: $F(1,29) = 58.23$, $P < 0.001$, $\eta_p^2 = 0.67$; category by positioning interaction: $F(1,29) = 24.56$, $P < 0.001$, $\eta_p^2 = 0.46$). The effect of category, $F(1,29) < 1$, *n.s.*, positioning, $F(1,29) = 2.15$, $P = 0.15$, and the interaction between positioning and orientation, $F(1,29) = 1.40$, $P = 0.24$, did not approach significance.

In sum, Experiment 1, using pairs of stimuli from the same class, converges with studies on single objects (e.g., Reed et al., 2003; Stein et al., 2012), in showing that the IE is the largest with bodies than with objects such as chairs (and plants¹). Moreover, Experiment 1 demonstrated that dyads of facing and nonfacing bodies were differently susceptible to the cost of inversion. In particular, the IE was reliably larger for facing than for nonfacing dyads, suggesting greater visual sensitivity to the former scenario. This pattern remained unchanged when stimuli had the heads blurred. Obviously, this result does not imply that, when available, information about head direction does not contribute to the effect of body positioning on the IE. However, it refutes the hypothesis that heads are uniquely accountable for the two-body inversion effect.

Experiment 2a

Results of Experiment 1 suggest that the visual system is selectively sensitive to one body facing another body; this circumstance implies a visual representation that would approach the representation of a social interaction. Experiment 2 aimed at ruling out the alternative hypothesis that the visual system is generally sensitive to scenarios with one body facing *anything*, that is, scenarios that imply a social relation (a body toward another) as well as a nonsocial relation (a body

¹ The accuracy with plant-trials was qualitatively better in the upright than in the inverted condition (means: 0.75 ± 0.006 SEM, 95% CI [0.67, 0.82] and 0.74 ± 0.006 SEM, 95% CI [0.65, 0.81], respectively). However, this difference was not significant, $t(29) = 1.21$, $P = 0.23$, and was smaller than the overall inversion effect observed with bodies across all conditions, $t(29) = 6.81$, $P < 0.001$.

toward an object). This issue was addressed by measuring the IE for facing and nonfacing dyads involving two bodies or one body and one object (i.e., a plant).

Participants

Thirty-one healthy adults with normal or corrected-to-normal vision (19 female, mean age 21.67 years $\pm$ 2.84 *SD*) participated as paid volunteers. We kept the same sample size of Experiment 1, which was larger than the required sample size ($N = 15$) to obtain an effect size of the three-way interaction (category by positioning by orientation), comparable to Experiment 1 ($\eta_p^2 = 0.54$, with β 0.80 and α 0.05; G*power 3.1). Having the same sample size, the sensitivity of this test for three-way interaction (i.e., the minimum detectable effect size) was equal to Experiment 1 (η_p^2 0.06, with β of 0.80, α 0.05).

Stimuli and apparatus

Stimuli included all the body trials used in Experiment 1 (60 facing dyads, 60 nonfacing dyads, and the same dyads rotated by 180°, with no blurring of any body area). By combining individual bodies with individual plants using the same procedure described for Experiment 1, the following new types of dyads were created: a body facing a plant ($N = 60$), a body facing away from a plant ($N = 60$), and the same dyads inverted upside-down ($N = 120$). Plants were chosen because they are familiar objects of a homogeneous class that, in the real-world size, cover approximately the same surface of the body that they replaced, and therefore, with comparable contrast level, they could be visible as much as bodies, under the current low-visibility condition.

To allow the categorization task, the stimulus set included 480 images displaying pairs of chairs (facing, nonfacing, upright and inverted; the same as in Experiment 1) or pairs with a chair facing or facing away from a plant (upright and inverted). In total, participants saw 960 images of homogeneous (240 featuring two bodies and 240 featuring two chairs) or mixed pairs (240 with body-plant pairs and 240 with chair-plant pairs). All stimuli subtended approximately 6° of visual angle and were shown on a grey background. Masking stimuli were the same as in Experiment 1.

Procedure

The experimental setup, the sequence and duration of events in a trial, and the task (basic-level categorization) were identical to Experiment 1. Differently from Experiment 1, in Experiment 2, participants had only two response options: they had to report whether, in each trial, they had seen bodies or chairs, irrespective of number (one or two), positioning (facing or nonfacing another item) and orientation (upright or inverted). They responded by pressing key 1 or key 2 with the right index and middle finger, respectively (for half of participants key 1 was for “body” and key 2 was for “chairs”; the opposite mapping was used for the other half). This change was implemented to limit the number of conditions and trials, and the experiment duration.

Results

Data from one participant were discarded due to a technical failure during the experiment. The mean accuracy rate and RTs for each of the remaining 30 participants did not exceed the 2.5 *SD* away from the group mean; therefore, they were all included in the final analysis.

