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Representing human hands haptically or visually from first-person versus third-person perspectives

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Abstract. Humans can recognise human body parts haptically as well as visually. We employed a mental-rotation task to determine whether participants could adopt a third-person perspective when judging the laterality of life-like human hands. Female participants adopted either a first-person or a third-person perspective using vision (experiment 1) or haptics (experiment 2), with hands presented at various orientations within a horizontal plane. In the first-person perspective task, most participants responded more slowly as hand orientation increasingly deviated from the *participant's* upright orientation, regardless of modality. In the visual third-person perspective task, most participants responded more slowly as hand orientation increasingly deviated from the *experimenter's* upright orientation; in contrast, less than half of the participants produced this same inverted U-shaped response-time function haptically. In experiment 3, participants were explicitly instructed to adopt a third-person perspective haptically by mentally rotating the rubber hand to the experimenter's upright orientation. Most participants produced an inverted U-shaped function. Collectively, these results suggest that humans can accurately assume a third-person perspective when hands are explored haptically or visually. With less explicit instructions, however, the canonical orientation for hand representation may be more strongly influenced haptically than visually by body-based heuristics, and less easily modified by perspective instructions.

1 Introduction

It is well-known that common objects are mentally represented in some 'canonical' or prototypical orientation at which objects are recognised most efficiently. The canonical orientation of visually represented body parts has previously been examined with cognitive psychological tasks that included both inversion (eg Bruce et al 1991; Diamond and Carey 1986; Freire et al 2000; Reed et al 2003; Rhodes 1988; Searcy and Bartlett 1996; Sergent 1984; Tanaka and Farah 1993; Yin 1969) and mental-rotation paradigms (eg Cooper and Shepard 1975; Parsons 1987a, 1987b). For instance, Yin (1979) demonstrated that humans can visually recognise faces better when they are upright than when they are inverted. This result has been interpreted as indicating that humans represent visual faces in a prototypical upright orientation. Cooper and Shepard (1975) presented participants with line drawings of hands at different orientations within a picture plane, and asked whether each drawing represented a right or left hand. The participants took increasingly longer to make their decision as the orientation of the presented hand deviated further from a position with fingers pointed upright. This result suggests that the upright orientation is 'canonical' or prototypical for visual hand representation. Cooper and Shepard proposed that participants mentally moved one of their own hands to match that of the stimulus, and then compared the two. In other words, the canonical orientation was derived from a first-person perspective (Cooper and Shepard 1975; Parsons 1987b).

Humans recognise common non-biological objects very effectively using haptics, as well as vision (Klatzky et al 1985). Recent studies have also shown that human body parts such as individual faces (Casey and Newell 2005, 2007; Kilgour et al 2004; Kilgour and Lederman 2002, 2006; Pietrini et al 2004), hands and feet (Kitada et al 2009), and facial expressions of emotion (Kitada et al, in press; Lederman et al 2007) can also be haptically identified at levels well above chance. These results indicate that the haptic system is an efficient sensory channel for recognising human body parts and for communicating with other individuals.

Unlike vision, however, few researchers have directly examined whether a canonical orientation is used to haptically represent human body parts. To our knowledge, there has been no previous study whether there is a canonical orientation for the haptic representation of human hands. Previous studies showed that haptically represented objects can also possess canonical orientation (Carpenter and Eisenberg 1978; Kilgour et al 2004; Kilgour and Lederman 2006; McGregor et al, in press; Prather and Sathian 2002; Woods et al 2008). For instance, Woods et al (2008) recently investigated whether a canonical orientation exists for familiar objects (eg shoe, model horse) and unfamiliar objects (eg piles of bricks). In their first experiment, participants were required to position each object in a way that would present the best view for haptically learning the object. They found a large degree of consistency in the viewpoint position across participants. In the second experiment, participants studied an object and then decided whether a second object was the same or different than the one that was just previously explored. Accuracy was higher when objects were presented in the preferred, as compared to other, orientations. This result suggests that a canonical orientation may also exist for haptic representations of other familiar objects such as hand.

Earlier mental-rotation studies have shown that humans can accurately identify familiar rotated characters using the sense of touch; as with vision, participants responded more slowly as the stimulus was presented at orientations increasingly further from their own upright orientation (Carpenter and Eisenberg 1978; Prather and Sathian 2002). In addition, several recent studies have documented the existence of haptic face-inversion effects (Kilgour et al 2004; Kilgour and Lederman 2006; McGregor et al, in press). These results suggest that faces elicit mental representations with upright canonical orientations, regardless of modality. Thus, we can expect that canonical orientations for hands will prove important for haptics, and similar to those for vision, especially when observers recognise hands with respect to their own (ie first-person) perspective.

Since the hand observed can belong to another person, as well as to oneself, potentially it can be processed from either first-person or third-person perspective. The ability to recognise human body parts in the third-person perspective is critical to understanding the actions of others. For instance, dance teachers must recognise the body actions of their students from the latter's perspective as the two face one another. Physiotherapists, hand therapists, and hand surgeons also face related challenges when treating their clients/patients. However, little is known about the ability to recognise human body parts from a third-person perspective. Earlier, researchers have examined spatial ability to recognise inanimate object scenes when the participants mentally moved to the vantage point of a new perspective (Heller and Kennedy 1990; Huttenlocher and Presson 1979; Pasqualotto et al 2005; Piaget and Inhelder 1967; Presson 1982; Simons et al 2002; Wraga et al 2000). Many of these studies have demonstrated that adults can perform such tasks with above-chance accuracy (Heller and Kennedy 1990; Pasqualotto et al 2005; Presson 1982; Simons et al 2002; Wraga et al 2000), although children can have difficulty recognising an array of objects (eg mountains) from someone else's viewpoint (Piaget and Inhelder 1967). For instance, Pasqualotto et al (2005) recently investigated how well observers could visually or haptically recognise object scenes after their own position was changed, and whether body movement could compensate for the changes in scene orientation. More specifically, participants were asked to learn the positions of wooden animals randomly placed on a platform. After the learning phase, the participants remained stationary or moved to a different position, while the scene was either rotated to the other position or remained stationary. Next the experimenter displaced one of the objects on the same platform, and asked participants to identify the displaced object. Performance was well above chance, regardless of task condition or sensory modality. This finding suggests that humans can recognise non-biological object scenes from the vantage point of the new perspective haptically, as well as visually.

The viewer-rotation task requires a spatial ability to mentally construct object scenes from a different perspective. By contrast, in order to recognise characteristics of body parts as a part of another person's body, the participant needs to mentally relate these body parts to the other person's body. Sirigu and Duhamel (2001) examined the nature of hand representations in order to clarify the functional relations between motoric and visual imagery. More specifically, participants were asked to imagine their own hand or the experimenter's hand in one of two orientations within the same plane, and to decide whether the thumb or little finger was on the participant's left or right side. The authors assumed that adopting a first-person perspective would engage covert motor-simulation processing, while a third-person perspective would involve visual processing. Participants were able to perform the task well, regardless of perspective. Moreover, the response-time (RT) patterns for the two perspective conditions were dependent on the position of the participants' own hands. More specifically, RTs were faster for the first-person than third-person perspective when participants placed their hands in their laps; however, the opposite occurred when participants placed their hands behind their backs. The authors interpreted these results as indicating the use of different cognitive processes in conjunction with first-person versus third-person imagery instructions.