To study the visual sensitivity to configurations involving body dyads or mixed pairs (one body-one plant), accuracy data were entered into a 2 x 2 x 2 repeated-measures ANOVA with factors, category (body, mixed), positioning (facing, nonfacing) and orientation (upright, inverted). All trials without bodies (chair-chair and chair-plants conditions) were excluded from the main ANOVA (statistics for these trials is provided as Supplementary Information). The ANOVA revealed an effect of category, $F(1,29) = 55.12, P < 0.001, \eta_p^2 = 0.65$, reflecting better performance with body dyads than with mixed dyads; an effect of positioning, $F(1, 29) = 9.70, P < 0.01, \eta_p^2 = 0.25$, reflecting better performance with nonfacing than with facing dyads; and an effect of orientation, $F(1, 29) = 41.87, P < 0.001, \eta_p^2 = 0.59$, reflecting a better performance with upright than inverted stimuli. Moreover, there was a significant interaction between position and orientation, reflecting a larger difference between upright and inverted trials (i.e., a larger IE) for facing than for nonfacing dyads, $F(1, 29) = 12.86, P < 0.01, \eta_p^2 = 0.31$. The three-way interaction between category, positioning and orientation was not significant, $F(1, 29) = 3.44, P = 0.07, \eta_p^2 = 0.11$ (Fig. 2A).

Given our hypothesis of an increased visual sensitivity to social interactions, we followed up on the above analysis and considered separately the trials with body dyads and those with mixed dyads. The two analyses revealed two different patterns for the two types of dyads. A 2 positioning x 2 orientation repeated-measures ANOVA on body dyads showed an effect of positioning, $F(1, 29) = 8.17, P < 0.01, \eta_p^2 = 0.22$; an effect of orientation, $F(1, 29) = 32.91, P < 0.001, \eta_p^2 = 0.531$; and a significant interaction between the two, $F(1, 29) = 14.58, P < 0.01, \eta_p^2 = 0.33$. Once again, the IE was significantly larger for facing

than for nonfacing dyads, this difference being driven by a higher cost of inversion for facing, relative to nonfacing trials (see Fig. 2A).

The same analysis on trials with mixed dyads showed an effect of orientation, $F(1, 29) = 36.14, P < 0.001, \eta_p^2 = 0.55$, but no effect of positioning $F(1, 29) = 2.65, P = 0.11, \eta_p^2 = 0.08$, or interaction between the two factors, $F(1, 29) = 3.16, P = 0.09, \eta_p^2 = 0.09$.

Thus, the magnitude of IE was affected by the relative positioning of two bodies, but not by the positioning of a body relative to a plant.

The analysis on trials displaying chairs only showed an effect of the category, $F(1, 29) = 59.11, P < 0.001, \eta_p^2 = 0.67$, reflecting more accurate performance in trials depicting two chairs than in trials with a chair and a plant; and an effect of orientation, $F(1, 29) = 19.68, P < 0.001, \eta_p^2 = 0.40$, reflecting better performance with upright than inverted trials. The interaction between category (chair, mixed) and orientation was significant, $F(1, 29) = 4.99, P = 0.03, \eta_p^2 = 0.15$, reflecting a larger IE for chair-plant dyad than for chair-chair dyads. No other effect or interaction was significant. Importantly, the relative positioning of two chairs or of a chair and a plant had no effect on performance. For chair trials, not shown in Figure 2A, descriptive statistics are reported as supplementary material (Table S2).

In sum, Experiment 2a showed that visual sensitivity as indexed by the IE was not affected by the relative positioning of objects in scenarios that involved a body and a non-body object (i.e., a plant). Notably, Experiment 2a generalized the difference in the IE between facing and nonfacing dyads, to a new task involving categorization with two (as opposed to three) target categories.

Experiment 2b

Typically, bodies are processed with higher priority relative to objects such as plants. Results of Experiment 1 confirmed this circumstance (accuracy for upright bodies: $M = 0.89 \pm 0.16 SD$, 95% CI [0.82, 0.94]; for plants: $M = 0.75 \pm 0.23 SD$, 95% CI [0.67, 0.83]; $t(29) = 5.16$, $P < 0.001$). This fact may have implications for Experiment 2a, where body-plant pairs were interleaved with body-body dyads. If bodies are seen better and/or faster than plants, then in a body-plant dyad the recognition of the body could bias the processing of the plant. In particular, if the participant first saw a body facing toward the center of the screen, she could have anticipated that the second object was a facing body; likewise, if she first saw a body facing away from the center of the screen, she could have anticipated that the second object was a facing-away body. Experiment 2b ruled out this possibility with a sample of naïve participants tested on mixed pairs only.