While the Sirigu and Duhamel results confirm that it is possible to *imagine* human hands from a third-person perspective, the study does not address whether humans are capable of recognising hands *visually* or *haptically* from a third-person perspective. We also note that, if humans are capable of adopting a third-person perspective, hands should be processed most rapidly in the orientation that is canonical with respect to the experimenter's body and more slowly as hand orientation progressively deviates from the canonical orientation. Unfortunately, only two orientations were tested in this experiment and no detailed pattern of RTs as a function of orientation was provided. Hence, this study does not directly or fully address the question whether participants process hands from a third-person perspective by mentally rotating the image of the hand and then directly comparing it with the canonically oriented representation of the experimenter's hand.

The primary goal of the current study was to determine whether participants can adopt a third-person perspective when haptically rather than visually recognising human hands. We employed a mental-rotation task in which a life-like rubber hand was placed in front of participants at various orientations on a tabletop (horizontal plane). The participant was asked to decide the side of space to which the rubber hand belonged as if it were *her own* hand (first-person perspective) versus as if it were the *experimenter's* hand (third-person perspective). We hypothesised that the participant would be capable of recognising human hands from the third-person perspective as well as from the first-person perspective, regardless of sensory modality. In experiment 1, we examined the canonical orientation of hands that were visually represented from first-person versus third-person perspective. Experiment 2 was identical to experiment 1, but the hands were presented haptically. In both experiments, we further predicted that, when participants were instructed to assume a first-person perspective, they would respond more slowly as the angle at which the hand was presented increasingly deviated from the *participant's* upright orientation. In contrast, we predicted that, when participants were instructed to recognise the hand using a third-person perspective, they would respond more slowly as the angle of presentation increasingly deviated from the *experimenter's* upright position (ie the converse of the participant's own upright orientation).

2 Experiment 1

We initially conducted a visual experiment to confirm the canonical orientation used to represent hands visually, as shown by previous studies (Cooper and Shepard 1975; Parsons 1987b), and to determine whether participants could adopt a third-person perspective when visually processing human hands.

2.1 *Materials and methods*

2.1.1 *Participants.* Forty-eight healthy female volunteers aged 18–35 years (mean 20.9 years) participated. They were recruited from the Subject Pool in Department of Psychology, Queen's University. All were right-handed as determined by the Edinburgh Handedness Inventory (Oldfield 1971), with no known sensorimotor manual deficits. They provided written informed consent at the start of the experiment. The experiment was approved by the local ethics committee of Queen's University (Canada).

2.1.2 *Stimuli.* Two different pairs of rubber hands were used (13 cm wide × 20 cm long × 5 cm high) (figure 1a). Each pair consisted of one left and one right hand for a total of two left and two right hands. Each pair was produced from the casts of two adult hands with gender-neutral features to avoid introducing potential gender bias.(1) These two adults submerged both of their outstretched hands into an alginate liquid (Alja-Safe Alginate, Smooth-on Inc., Easton, PA, USA) and held them in place with no movement for ~10 min until the alginate liquid became solid. Silicon rubber liquid (Dragon Skin Q, Smooth-on Inc., Easton, PA, USA) was mixed with a pigment that resembled the colour of human skin, and then poured into the mould. Each rubber hand was removed from the mould and severed at the level of the wrist after the cast solidified. The base was covered with a foam sheet to prevent participants from using the texture of the wrist surface as a tactile cue.

The rubber hand was placed at different orientations within the horizontal plane of the tabletop. With respect to hand orientation, we defined 0° as a vector from the middle of the wrist through to the metacarpophalangeal (MCP) joint of the middle finger, perpendicular to the table edge and pointing away from the subject toward the experimenter (figure 1b). The rubber hand was rotated about a central point approximately located at the MCP joint of the middle finger.

2.1.3 *Experimental setup.* Participants were seated in front of a table and donned a pair of LCD goggles (PlatoTM, Translucent Technologies, Toronto, ON, Canada) with lenses that could be rendered opaque to block vision. They wore earplugs through the entire experiment to minimise task-related sound cues. A black cloth (35 cm wide × 30 cm long) was fixed to the tabletop so that its centre was aligned with the participant's body midline (figure 1b). A small protractor (3 cm diameter) was glued to the centre of the black cloth. A rubber hand was placed at the centre of the black cloth on each trial. The rubber hand was positioned over the protractor such that it was not visible to participants. The participants were instructed to hold a plastic cup (top and base diameters: 8 and 12 cm, respectively; height: 13 cm) with both hands resting on

(1) In the present study, the female participants were asked to assume the rubber hand as their own hand or a male experimenter's hand. Thus, gender-neutral hands were needed to minimise any bias as a result of the gender of the hand models. It was serendipitous that these gender-neutral hands were derived from male individuals.

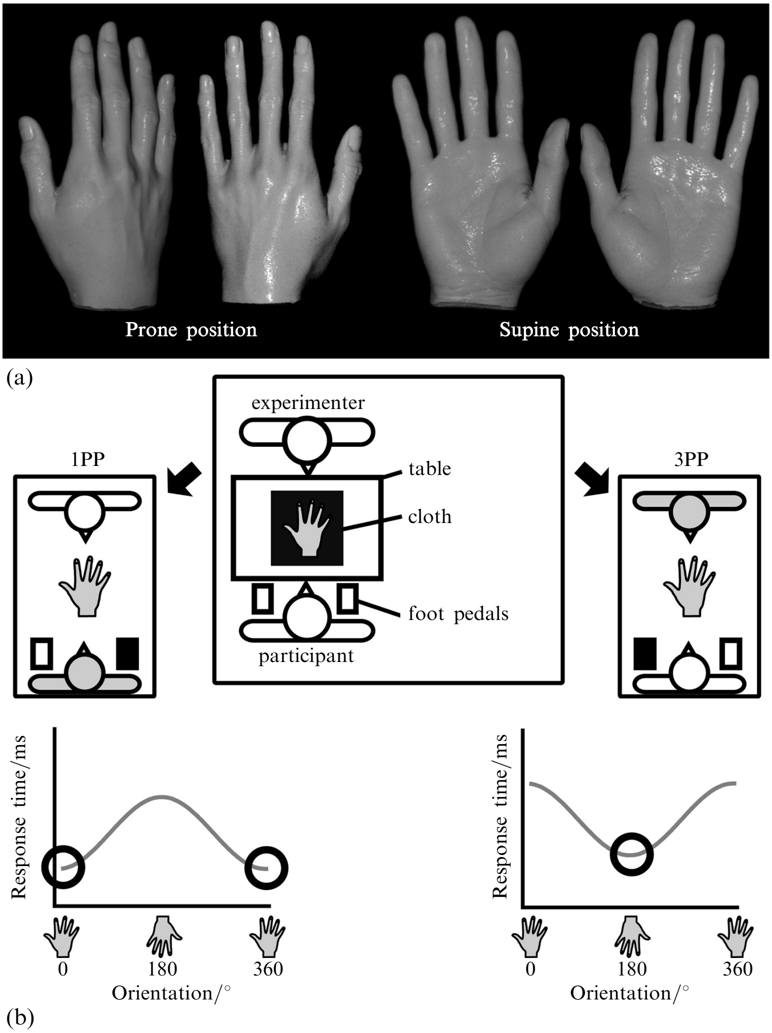


Figure 1. Stimuli and experimental setup. (a) A pair of rubber hands from a hand model. (b) The participant sat across the table from the experimenter (top centre). In the first-person perspective (1PP) task, participants were asked to visually or haptically decide which side of the *participant's* body the rubber hand belonged, while treating the hand model as their own (top left). Participants were asked to press the foot pedal that corresponded to the same side of space. The correct foot is highlighted in black. In the third-person perspective (3PP) task, participants were asked to visually or haptically decide to which side of the *experimenter's* body the rubber hand belonged when the hand was treated as the experimenter's hand (top right).

the table, as a way of minimising any possibility that participants might try to manually rotate their hands while performing the visual task. Both the plastic cup and the participants' hands were covered to prevent sight of their own hands during the experiment. Participants placed their left and right feet on corresponding foot pedals beneath the table. These foot pedals were connected to a Windows-based computer that recorded left – right responses and response times on each trial via a computer applications program (Direct RT Precision Timing Software, Empirical Corp., New York, USA).