Participants

Twenty-one healthy adults with normal or corrected-to-normal vision (14 female, mean age 20.67 years $\pm 1.91 SD$) participated as paid volunteers. This sample size corresponded to the required sample size ($N = 20$) for obtaining an effect size as large as in Experiment 1 ($\eta_p^2 = 0.37$), for the positioning by orientation effect (G*Power 3.1). Based on sensitivity analysis (G*Power 3.1), the minimal detectable effect size for the critical positioning by orientation interaction was $\eta_p^2 = 0.16$ ($\beta = 0.80$ and $\alpha = 0.05$).

Stimuli, apparatus and procedures

Experiment 2b included the mixed trials of Experiment 2a: a body facing toward/away from a plant and the same dyads inverted upside-down, for a total of 240 trials. To allow the categorization task, the stimulus-set also included the 240 mixed pairs displaying a chair facing toward or away from a plant (upright and inverted). Thus, participants saw 480 trials in total. Participants were instructed to report whether, in each trial, they had seen a body or a chair, irrespective of positioning (facing or nonfacing) and orientation (upright or inverted). They responded by pressing key 1 or key 2 with the right index and middle finger, respectively (for half of the participants, key 1 was “body” and key 2 for “chairs”; the opposite mapping was used for the other half). Everything else was identical to Experiments 1-2a.

Results

Mean accuracy rates and/or RTs for every participant were within 2.5 *SD* from the group mean; therefore, they were all included in the final analysis.

To study the visual sensitivity to dyadic configurations with a body facing toward vs. away from a plant, accuracy data were entered into a 2 positioning x 2 orientation repeated-measures ANOVA. The analysis revealed an effect of orientation, $F(1, 20) = 28.22, P < 0.001, \eta_p^2 = 0.58$, reflecting overall better performance with upright than inverted stimuli. The effect of positioning was far from significance, $F(1, 20) < 1, n.s.$, and did not affect the magnitude of the IE (positioning x orientation: $F(1, 20) < 1, n.s., \eta_p^2 = 0.03$) (Fig. 2A).

The analysis on trials displaying a chair with a plant showed only an effect of orientation, $F(1, 29) = 8.25$, $P < 0.01$, reflecting higher accuracy for upright than inverted trials. No other effect or interaction was significant, $F(1, 20) < 1$, *n.s.* For chair-plant conditions, not shown in Figure 2A, descriptive statistics are provided as supplementary material (Table S2).

Experiment 2b addressed the visual recognition of a body facing toward vs. away from an object, in a task setting where participants could not expect the object to be another body. In line with Experiment 2a, Experiment 2b showed that the spatial positioning of a body relative to a non-body object did not affect the magnitude of the IE.

Experiment 3

In Experiment 3, we replicated Experiment 2b with one important change: plants were replaced by another class of non-body objects, namely, machines (i.e., various exemplars of automated teller machines and game machines). Machines are familiar objects that enable acting-upon. Importantly, their morphology defines an anteroposterior organization (i.e., the leading-end morphologically more complex than the trailing-end), which allows representing facing/nonfacing positioning and can further promote action representation (Hernik, Fearon, & Csibra, 2014). Thus, Experiment 3 was conceived to test the effect of the object class used as context for another body (body vs. non-body object), while matching the asymmetry around the vertical axis to allow a direction (facing vs. nonfacing).

Participants

We kept the sample size and, hence the sensitivity of the test, identical to Experiments 1-2 by including 31 healthy adults with normal or corrected-to-normal vision (19 female, mean age 21.3 years $\pm$ 3.1 *SD*). They participated as paid volunteers after signing an informed consent. As data from three participants were discarded (see below), the minimum detectable effect size calculated for this design with $N = 28$ was $\eta_p^2 = 0.12$ ($\beta = 0.80$, $\alpha = 0.05$).

Stimuli, apparatus and procedures

For Experiment 3, we selected and edited five exemplars of electronic devices in lateral view, including two automated teller machine, and three game machines (slot machine or arcade game machine). Bodies were the same as in previous experiments. Bodies and machines were combined in pairs, using the same procedure described in Experiment 1. The following new types of pairs were created: a body facing a machine ($N = 60$), a body facing away from a machine ($N = 60$) and the same dyads inverted upside-down ($N = 120$). To allow the categorization task, the same type and number of pairs (60 per condition) were created replacing bodies with chairs. Thus, participants saw a total of 480 trials evenly distributed across eight conditions: facing and nonfacing body-machine or chair-machine pairs presented upright or inverted. Participants were instructed to report whether, in each trial, they had seen a body or a chair, irrespective of positioning (facing or nonfacing) or orientation (upright or inverted). They responded by pressing key 1 or key 2 with the right index and middle finger, respectively (for half of the participants, key 1 was “body” and key

2 for “chairs”; the opposite mapping was used for the other half). Everything else was identical to previous experiments.

Results

Data from two participants were discarded because average accuracy or RTs were more than 2.5 *SD* below the group mean. Another participant did not perform the task (he pressed always the same response key). The final analysis included data from 28 participants.