2.1.4 *Experimental design.* A five-factor mixed-model design was used with one between-subjects factor and four within-subjects factors. In order to examine the RT pattern as a function of orientation under two different person – perspective instructions, participants were alternately assigned to one of two instruction groups (perspective, 2 levels: first person versus third person). In each group, the rubber hand was placed in eight different orientations (orientation, eight levels: 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). We added three within-subjects factors to increase the difficulty of the task: hand (two levels: right versus left), hand model (two levels: 2 adult models); and hand position (two levels: supine versus prone). Each participant therefore performed a total of 64 trials (2 hand models × 2 hands × 2 hand positions × 8 orientations). The order in which the conditions were presented was pseudo-randomised with each condition presented once.

2.1.5 *Procedure.* The experimenter sat facing the participant across the table (figure 1b), with his hands placed beneath the table out of the participant's view. Before practice began, we measured how quickly the participant could press the foot pedals. As soon as the experimenter said "right" or "left", the experimenter started a program to record the participant's reaction time and the participant pressed the corresponding foot pedal. This procedure was repeated three times for each foot pedal.

Next participants were given some practice trials to familiarise themselves with the task. Their vision of the experimental setup was blocked by the LCD goggles with the lenses initially set to opaque. At the beginning of each trial, the experimenter said "go" and started a program to clear the lenses and to record responses. In the 'first-person perspective' task (1PP task), participants were asked to treat the rubber hand as their *own* hand and to then decide to which side of space surrounding their own body the rubber hand belonged (figure 1b). They were to respond as quickly as possible by pressing the appropriate foot pedal. For instance, if the right rubber hand was placed at 0° orientation, the correct answer was the right foot pedal. By contrast, in the 'third-person perspective' task (3PP task), participants performed the same task except that they were instructed to treat the rubber hand as that of the experimenter's, and then to decide to which side of space around the experimenter's body the rubber hand belonged (figure 1b). The rubber hand was presented in the same orientations as in the 1PP task. For instance, if the right rubber hand was placed at 0° orientation, the correct answer would be the left foot pedal. We deliberately avoided instructing participants to decide whether the rubber hand was the *experimenter's* left (right) hand by pressing the *participant's* left (right) foot pedal in the 3PP task for the following reason. If participants adhered to this instruction, it would have been necessary to choose the space to which the experimenter's hand belonged in terms of their own left or right side, thus requiring a first-person perspective. Such a process is not desirable when participants are being assessed whether they are capable of recognising human hands from a third-person perspective. The current instructions avoided any first-person bias by requiring participants to directly indicate the space around the experimenter's body to which the rubber hand belonged. Pressing the foot pedal immediately rendered the goggle lenses opaque. The experimenter then removed the stimulus hand and substituted the next hand in the trial series.

Participants were given 8 practice trials, which were quasi-randomly selected from the 64 conditions such that each level within each factor was presented an equal number of times. The maximum time limit was set at 30 s per trial. If the time limit was exceeded, the experimenter moved on to the next trial and the eliminated trial was repeated at the end of the trial series. After practice was completed, participants performed the formal experiment involving a total of 64 trials. It took 30 min to complete the visual experiment. At the end of the experiment, we again measured the RTs for the left and right foot pedals. The procedure for recording and calculating RTs was the same as that before practice.

2.2 *Result and discussion*

2.2.1 *Performance accuracy.* Participants were able to perform the task substantially above chance level (50%): mean percentage correct ($\pm$1 SEM) was 95.6 ($\pm$0.8) for the 1PP task, and 87.2 ($\pm$2.2) for the 3PP task. A five-way ANOVA with one between-subjects (perspective, with two levels) and four within-subjects (orientation, with eight levels; hand model with two levels; hand with two levels, hand position with two levels) factors was performed with percentage correct as the dependent variable.(2) This produced significant main effects of perspective ($F_{1,46} = 12.7$, $p < 0.01$, $\eta_p^2 = 0.216$) with the 1PP task producing higher performance accuracy than the 3PP task, and of hand position ($F_{1,2898} = 48.2$, $p < 0.001$, $\eta_p^2 = 0.016$), the prone position producing higher performance accuracy than the supine position. Other significant effects included five higher-level interaction terms: orientation $\times$ perspective ($F_{7,2898} = 6.3$, $p < 0.001$, $\eta_p^2 = 0.015$); hand position $\times$ perspective ($F_{1,2898} = 7.2$, $p < 0.01$, $\eta_p^2 = 0.002$); hand model $\times$ hand position $\times$ perspective ($F_{1,2898} = 5.8$, $p < 0.05$, $\eta_p^2 = 0.002$); hand $\times$ orientation $\times$ perspective ($F_{7,2898} = 2.2$, $p < 0.05$, $\eta_p^2 = 0.005$); and hand model $\times$ hand position $\times$ orientation $\times$ perspective ($F_{7,2898} = 2.4$, $p < 0.05$, $\eta_p^2 = 0.006$). Given significant interactions that involved orientation and perspective, it is possible that the different orientation RT patterns for 1PP and 3PP perspectives could be explained by speed–accuracy trade-off rather than mental rotation. We will show in section 2.2.3 that this is highly unlikely.

2.2.2 *Response time.* For each individual, we subtracted the mean RT for the foot response from her individual RT judgments in the formal experiment. This procedure was conducted separately for the left and right foot responses. To consider whether perspective affected the pattern of RT across hand orientation, only correct trials were included in the subsequent analyses. An omnibus five-way ANOVA with one between-subjects (perspective, with two levels) and four within-subjects (orientation, with eight levels; hand model with two levels; hand with two levels; hand position with two levels) factors was performed with RT (correct) as the dependent variable. This produced significant main effects as follows: perspective ($F_{1,46} = 20.3$, $p < 0.001$, $\eta_p^2 = 0.306$), the 3PP task producing longer response time than the 1PP task; orientation ($F_{7,2642} = 5.7$, $p < 0.001$, $\eta_p^2 = 0.015$); hand ($F_{1,2642} = 11.3$, $p < 0.01$, $\eta_p^2 = 0.004$), the left hand producing longer response time than the right hand; and hand position ($F_{1,2642} = 128.9$, $p < 0.001$, $\eta_p^2 = 0.047$), the supine position producing longer response time than the prone position. In addition, we observed significant interactions of orientation $\times$ perspective ($F_{7,2642} = 21.3$, $p < 0.001$, $\eta_p^2 = 0.053$) and hand position $\times$ perspective ($F_{1,2642} = 37.7$, $p < 0.001$, $\eta_p^2 = 0.014$). Table 1 shows RT $\pm$ SEM for all factor combinations involving hand, hand position, orientation, and perspective.

Because we found a significant interaction between orientation and perspective, we further conducted a subsequent one-way ANOVA (orientation) on RT time for each perspective group. The factors of hand, hand position, and hand model were collapsed for this analysis, since no significant interaction between orientation and any combination of these factors was found. This analysis showed significant main effects for both first-person perspective ($F_{7,161} = 29.4$, $p < 0.001$, $\eta_p^2 = 0.561$) and third-person perspective ($F_{7,161} = 3.0$, $p < 0.01$, $\eta_p^2 = 0.116$).

(2) As customary when addressing issues of process, the error trials were excluded from our analysis of RTs. Because each condition occurred only once, a five-way ANOVA with all factors inevitably required data that were missing (Kirk 1982). Accordingly, we chose to use a repeated-measures ANOVA with a pooled-error model throughout this paper. Although this model is less commonly used, it is sufficient to test whether patterns of behavioural performance are highly similar across hand model, hand, and hand position. Because pooling error terms for within-subjects factors increases their sums of squares (SSs), the absolute magnitude of the effect size, η_p^2, of within-subjects factors, given by SSfactor/(SSfactor + SSerror), is necessarily lower than obtained with a partitioned error model. However, the relative effect sizes, which are of primary concern here, are still meaningful.

Table 1. Response time in experiment 1 (vision). Mean ±1 SEM.

Hand	Hand position	Orientation/°							
		0	45	90	135	180	225	270	315
1PP task									
Left	supine	651± 75	717±107	791±110	1192±138	1486±123	1367±233	824±110	771± 99
	prone	434± 59	408± 42	502± 51	1074±121	1662±250	1025±120	680± 84	487± 64
Right	supine	576± 70	718± 91	903±128	1142±201	1176±150	939±142	790±110	606± 78
	prone	274± 29	439± 60	613± 82	1089±209	1308±194	699±100	363± 50	295± 29
3PP task									
Left	supine	2075±293	2614±581	2066±319	1941±305	1662±260	1888±306	1469±208	1847±414
	prone	1683±311	1282±145	1380±253	1306±226	1058±145	989±125	983±117	1274±150
Right	supine	2025±376	1922±333	1766±269	1663±244	1968±279	1422±159	1742±291	1681±321
	prone	1524±187	1469±220	1327±191	905± 92	985± 98	1186±127	1222±172	1386±105

2.2.3 *Minimum response time across orientations.* The orientation in which the hand was presented clearly altered RT (figure 2). In the 1PP task, it varied as a U-shaped function of orientation, with the minimum RT at 0°. The mean response RT (±1 SEM) for the 1PP task ranged from 489 (±49) ms at 0° to 1423 (±157) ms at 180°. In contrast, RT in the 3PP task varied as an inverted U-shaped function of orientation, with the maximum RT at 0°. Mean RTs (±1 SEM) varied from 1330 (±140) ms at −90° to 1900 (±244) ms at 0°.

Although we found different patterns of RT as a function of orientation in the two perspective conditions, it is possible that such patterns are produced by a speed–accuracy trade-off; that is, participants may have devoted more time with some hand orientations in order to increase performance accuracy. We therefore calculated the Pearson product–moment correlation coefficient between percentage correct and RT across orientations. A relatively strong negative correlation coefficient was obtained for each perspective ($r_6 = -0.87$ for 1PP task and $r_6 = -0.67$ for 3PP task), indicating that the faster the participants responded, the more accurate their responses. Thus, it is highly unlikely that the difference in RT was caused by a speed–accuracy trade-off, as opposed to mental rotation.

Next we fitted a sine function to the RT data as a function of orientation for the two perspective groups (figure 2a). More specifically, RT was fitted with the following function: $\mathrm{RT} = \mathrm{amplitude} \times \sin(\mathrm{orientation} + \mathrm{phase}) + \mathrm{constant}$. The fitted function yielded R^2 values of 0.89 for both functions in the 1PP task, while it produced R^2 values of 0.86 in the 3PP task. The corresponding minimum RTs for the fitted sine functions were found to be very close to 0° (or 360°) in the 1PP task (354.9°) and to 180° in the 3PP task (210.0°). The RT data are also shown in polar coordinates, with orientation around the circumference and RT along the radius (figure 2b).

In order to confirm the consistency of the RT pattern across participants, sine functions were fitted to the RT data as a function of orientation for each participant. The minimum RT values for all participants in the 1PP task were located at an orientation more close to the participant than the experimenter. Angular deviation was calculated as the absolute value of the angular difference from 0° for each participant. The mean angular deviation (±1 SEM) was 12.5° (±2.4°). The minimum RT values for 17 out of 24 participants (71%) in the 3PP task were located at an orientation more close to the experimenter than the participant. Mean angular deviation (±1 SEM) for these participants was 159.5° (±4.8°). The minimum RT values for the remaining seven participants (29%) were located at an orientation more close to the participant than the experimenter. The mean angular deviation (±1 SEM) for the seven participants (±1 SEM) was 19.6° (±9.6°). In other words, the minimum RT of

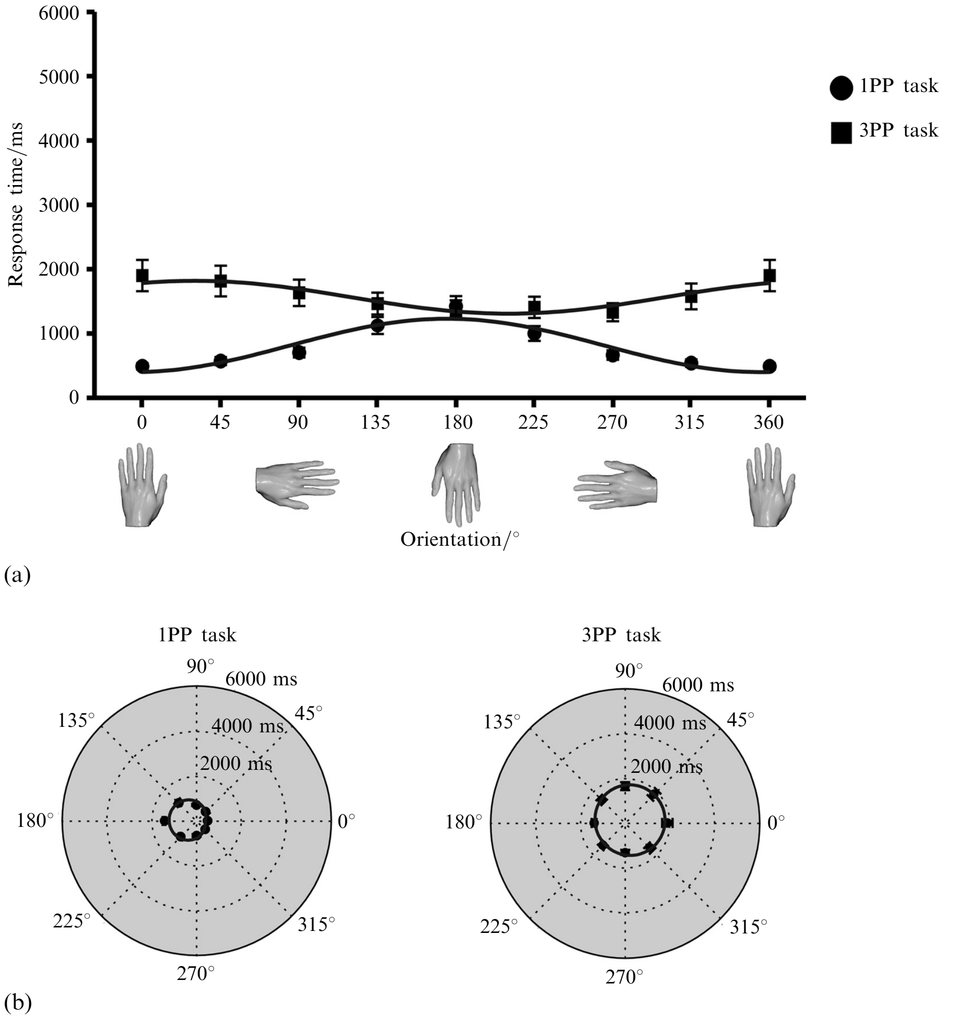


Figure 2. Experiment 1. (a) Visual response time as a function of orientation for first-person and third-person perspectives. Response time (RT) at 360° is equivalent to that at 0°. Sine functions fitted to the data and their R^2 values were as follows. Visual 1PP task: $\text{RT} = 414.7 \times \sin(\text{orientation} - 84.9°) + 814.0$, $R^2 = 0.89$. For the visual 3PP task, $\text{RT/ms} = 255.2 \times \sin(\text{orientation} + 60.0°) + 1563.3$, $R^2 = 0.86$. The data represent the mean (± SEM) of twenty-four participants. (b) RT function expressed in polar coordinates, with orientation around the circumference and RT along the radius.

all participants in the 1PP task was located very close to 0°; in contrast, the minimum RT for the majority of the participants in the 3PP task was located close to 180°.