Using accuracy data, a 2 x 2 repeated-measures ANOVA with factors, positioning and orientation confirmed, for body-machine pairs, the results found for body-plant pairs (Experiment 2). The ANOVA showed an effect of orientation, $F(1, 27) = 47.34, P < 0.001, \eta_p^2 = 0.64$, showing better performance with upright than inverted stimuli. But, neither the effect of positioning nor the positioning by orientation interaction was significant ($F(1, 27) = 3.23, P = 0.08, \eta_p^2 = 0.11$; $F(1, 27) = 2.91, P = 0.15, \eta_p^2 = 0.75$, respectively) (Fig. 2A).

The analysis on trials displaying a chair with a machine showed an effect of orientation, $F(1, 27) = 13.60, P = 0.001$, reflecting higher accuracy for upright than inverted trials. While the effect of positioning was not significant, $F(1, 27) < 1, n.s.$, surprisingly, the interaction between the two factors showed a significant effect, $F(1, 27) = 6.84, P = 0.01, \eta_p^2 = 0.20$. However, the RTs analysis revealed a significant interaction, but in opposite direction, $F(1, 27) = 6.27, P = 0.02, \eta_p^2 = 0.18$ (see Supplementary material). That is, the cost of inversion on chair recognition was higher for facing chair-machine trials, in terms of accuracy, and for nonfacing chair-machine pairs, in terms of RTs. This pattern prevents any further interpretation of the effect.

Experiment 3 addressed visual recognition of a body facing toward vs. away from an object that could be reciprocally oriented toward or away from the body and could be in an action-mediated relation with the body. These properties of machines did not change the mechanisms underlying body perception, as measured by the inversion effect.

Experiment 4

Experiments 1-3 have demonstrated that human visual perception is particularly sensitive to two bodies (as opposed to object-object or body-object pairs) positioned in a way that cues an ongoing relation. Experiment 4 addressed the specificity of this relation: reciprocal with one body facing the other, or non-reciprocal with one body acting on the other (transitive relation). Both relations are mediated by an action but only the former implies interaction.

Participants

Thirty-two healthy adults with normal or corrected-to-normal vision (19 female, mean age 21.97 years $\pm$ 3.49 *SD*) participated as paid volunteers. Data from one participant were discarded (see below); thus, the minimal detectable effect size for this design was $\eta_p^2 = 0.05$ (with $N = 31$, $\beta = 0.80$ and $\alpha = 0.05$).

Stimuli, apparatus and procedures

Stimuli included all the body trials used in Experiment 1: 60 facing dyads, 60 nonfacing dyads, and the same dyads rotated by 180° (inverted trials). In addition, using the procedure described in Experiment 1, 60 new dyads (and the corresponding inverted ones) were created by pairing each individual body with

a body in a standing position, so that the former faced the back of the latter. We called this condition “transitive” as the relative positioning of the bodies gave the impression that one was acting upon the other. The passive (standing) position of the acted-upon individual was meant to accentuate this impression.

To allow the categorization task, the stimulus-set included 360 images displaying upright and inverted pairs of facing chairs, nonfacing chairs (the same as in Experiment 1), and a new set where a chair faced toward the back of another (analogously to the transitive-body positioning above).

In total, during Experiment 3, participants saw 720 images (360 body dyads: 120 facing, 120 nonfacing, and 120 transitive; 360 chair pairs: 120 facing, 120 nonfacing, and 120 transitive). They were instructed to report whether, in each trial, they had seen bodies or chairs, irrespective of positioning (facing or nonfacing) and orientation (upright or inverted). They responded by pressing key 1 or key 2 with the right index and middle finger, respectively (for half of the participants, key 1 was “body” and key 2 for “chairs”; the opposite mapping was used for the other half). Everything else was identical to Experiments 1-2.

Results

Data from one participant were discarded as his accuracy rates were $>2.5 SD$ below the group mean; the remaining 31 participants were included in the analysis.

Accuracy data of Experiment 3 entered a repeated-measures ANOVA with factors: category (2: body, chair), positioning (3: facing, transitive, nonfacing) and orientation (2: upright, inverted). The analysis revealed a trend for the effect

of category, $F(1,30) = 3.68$, $P = 0.06$, $\eta_p^2 = 0.11$, reflecting higher accuracy rates for chair-trials than body-trials; a significant effect of positioning, $F(2, 60) = 3.94$, $P = 0.02$, $\eta_p^2 = 0.12$, reflecting a better performance with nonfacing than with facing and transitive dyads; and an effect of orientation, $F(1, 30) = 27.91$, $P < 0.001$, $\eta_p^2 = 0.48$, reflecting a better performance with upright than inverted stimuli. Moreover, there was significant interaction between category and positioning, $F(2, 60) = 4.07$, $P = 0.02$, $\eta_p^2 = 0.12$; and a significant interaction between positioning and orientation, $F(2, 60) = 3.17$, $P < 0.05$, $\eta_p^2 = 0.09$. Those interactions were qualified by the three-way interaction, $F(2, 60) = 4.03$, $P = 0.02$, $\eta_p^2 = 0.12$, showing that positioning modulated the inversion effect to a different extent for bodies and chairs (Fig. 2B).

To follow up on this analysis, body-stimuli and chair-stimuli were analyzed separately. A 3 positioning x 2 orientation repeated-measures ANOVA on body dyads showed an effect of positioning, $F(2, 60) = 6.10$, $P < 0.01$, $\eta_p^2 = 0.17$; an effect of orientation, $F(1, 30) = 26.20$, $P < 0.001$; and a significant interaction between the two, $F(2, 60) = 4.87$, $P = 0.01$, $\eta_p^2 = 0.47$.

Pairwise t tests showed that the IE was significantly larger for facing than for nonfacing body dyads, $t(30) = 2.87$, $P < 0.01$, and for facing than for transitive pairs, $t(30) = 2.07$, $P = 0.04$; while it was comparable for transitive and nonfacing dyads, $t(30) = 1.08$, $P > 0.25$.

The same analysis on chair-trials showed only an effect of orientation, $F(1, 30) = 5.40$, $P = 0.03$, $\eta_p^2 = 0.15$, but no effect of positioning $F(2, 60) = 1.04$, $P > 0.25$, or interaction between the two, $F(2, 60) = 1.19$, $P > 0.25$.

In sum, Experiment 4 showed higher visual sensitivity for dyads of body whose positioning cued a reciprocal action, or interaction, than for dyads seemingly involved in a transitive action-relation or in no relation.

Discussion

The recognition of social multipart objects such as faces and bodies is particularly important in the human life. Indeed, the human visual system proves especially sensitive to spatial configurations that characterize those object classes (Tsao & Livingstone, 2008). The IE, the cost of perturbing the characteristic spatial configuration through upside-down rotation, is an index of this sensitivity; as such, it is consistently larger for objects such as faces and bodies, than for other object classes (Bruyer, 2011; Maurer et al., 2002). Extensive research on face/body perception has linked this kind of sensitivity to the existence of specialized perceptual mechanisms for those object-classes (Diamond & Carey, 1986; Rhodes et al., 1987; Maurer et al., 2002).

Recently, we have shown that the IE is larger for two bodies facing each other than for two bodies facing away from each other (Papeo et al., 2017). The two-body inversion effect has suggested the existence of specific perceptual adaptations for detection and recognition of interacting bodies, or social interactions. If so, visual sensitivity to multi-body configurations should be specific to body dyads, as opposed to any pair of seemingly related objects (i.e., body-object or object-object pairs), and to spatial relations that cue a social interaction, as opposed to any action-mediated relation. In addressing this hypothesis, the current series of experiments defined the properties of the

dyadic configuration that the visual system appears especially prepared to recognize.

First, we asked whether the difference in the IE between facing and nonfacing dyads depends on the relative positioning of two bodies, or on the relative positioning of two faces/heads. The results of Experiment 1 showed that the cost of inversion was reliably larger for facing than for nonfacing dyads, irrespective of whether the face/head directions were available in the input. One might reason that the effect could still be mediated by the heads' positioning inferred by the rest of the body. Although we cannot exclude this possibility, one would expect the effect to be attenuated when the head direction is inferred, relative to when it is given in the stimulus. Either way, the conclusion remains that visual perception of head/face is not uniquely accountable for the effect of body positioning on IE.

Then, we asked whether visual sensitivity is enhanced for a body facing another body *versus* a body facing an object (Experiments 2-3), and for spatial positioning cueing any action-mediated relation (e.g., a body facing another, as if acting on it) *versus* a reciprocal exchange, seen as the prototype of social interaction (Experiment 4). The results showed that the cost of inversion was reliably larger for facing than for nonfacing dyads, only when the stimuli involved two bodies (*versus* a body and an object), in a positioning that cued a reciprocal (*versus* a non-reciprocal) relation.

The special sensitivity of human visual perception to body dyads encourages the thinking that visual configural representations can capture structures more complex than an individual face or body. The dyadic

configuration emerging from our research matches the representation of a prototypical social exchange, where two spatially close and mutually accessible bodies appear to engage in a reciprocal exchange.

Before concluding in favor of selective visual sensitivity to human-human scenarios, we discuss possible sources of difference between human-human and human-object pairs.

The effect of positioning could be reduced for human-object pairs relative to human-human dyads because in the former case the object was task irrelevant (i.e., the task in Experiments 2-3 did not require recognizing plants or machines), while in the latter case both items were task relevant. We can rule out this explanation based on the results of Experiment 4. We have characterized the effect of positioning as a larger IE for facing than for nonfacing dyads. If the increased IE required a body facing any other item, provided that the latter was task relevant too, we would have found no difference in the IE between facing dyads and transitive dyads (one body faced another body that faced away).