These results confirm that the canonical orientation for visually represented hands is located close to the participant's own upright orientation, ie 0°. These results further show that participants can visually recognise human hands from a third-person perspective. In the next experiment, we repeated experiment 1 with the one exception that the rubber hands were explored haptically, as opposed to visually.

3 Experiment 2

3.1 *Materials and methods*

3.1.1 *Participants.* Forty-eight healthy female volunteers aged 17 – 41 years (mean 20.4 years) participated in the experiment. They were recruited from the Subject Pool in

Department of Psychology, Queen's University. All participants were right-handed as defined by the Edinburgh Handedness Inventory (Oldfield 1971), had no known sensorimotor manual deficits, and gave their written informed consent. The experiment was approved by the local ethics committee of Queen's University (Canada).

3.1.2 *Stimuli.* The hand stimuli from experiment 1 were also used here.

3.1.3 *Experimental setup.* The experimental setup was identical to that of experiment 1 with two modifications. First, the lenses in the goggles remained opaque throughout the experiment. Participants were not allowed to see the stimuli until the experiment was complete. Second, the participants were instructed to hold the plastic cup in their left hand, because the right hand was used for manual exploration of the rubber hands.

3.1.4 *Experimental design.* The experimental design was the same as in experiment 1.

3.1.5 *Procedure.* The procedure was identical to that used in experiment 1 with two alterations. Participants placed their right hands at the edge of the table, while holding the plastic cup with their left hands on the table. The position of the black cloth was fixed slightly to the right of the participants' right shoulders allowing them to comfortably explore the rubber hands with their right hand.

In each trial, the experimenter guided the participants' right hands to a position directly over the centre of the rubber hand. As soon as he said "go", the experimenter started a program to record the response while simultaneously releasing the participants' hands. Participants then lowered their right hand to make contact with the rubber hand and immediately began to manually explore it. In an initial haptic pilot study, a few participants physically rotated their right hands to match the orientation of the rubber hand. Such physical rotation of the hand was deemed undesirable because it would produce the same RT pattern as mental rotation in the first-person perspective condition. Accordingly, to ensure valid interpretation of the canonical orientation for haptically derived hand representations in the current task, the participant was not allowed to physically rotate her own hand to match the orientation of the rubber hand. In addition, to avoid dislodging the position of the rubber hand, the participant was instructed not to lift or rotate the rubber hand. After pressing the foot pedal, she was instructed to return her hand to the edge of the table. A session in the haptic experiment lasted ~ 50 min.

3.2 *Results and discussion*

3.2.1 *Performance accuracy.* Participants were able to perform the haptic task substantially above chance level (50%): the mean percentage correct (± 1 SEM) was 92.3 (± 1.1) for the 1PP task, and 88.0 (± 1.9) for the 3PP task. A five-way ANOVA with one between-subjects (perspective, with two levels) and four within-subjects (orientation, with eight levels; hand model with two levels; hand with two levels; hand position with two levels) factors was performed with percentage correct as the dependent variable. This produced significant main effects of hand model ($F_{1,2898} = 7.6$, $p < 0.01$, $\eta_p^2 = 0.003$) and hand position ($F_{1,2898} = 49.5$, $p < 0.001$, $\eta_p^2 = 0.017$), with the prone position producing higher performance accuracy than the supine position. Moreover, we observed significant interactions of hand model $\times$ orientation ($F_{7,2898} = 2.6$, $p < 0.05$, $\eta_p^2 = 0.006$) and hand position $\times$ perspective ($F_{1,2898} = 7.0$, $p < 0.01$, $\eta_p^2 = 0.002$). Because we did not find either a significant main effect of orientation or a significant interaction between orientation and perspective, it is unlikely that the different orientation RT patterns are the result of a speed–accuracy trade-off. Having confirmed that participants performed both perspective tasks with high accuracy, we focus our analysis on RT patterns.

3.2.2 *Response time.* We conducted the same analysis as in experiment 1. Initially, we performed an omnibus five-way ANOVA with one between-subjects (perspective, with two levels) and four within-subjects (orientation, with eight levels; hand model with two levels; hand with two levels; hand position with two levels) factors with RT as the dependent variable. This produced significant main effects of orientation ($F_{7,2602} = 12.9$, $p < 0.001$, $\eta_p^2 = 0.034$); hand model ($F_{1,2602} = 33.7$, $p < 0.001$, $\eta_p^2 = 0.013$); hand ($F_{1,2602} = 46.5$, $p < 0.001$, $\eta_p^2 = 0.018$), with the left hand producing longer response times than the right hand; and hand position ($F_{1,2602} = 14.3$, $p < 0.001$, $\eta_p^2 = 0.005$), with the prone position producing longer response times than the supine position. The main effect of perspective was not significant. We also observed significant interactions for orientation × perspective ($F_{7,2602} = 6.7$, $p < 0.001$, $\eta_p^2 = 0.018$); hand model × hand ($F_{1,2602} = 28.1$, $p < 0.001$, $\eta_p^2 = 0.011$); and hand × hand position × orientation ($F_{7,2602} = 3.9$, $p < 0.001$, $\eta_p^2 = 0.01$).

To further examine the interaction between orientation and perspective, for each perspective we further conducted a three-way ANOVA with three within-subjects (orientation, with eight levels; hand with two levels; hand position with two levels) factors with RT as the dependent variable. Because the interaction between hand model and orientation in the omnibus ANOVA was not significant, the factor of hand model was collapsed by averaging over both levels for purposes of this analysis. Table 2 shows RT ± SEM for conditions for hand, hand position, orientation, and perspective. This reduced ANOVA for the 1PP task produced significant main effects of orientation ($F_{7,699} = 14.5$, $p < 0.001$, $\eta_p^2 = 0.127$) and hand ($F_{1,699} = 17.3$, $p < 0.001$, $\eta_p^2 = 0.024$), the left hand producing longer response times than the right hand. The interaction, however, was non-significant. The same ANOVA on response time in the 3PP task revealed significant main effects of hand ($F_{1,691} = 9.5$, $p < 0.01$, $\eta_p^2 = 0.014$), the left hand producing longer response times than the right hand; and of hand position ($F_{1,691} = 7.0$, $p < 0.01$, $\eta_p^2 = 0.010$), the prone position again producing longer response times than the supine position. As before, no interactions were statistically significant. Because hand and hand position factors did not significantly interact with orientation, for purposes of determining the orientation at which the RT was at a minimum for each perspective, these two factors were collapsed by averaging across levels.

Table 2. Response time in experiment 2 (haptics). Mean ±1 SEM.

Hand	Hand position	Orientation/°							
		0	45	90	135	180	225	270	315
1PP task									
Left	supine	3330±467	3485±323	3455±351	4629±753	5006±766	4854±468	4145±529	4045±415
	prone	3311±385	3847±440	4231±559	4486±606	6265±925	4798±869	3725±399	3273±392
Right	supine	2854±371	3265±397	3543±417	4136±673	4194±496	4282±571	3608±442	2568±321
	prone	2879±351	3615±366	3426±438	4031±468	4560±501	4488±499	4210±457	3507±395
3PP task									
Left	supine	4188±415	3881±313	4466±560	4088±404	4025±420	4040±389	4980±374	4004±310
	prone	4051±330	4573±445	4514±431	4307±368	4428±317	4536±462	4592±432	4305±451
Right	supine	3340±236	3520±355	3406±390	4376±743	4119±489	4334±558	3594±464	3318±305
	prone	4023±282	4078±274	4341±347	3743±420	4084±428	4144±376	4641±370	4730±472

3.2.3 *Minimum response time across orientations.* As hypothesised for the 1PP task, RT varied as a U-shaped function of orientation, with the minimum at 0° orientation (ie with the hand pointed forward and away from the participant, as shown in figure 3). RTs (±1 SEM) ranged from 3092 (±330) ms at 0° to 4938 (±556) ms at 180°. In contrast, in the 3PP task the RTs remained approximately constant, ranging only from 3935 (±257) ms at 0° to 4452 (±304) ms at 270°.

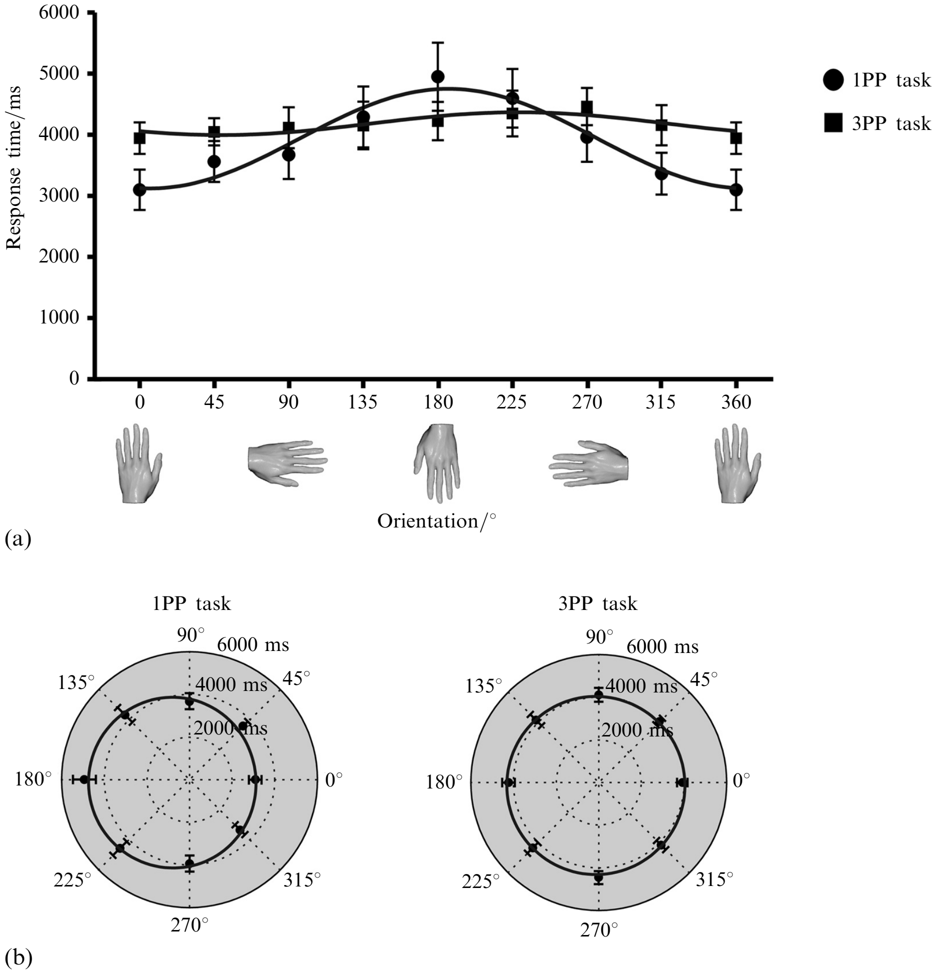


Figure 3. Experiment 2. (a) Haptic response time (RT) as a function of orientation for first-person and third-person perspectives. Sine functions fitted to the data and their R^2 values were as follows. Haptic 1PP task: $\text{RT/ms} = -812.8 \times \sin(\text{orientation} + 83.6°) + 3927.2$, $R^2 = 0.94$; haptic 3PP task: $\text{RT} = 185.9 \times \sin(\text{orientation} - 139.1°) + 4171.4$, $R^2 = 0.74$. The data represent the mean ($\pm$ SEM) of twenty-four participants. (b) RT function expressed in polar coordinates, with orientation around the circumference and RT along the radius.

Sine functions were fitted to the RT data as a function of orientation for first-person and third-person perspective conditions (figure 3a). More specifically, RT was fitted with the following function: $\text{RT} = \text{amplitude} \times \sin(\text{orientation} + \text{phase}) + \text{constant}$. The RT data are further displayed in polar coordinates (figure 3b), with orientation around the circumference and RT along the radius. The fitted function yielded R^2 values of 0.94 for both functions in the 1PP task, while it produced R^2 values of 0.74 in the 3PP task. The corresponding minimum RT values were located at an orientation very close to 0° for the 1PP task (6.4°); for the 3PP condition, these values deviated somewhat further from 0° (49.1°). The absolute value of the amplitude of the fitted sine function in the 3PP task (185.9 ms) was notably smaller than that for the 1PP task (812.8 ms), indicating that RT in the 3PP task was more flat across orientations as compared to the 1PP task.

In order to further examine the orientation which produced minimum RT, sine functions were fitted to the RT data as a function of orientation for each participant.

The minimum RT values for twenty-two out of twenty-four participants (92%) in the 1PP task were located at an orientation more close to the participant than the experimenter. In order to evaluate the location where the minimum RT values were found, angular deviation from 0° was calculated for each participant. Mean angular deviation (±1 SEM) for these twenty-two participants was 27.0° (±4.0°). The minimum RT values for the remaining two participants (8%) in the 3PP task were located at an orientation closer to the experimenter than to the participant. The mean angular deviation (±1 SEM) for the two participants was 138.2° (±27.3°). This result confirms that minimum RT for the haptic 1PP task is located close to 0°.

In contrast, the location for the minimum RT values was more variable among the participants in the 3PP task as compared to the 1PP task. More specifically, the minimum RT values for fourteen out of twenty-four participants (58%) in the 3PP task were located at an orientation closer to the participant than to the experimenter. The mean angular deviation (±1 SEM) for the fourteen participants was 32.0° (±5.9°). On the other hand, the minimum RT values for ten participants (42%) were located at an orientation closer to the experimenter than to the participant. The mean angular deviation (±1 SEM) for the ten participants (±1 SEM) was 150.5° (±9.3°).

These results show that the canonical orientation for representing hands was also located near the subjects' own upright orientation, regardless of sensory modality. In contrast, the results for the third-person perspective instructions were different for vision and haptics. Most visual participants and fewer than a half of the haptic participants adopted a 'pure' third-person perspective, yielding the predicted inverted U-shaped RT curve as a function of orientation. However, the rest of the haptic participants appeared to favour a two-stage response strategy; initially, they mentally rotated the stimulus hand to their own upright orientation to make a preliminary laterality judgment based on a first-person perspective; they subsequently reversed this judgment (ie 'left' became 'right'; 'right' became 'left'), as demanded by a correct third-person perspective response.

To evaluate this interpretation, we conducted experiment 3, in which participants performed the same task haptically from a third-person perspective. This time, however, they were explicitly instructed to *mentally rotate the rubber hand to the experimenter's position*. We expected that the more explicit instruction would bias participants toward adopting a mental-rotation heuristic guided by a third-person perspective.