Another source of difference between human-human and human-object pairs may concern the semantic congruence. In designing the experiment, we selected common body poses that are ambiguous, in the sense that they could subsume different meanings depending on the context in which they appear. Moreover, items were paired with scant consideration of the coherence of the scene (i.e., a body pose could be more or less congruent in the context of a plant, a machine, or of another body). Thus, one might wonder whether body poses were more appropriate in the context of a body than an object, and whether this circumstance hindered the representation of a relation in body-object pairs.

With this respect, we emphasize that a body-object relation is hardly reciprocal, while Experiment 4 has shown that reciprocity contributes to the increased visual sensitivity to dyadic configurations. Moreover, our previous research had shown that the semantic congruence of the scene did not affect the magnitude of the IE: the IE was comparable for meaningful and less meaningful dyadic scenarios (Papeo et al., 2017, Experiment 2). In effect, under the current conditions of stimulus presentation, individuals might not access key visual details that contribute to action recognition (e.g., hand shapes). This implies that the effect of body positioning could take place before a conscious, elaborated processing of the scene –i.e., before recognition of body poses/actions.

However, we shall remark that the current study included a limited number of poses and did not quantify the congruence of the scenes, leaving open to further research, questions concerning the generality of the effect (i.e., whether the increased sensitivity to human-human interactions is constrained by the current body poses), the role of familiarity (i.e., the current human-human scenes could be more frequent than human-plant/machine scenes) and the role of the semantic properties of the scenes (i.e., when and how they come into play).

Positioning did not affect the IE for pairs of non-body objects (chair-chair, chair-plant, chair-machine; Experiments 1-4), even when the morphology of those objects unambiguously defined a direction: facing toward or away (chairs and machines). This circumstance implies that perception of body dyads is mediated by the representation of functional relations among bodies, beyond mere physical orientation (facing toward one another). The brief stimulus presentation and the task requirement for basic-level category information

suggest that functional relations among bodies are captured rapidly and automatically (see also Hafri, Trueswell, & Strickland, 2018).

In the case of single faces and bodies, the IE has been taken as a signature of an internal visual representation, or template, that specifies a stimulus in terms of spatial relations among its part (for bodies: head above trunk, trunk above legs, etc.) (Diamond & Carey, 1986; Reed et al., 2003). Internal representations generate expectations about the world, which resolves in more efficient detection and recognition of stimuli that match those representations. Tasks such as change detection and visual search have emphasized such advantage for faces and bodies (but also for eye gaze and biological motion; e.g., Bindemann et al., 2010; Birmingham, Bischof, & Kingstone, 2009; Downing et al., 2004; New et al., 2007).

By extension, the enhanced IE for facing-body dyads suggests an internal representation of two bodies in a spatial relation that matches a facing dyad better than a nonfacing dyad (for which the IE is reduced). In this perspective, we predict an advantage in the detection and recognition of multiple facing bodies over bodies in other spatial relations. Such advantage could serve to select socially relevant portions of the environment for further higher-level processing. This perceptual adaptation may be particularly relevant for visual processing of crowded everyday environments (e.g., the audience of a concert, the customers in a bar during the happy hour, the commuters in a bus), where our preferred stimuli, faces and bodies, are everywhere. While the non-naturalistic paradigm used here served to highlight visual sensitivity to the global structure of facing body dyads, other, more naturalistic paradigms could

highlight the perceptual benefit expected for stimuli that are represented as one structured unit.

The possibility of specialized representations and mechanisms for the perception of two facing bodies could provide a unifying framework to recent phenomena showing that entities perceived as interacting are treated as an attentional unit (Yin, Ding, Zhou, Shui, Li, & Shen, 2013), or a single chunk in working memory, in infants (Stahl & Feigenson, 2014) and adults (Ding, Gao, & Shen, 2017). Recent functional MRI results further support this framework, showing brain regions selective to observed dyadic interactions, in humans (Isik, Koldewyn, Beeler, & Kanwisher, 2017; Walbrin, Downing, & Koldewyn, 2018) and macaques (Sliwa & Freiwald, 2017). Just like in the case of single faces/bodies (Gauthier, 2017; Kanwisher, 2017), this research brings up fundamental questions concerning the origin of neural specialization: biological disposition *versus* result of extensive exposure or expertise.