4 Experiment 3

Although instructed to use first-person or third-person perspectives in experiments 1 and 2, the participants were free to select their own heuristic. In experiment 3, participants were asked to perform the same 3PP task; however, this time they were explicitly instructed to mentally rotate the image of the rubber hand to match the orientation of the experimenter's hand (third-person perspective). We also strongly discouraged them from performing the mental match with respect to the upright orientation of their own hand (first-person perspective). We predicted that if participants were capable of adopting this one-step 3PP heuristic, RT as a function of orientation should be fitted best by an inverted U-shaped function.

4.1 *Materials and methods*

4.1.1 *Participants.* A total of twenty-three female volunteers aged 17 – 26 years (mean = 19.4 years) participated. They were recruited from Subject Pool in Department of Psychology, Queen's University. All were right-handed according to the Edinburgh Handedness Inventory (Oldfield 1971), with no known manual sensorimotor deficits. Participants provided written informed consent. The experiment was approved by the local ethics committee of Queen's University (Canada).

4.1.2 *Procedure.* The rubber hands used previously served as stimuli. The experimental setup was identical to that of the haptic 3PP task in experiment 2. The experimental design was equivalent to that of experiment 2, with one exception. The aim of experiment 3 was to examine whether participants could perform the 3PP task by utilising a one-step third-person-perspective heuristic when explicitly instructed to do so. *Participants were strongly discouraged from ever mentally rotating the rubber hand to their own upright position (first-person perspective).* The experiment lasted ~50 min.

4.2 *Results and discussion*

4.2.1 *Performance accuracy.* Once again, the mean (±1 SEM) percentage correct was substantially above chance level (ie 50%): 91.6 (±1.7)%. This result demonstrates that the participants could perform the task well, despite being biased toward adopting a heuristic that explicitly involved a third-person perspective. A four-way ANOVA with four within-subjects (orientation, with eight levels; hand model with two levels; hand with two levels; hand position with two levels) factors was performed with percentage correct as the dependent variable. This produced significant main effects of orientation ($F_{7,1386} = 2.1$, $p < 0.05$, $\eta_p^2 = 0.011$); hand model ($F_{1,1386} = 3.9$, $p < 0.05$, $\eta_p^2 = 0.003$); and hand position ($F_{1,1386} = 10.0$, $p < 0.01$, $\eta_p^2 = 0.007$), with the prone position producing higher performance accuracy than the supine position. No significant interaction was observed. Since we observed a significant main effect of orientation, we address the possibility of a speed–accuracy trade-off, as before, in section 4.2.2.

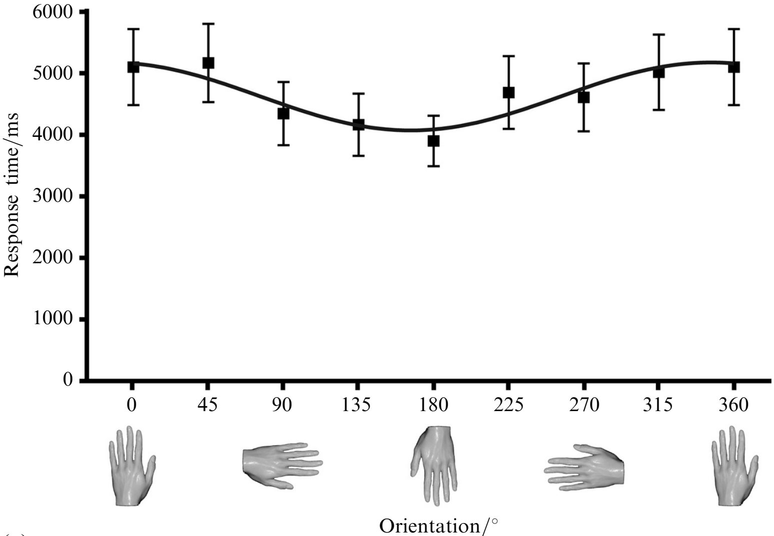
4.2.2 *Response time (RT).* We conducted the same analysis as in the two previous experiments. An omnibus four-way ANOVA with four within-subjects (orientation, with eight levels; hand model with two levels; hand with two levels; hand position with two levels) factors was performed with percentage correct as the dependent variable. This produced significant main effects of orientation ($F_{7,1263} = 8.9$, $p < 0.001$, $\eta_p^2 = 0.047$); hand model ($F_{1,1263} = 7.3$, $p < 0.01$, $\eta_p^2 = 0.006$); and hand ($F_{1,1263} = 21.3$, $p < 0.001$, $\eta_p^2 = 0.017$), the left hand producing longer response times than the right hand. The hand × hand position interaction term was also statistically significant ($F_{1,1263} = 4.3$, $p < 0.05$, $\eta_p^2 = 0.003$). Because we found no significant interactions between orientation and any other factors in any combination, hand model, hand, and hand position were collapsed by averaging to simplify our subsequent analyses. Table 3 presents summary response time ± SEM for all levels of orientation, hand, and hand position factors.

Table 3. Response time for 3PP task in experiment 3 (haptics). Mean ±1 SEM.

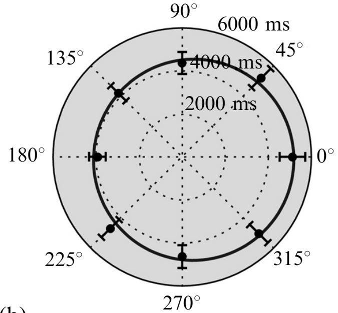
Hand	Hand position	Orientation/°							
		0	45	90	135	180	225	270	315
Left	supine	5295±647	5765±986	4804±745	4914±735	4373±575	4529±576	5203±704	5861±1014
	prone	5710±743	5032±524	4880±594	4174±452	4372±502	5291±716	4409±542	4454±433
Right	supine	4990±787	5378±752	4029±611	3806±612	3075±328	4334±658	4564±699	4554±753
	prone	4808±645	5034±658	3800±408	3841±431	3823±444	4725±760	4453±445	5276±578

In order to examine whether the effect of orientation was merely due to a speed–accuracy trade-off, we calculated the correlation coefficient (Pearson) between percentage correct and RT across orientations. Once again, we observed a negative correlation coefficient for each perspective ($r_6 = -0.82$), indicating that the faster the participants responded, the more accurate their responses. We conclude that it is highly unlikely that the differences in RT observed in experiment 3 were the result of a speed–accuracy trade-off.

4.2.3 *Minimum response time across orientations.* Figure 4 shows the mean haptic RTs as a function of hand orientation. Haptic mean RTs ranged from 3920 (±410) ms at 180° to 5187 (±634) ms at 45° across orientations. One possible concern about explicitly instructing participants to mentally rotate the rubber hand to *the experimenter's position* is that the participant may have known how their RTs would be affected by changes in stimulus orientation. However, the mean RTs in this experiment were highly similar to those of previous experiments, regardless of sensory modality: 4644 (±526) ms in experiment 3 versus 4171 (±285) ms in experiment 2. Thus, it is unlikely that the participant produced an inverted U-shaped function not by adopting a third-person perspective, but by consciously delaying her RTs as the stimulus orientation was rotated further from the experimenter's upright orientation.



(a)



(b)

Figure 4. Experiment 3. (a) Haptic response time as a function of orientation for third-person perspective. Sine functions fitted to the data and their R^2 values were as follows. $\mathrm{RT} = 551.4 \times \sin(\mathrm{orientation} + 103.8°) + 4643.7$, $R^2 = 0.82$. The data represent the mean (± SEM) of twenty-three participants. (b) RT function expressed in polar coordinates, with orientation around the circumference and RT along the radius.

Sine functions were fitted to the RT data as a function of orientation for first-person and third-person perspective conditions (figure 4a) by using the following algorithm: $\mathrm{RT} = \mathrm{amplitude} \times \sin(\mathrm{orientation} + \mathrm{phase}) + \mathrm{constant}$. The same RT data are also displayed in a polar plot in figure 4b. The fitted function yielded R^2 values of 0.82. The corresponding minimum RT values were angularly located near 180° (166.2°). In order to confirm the consistency of the RT pattern across participants, sine functions were fitted to the RT data as a function of orientation for each participant. The minimum RT values for nineteen of the twenty-three participants (83%) were angularly located closer to the experimenter than to the participant. The mean angular deviation from the participant's upright position was calculated as the absolute value of minimum angular difference from 0° (or 360°) for each participant. The mean angular deviation (±1 SEM) for the nineteen participants was 159.1° (±4.2°). For the remaining four participants (17%), the minimum angular deviation was closer to the participant than to the experimenter, 23.9° (±9.6°). These results suggest that minimum RT for a large majority of the participants was located close to the experimenter's upright position.

In summary, the haptic RT pattern in experiment 3 was more consistently shaped like an inverted U (cf experiment 2), confirming that our observers were haptically capable of adopting a one-stage mental-rotation heuristic from the experimenter's (third-person) perspective.

5 General discussion

As hypothesised, when participants judged to which side of their own body the rubber hand belonged, they responded more slowly as its orientation increasingly deviated from the *participant's* own upright orientation, regardless of sensory modality. This result suggests that when instructed to assume a first-person perspective, the canonical orientation for representing the human hand in the horizontal plane was similar for haptics and vision. Thus, we have extended the earlier studies by showing that the same canonical orientation, ~0°, is used *haptically* when the participant is instructed to assume a first-person perspective. The result is also consistent with other studies that have shown that face-inversion effects occur haptically (Kilgour et al 2004; Kilgour and Lederman 2006; McGregor et al, in press), as well as visually (eg Yin 1969).

The main aim of the present study was to test the hypothesis that viewers can assume a third-person perspective when required to judge the laterality of hands presented visually or haptically. In accord with our prediction, participants responded more *slowly* as the visual orientation increasingly deviated from the experimenter's upright orientation (experiment 1). This result confirms that participants are visually capable of recognising human hands from a third-person perspective. Our finding extends imagery results obtained earlier by Sirigu and Duhamel (2001) by showing that the canonical orientation of visually represented hands changed depending on which perspective participants were instructed to adopt. The current study further confirms that participants responded more rapidly in the first-person perspective task than in the third-person perspective task. Thus, although participants were able to assume a third-person perspective, human hands may be more efficiently represented with respect to a person's own upright orientation than to that of another person.

The results for the third-person perspective task with haptics (experiment 2) were more complicated than those obtained with vision (experiment 1). Participants were considerably more accurate than chance; however, two different RT patterns were observed. Fewer than half of the participants responded more slowly as orientation increasingly deviated from the *experimenter's* upright position (inverted U-shaped function). This result suggests that only these participants were capable of adopting a 'true' third-person perspective in the haptic task. Presumably they mentally rotated the rubber hand to the experimenter's upright orientation and then directly made their laterality judgment. In contrast, the other half responded more slowly as orientation increasingly deviated from *their own* upright orientation (U-shaped function). How might the latter participants have performed the task without directly processing the hands using a third-person perspective? They could have mentally rotated the rubber hand to their own upright orientation in order to derive an initial judgment. However, to perform at such a high level of accuracy they would then have had to reverse their initial laterality judgment because a correct answer from a third-person perspective is spatially opposite the side that is correct from a first-person perspective. Because this heuristic involves mentally rotating the hand to the viewer's own upright orientation, the resulting RT function resembled the U-shaped function obtained with the first-person perspective instruction. In support of this speculation, the results of the post-experimental questionnaire showed that thirteen of the fourteen participants (93%) who responded more slowly as the orientation increasingly deviated from the *participant's* upright orientation reported that they initially adopted a first-person perspective at least once. However, only three of the ten participants (30%) who responded more slowly as the orientation increasingly deviated from the *experimenter's* upright orientation reported using this heuristic at least once during the experiment. It would appear that more than half the participants in experiment 2 adopted a two-step heuristic that initially involved a first-person perspective, presumably because it was more familiar and thus easier to use than a third-person perspective.

Such speculation is further supported by the findings of experiment 3, in which participants were explicitly instructed to mentally rotate the stimulus hand to the experimenter's orientation. Unlike experiment 2, the majority of the participants responded more slowly as the orientation increasingly rotated further from the *experimenter's* upright orientation. This result confirms that most participants can accurately adopt a third-person perspective when discouraged from using the alternative heuristic involving a first-person perspective.

In order to adopt a third-person perspective when processing, representing, and recognising human hands, the mentally represented rubber hand would be compared with respect to the third person, namely with an allocentric frame of reference. However, previous studies suggest that haptic object perception can be highly influenced by an egocentric frame of reference, in which spatial properties of an object are encoded with respect to the perceiver (Kappers 2007; Prather and Sathian 2002; Volcic et al 2009). For instance, Volcic et al (2009) recently conducted a haptic mental-rotation task to examine how patterns of RT were influenced by multiple spatial frames of reference including egocentric (hand-centred and body-centred) reference frames and allocentric reference frames. In this study, participants were asked to explore haptically two L-shaped cylindrical bars simultaneously with two hands and respond whether the two stimuli were the same or different. Participants placed their hands in different orientations, such that the effect of using the egocentric frames of reference could be measured. A triangular wave function was fitted to the RT patterns as a function of the difference in orientation between the two objects, as determined by a weighted contribution of egocentric (with separate weights for the two different types) and allocentric frames of reference. For most of the participants, the estimated weight was substantially higher for the egocentric frame (each weight for the two different types) than for the allocentric frame of reference. This result indicates that an egocentric reference frame (eg hand-centred) predominates in a haptic mental-rotation task. Indeed, when viewers normally explore an object haptically, they must not only plan their own manual movements, but receive updated somatosensory information from the hand movements that are physically executed. Therefore, continued awareness of one's own hand during manual exploration may enhance its importance during haptic processing while discouraging, perhaps even impeding, the haptic viewer from imagining the experimenter's body and its position.

In contrast, previous studies suggest that an allocentric, gravitationally aligned, reference frame was more heavily used than an egocentric frame of reference for visual recognition of familiar and unfamiliar 2-D patterns (Corballis et al 1976, 1978). Visual extraction of information is a more simultaneous process (Lederman and Klatzky 1990) that also provides spatial details pertaining to the stimulus hand *and* to the experimenter's spatial circumstances (position, orientation, etc), relative to that hand.

Thus, participants may be more reluctant and/or find it less comfortable adopting a third-person perspective haptically as opposed to visually owing to such inherent differences in perceptual processing and in the relative weighting of egocentric versus allocentric spatial frames of reference employed.

To summarise, the present study shows that a canonical orientation was used to represent human hands haptically, as well as visually, and that it is similar for these two modalities when participants are instructed to assume a first-person perspective. It further demonstrates that a majority of viewers were capable of adopting a third-person perspective in order to process human hands, regardless of sensory modality. This ability may contribute to understanding the body actions of others, and is thus critically important for social communication. Nonetheless, the canonical orientations used to represent hands haptically under first-person and third-person perspectives would appear to be more strongly influenced by body-based heuristics than those that are derived visually. In the present study, we used only female participants and tested canonical orientation within a horizontal plane. In future, we plan to extend the current investigation by directly addressing possible gender differences and by examining the canonical orientation for representing human hands in 3-D space from first-person and third-person perspectives.

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