Conclusions

By studying perception of multiple-person scenarios, we aim at accounting for how visual body-shapes become representations of social relations. In this enterprise, the current study demonstrates the existence of perceptual adaptations specific to the category of body dyads and the domain of social interactions, of which two mutually accessible bodies are prototypical and rudimentary illustration. Indeed, the IE, used as a measure of visual sensitivity, was selectively and reliably higher for dyads in which two bodies faced each other, as compared with pairs of non-body objects, pairs in which a body faced a

non-body object, and dyads with no reciprocal perceptual access of the two bodies. These findings open to the possibility of visual configural representations of a higher hierarchical nature, providing fast and automatic parsing of complex relationships beyond individual faces or bodies. Multi-body configurations may constitute the intermediate step between body perception and domain-specific inferential processes that lead to social action understanding.

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Figure caption

Fig. 1. Experiment 1: inversion effect (darker gray bars in front line) defined as the performance (proportion of correct responses) with upright minus inverted trials (light gray bars in the back). A) Accuracy results as a function of the positioning of members in the dyad, for body trials and chair trials. B) Accuracy results for body trials as a function of the head (blurred or visible) and the positioning of members in the dyad. Error bars represent bootstrap 95% confidence intervals around the mean with 1000 resampling. Asterisks indicate significant differences between stimulus groups (* $p < .05$, *** $p < .001$).

Fig. 2. Experiments 2, 3 and 4: Inversion effect (darker gray bars in front line) defined as the performance (proportion of correct responses) with upright minus inverted trials (light gray bars in the back). A) Accuracy results as a function of the positioning of members in the dyad, for body trials and mixed (body-plant) trials in Experiment 2a, for mixed body-plant trials in Experiment 2b, and for mixed body-machine trials in Experiment 3. B) Accuracy results for body trials and chair trials as a function of the positioning of members in the dyad (facing, transitive, nonfacing) in Experiment 4. Error bars represent bootstrap 95% confidence intervals around the mean with 1000 resampling. Asterisks indicate significant differences between stimulus groups (* $p < .05$, ** $p < .01$, *** $p < .001$).

Experiment 1

Table S1. Mean reaction times (ms) and corresponding $\pm$ bootstrap 95% confidence intervals (in *Italics*) in Experiments 1-4. RT values associated with incorrect responses were discarded (Experiment 1: 21.6% of total trials; Experiment 2a: 17.3%; Experiment 2b: 25.6%; Experiment 3: 18%; Experiment 4: 8.9%). Based on individual averages, RT values that were >2 *SD* away from the individual's mean value were also discarded before the analysis.

Experiment 1											
Bodies								Chairs			
facing				nonfacing				facing		nonfacing	
upright		inverted		upright		inverted		upright	inverted	upright	inverted
blurred-heads	full-body	blurred-heads	full-body	blurred-heads	full-body	blurred-heads	full-body				
637.06	640.48	686.30	705.97	638.10	643.77	676.19	687.85	701.96	736.52	715.72	728.23
[604.01,675.17]	[606.69,678.33]	[644.64,727.41]	[660.26,741.80]	[602.42,677.07]	[603.49,678.73]	[638.05,712.78]	[647.71,720.79]	[655.00,745.69]	[688.90,788.68]	[668.75,757.94]	[680.84,773.13]
Experiment 2a								Experiment 2b			
Body-body				Body-plant				Body-plant			
facing		nonfacing		facing		nonfacing		facing		nonfacing	
upright	inverted	upright	inverted	upright	inverted	upright	inverted	upright	inverted	upright	inverted
586.77	637.04	592.22	628.83	635.83	684.45	643.11	685.35	693.91	790.89	711.42	746.04
[544.62,645.11]	[593.93,750.17]	[550.24,654.36]	[580.43,724.20]	[584.13,727.17]	[634.09,761.43]	[593.62,720.36]	[634.10,807.28]	[616.00,861.84]	[690.02,861.84]	[624.22,857.79]	[661.02,850.16]
Experiment 3											
Body-machine											
facing		nonfacing									
upright	inverted	upright	inverted								
582.56	642.04	577.89	623.17								
[546.83,615.74]	[594.73,691.20]	[536.28,609.29]	[586.40,660.26]								
Experiment 4											
Bodies						Chairs					
facing		nonfacing		transitive		facing		nonfacing		transitive	
upright	inverted	upright	inverted	upright	inverted	upright	inverted	upright	inverted	upright	inverted
506.50	560.88	508.26	551.99	514.90	559.20	570.69	595.83	569.76	598.81	569.02	594.94
[486.89,528.05]	[538.24,603.57]	[486.86,530.87]	[527.34,582.25]	[498.72,534.62]	[533.28,587.60]	[547.59,594.69]	[568.86,617.77]	[542.05,593.66]	[575.72,631.68]	[544.24,595.52]	[565.78,622.48]

Table S2. Mean proportion of correct responses and corresponding bootstrap 95% confidence intervals (in Italics) in Experiments 2a, 2b and 3 for trials with chair-chair, chair-plant, and chair-machine pairs.

Experiment 2a							
<i>Chair-chair</i>				<i>Chair-Plant</i>			
<i>facing</i>		<i>nonfacing</i>		<i>facing</i>		<i>nonfacing</i>	
<i>upright</i>	<i>inverted</i>	<i>upright</i>	<i>inverted</i>	<i>upright</i>	<i>inverted</i>	<i>upright</i>	<i>inverted</i>
0.89	0.88	0.88	0.87	0.83	0.78	0.84	0.78
<i>[0.84, 0.94]</i>	<i>[0.82, 0.92]</i>	<i>[0.82, 0.92]</i>	<i>[0.81, 0.91]</i>	<i>[0.77, 0.88]</i>	<i>[0.74, 0.83]</i>	<i>[0.79, 0.89]</i>	<i>[0.73, 0.83]</i>
Experiment 2b							
<i>chair-plant</i>							
<i>facing</i>		<i>nonfacing</i>					
<i>upright</i>	<i>inverted</i>	<i>upright</i>	<i>inverted</i>				
0.78	0.73	0.79	0.73				
<i>[0.72, 0.85]</i>	<i>[0.65, 0.79]</i>	<i>[0.71, 0.85]</i>	<i>[0.67, 0.80]</i>				
Experiment 3							
<i>chair-machine</i>							
<i>facing</i>		<i>nonfacing</i>					
<i>upright</i>	<i>inverted</i>	<i>upright</i>	<i>inverted</i>				
0.85	0.83	0.88	0.79				
<i>[0.80, 0.90]</i>	<i>[0.77, 0.86]</i>	<i>[0.83, 0.94]</i>	<i>[0.07, 0.91]</i>				

Table S3. Results of statistical analysis on RT values in Experiments 1-4.

Experiment 1	
<i>2 category (body, chair) x 2 positioning (facing, nonfacing) x 2 orientation (upright, inverted)</i>	
Category: $F(1,29) = 13.76, P = 0.001$	
Positioning: $F(1,29) = 0.21, P = 0.649$	
Orientation: $F(1,29) = 25, P < 0.001$	
Category*Positioning: $F(1,29) = 1.43, P = 0.242$	
Category*Orientation: $F(1,29) = 6.03, P = 0.020$	
Positioning*Orientation: $F(1,29) = 4.34, P = 0.046$	
Category*Positioning*Orientation: $F(1,29) = 0.42, P = 0.524$	
Experiment 2a	
<i>2 category (body-body, body-plant) x 2 positioning x 2 orientation</i>	
Dyad: $F(1, 29) = 45.21, P < 0.000$	
Positioning: $F(1, 29) = 0.107, P = 0.746$	
Dyad* Positioning: $F(1, 29) = 0.313, P = 0.580$	
Orientation: $F(1, 29) = 26.323, P < 0.001$	
Dyad*orientation: $F(1, 29) = 0.020, P = 0.889$	
Positioning*Orientation: $F(1, 29) = 1.166, P = 0.289$	
Dyad*Positioning*Orientation: $F(1, 29) = 0.090, P = 0.767$	
Experiment 2b	
<i>2 positioning x 2 orientation</i>	
<i>Body-plant trials</i>	<i>Chair-plant trials</i>
Positioning: $F(1, 20) = 0.567, P = 0.460$	Positioning: $F(1, 20) = 0.273, P = 0.607$
Orientation: $F(1, 20) = 9.302, P = 0.006$	Orientation : $F(1, 20) = 1.541, P = 0.229$
Positioning*Orientation: $F(1, 20) = 2.383, P = 0.138$	Positioning*Orientation: $F(1, 20) = 0.133, P = 0.719$

Table S3 continued

Experiment 3

2 positioning (facing, nonfacing) x 2 orientation (upright, inverted)

Body-machine trials

Positioning: $F(1, 27) = 3.305, P = 0.080$

Orientation: $F(1, 27) = 29.975, P < 0.001$

Positioning*Orientation: $F(1, 27) = 1.76, P = 0.196$

Chair-machine trials

Positioning: $F(1, 27) = 1.651, P = 0.210$

Orientation: $F(1, 27) = 11.965, P = 0.002$

Positioning*Orientation: $F(1, 27) = 6.276, P = 0.019$

Experiment 4

2 category (body, chair) x 3 positioning (facing, transitive, nonfacing) x 2 orientation

Category: $F(1, 30) = 49.053, P < 0.001$

Positioning: $F(1, 30) = 0.172, P = 0.838$

Category*Positioning: $F(2, 60) = 0.610, P = 0.522$

Orientation: $F(1, 30) = 53.335, P < 0.001$

Category*Orientation: $F(1, 30) = 5.318, P = 0.028$

Positioning*Orientation: $F(2, 60) = 0.270, P = 0.761$

Category*Positioning*Orientation: $F(2, 60) = 0.596, P = 0.538$

Experiment 1

Experiments 2a & 2b

Experiment 3

Experiment 4

Figure S1. Illustration of stimuli used In Experiments 1-4.