

## Article

# The Bias toward the Right Side of Others Is Stronger for Hands than for Feet

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**Abstract:** As shown by a series of previous studies, ambiguous human bodies performing unimanual or unipedal actions tend to be perceived more frequently as right-handed or right-footed rather than left-handed or left-footed, which indicates a perceptual and attentional bias toward the right side of others' body. However, none of such studies assessed whether the relative strength of such a bias differs between the upper and lower limbs. Indeed, given that the prevalence of right-handedness is slightly larger than that of right-footedness, and given that hands provide more information than feet as regards both communicative and aggressive acts, it is plausible that the bias toward the right side of human bodies should be stronger for the hand than for the foot. We performed three experiments in each of which participants had to indicate the rotating direction (revealing the perceived handedness/footedness) of ambiguous human figures with either one limb (arm or leg) or two limbs (one arm and the contralateral leg) extended. The hypothesized advantage of the right hand over the right foot was found in both the second and the third experiment.

**Keywords:** handedness; footedness; human body; ambiguous figures; perceptual frequency effect



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## 1. Introduction

Handedness, which refers to the preferential use of one limb over the other for manual activities, is the most studied behavioral asymmetry in humans [1]. Handedness is often determined by self-reports of the hand used for writing and other common unimanual tasks, such as cutting with a knife or hammering a nail into a wall, and it is used to categorize individuals into groups when exploring lateralized behaviors. Although most research studying human motor asymmetry initially concerned handedness, there has been a growing interest for foot preference [2]. This topic came to be popular probably because footedness might be a less biased measure of lateral preference than handedness (e.g., [3]), foot preference being less influenced by environmental and social factors, and/or by years of practice in performing complex unilateral tasks compared with hand preference [4–7].

Laterality surveys indicate that the prevalence of dextral bias appears to be larger for handedness than for footedness (e.g., 88.2% vs. 83.2%; [8]). This might be linked to several factors, including the aforementioned difference between hands and feet with regard to external influences and asymmetrical practice [4–7], the fact that mixed-handedness is less frequent (2–7%) compared with mixed-footedness (26–35%; [7]), and the observation that the concordance between handedness and footedness is more common among right-handers than among left-handers [9–13].

Although social interaction represents a long-standing topic in psychological science, the role of handedness has been investigated only to a limited extent in this context. In particular, it should be pointed out that, in most cases, we observe and interact with

right-handed individuals. It has been recently proposed that the high frequency of face-to-face interactions with right-handers could contribute to explain the attentional and perceptual advantages of the left visual field, which could also be adaptive in social life (see [14] for a more detailed discussion). Specifically, a perceptual frequency effect [15] could prompt people to preferentially pay attention to the right rather than the left side of human bodies, and thus reduce monitoring of the left limbs, resulting in a reduced ability to discriminate left-limbed movements rather than right-limbed movements, and could explain the 'surprise effect' proposed for the advantage of left-handers in fighting.

It has also been proposed that left-handers might be favored over right-handers in different interactive sports, that is, those sports involving the direct confrontation with one or more opponents [16–18]. Indeed, there is some evidence of an advantage of left-handedness in several combat sports [19], including mixed martial arts [20–22], karate and taekwondo [23], boxing [22,24,25], wrestling [26], and fencing [27,28]. Similar results have also been reported for non-combat sports such as tennis [29–31], baseball [32], basketball [33], and cricket [34]. It is plausible that a similar advantage could also exist for left-footedness [35,36], which would be consistent with the findings by McMorris and Colenso [37] and Loffing and Hagemann [38], which shows that goalkeepers recognize the direction of right-footed penalty shots better than the direction of left-footed penalty shots. Besides sport research, the notion of an attentional bias toward the right side of others' body is supported by several findings. For example, when a point-light walker is ambiguous with regard to its lateral direction because of equal motion cues to each side, it is interpreted more often as right-facing rather than left-facing, a percept in which the right arm and leg of the walker are in the foreground [39]. Moreover, several studies [40–44] demonstrate that both right- and left-handers show a tendency to perceive a right rather than a left limb as the active one when interpreting ambiguous human silhouettes performing hand or foot actions. Differently from previous studies investigating the representations of others' handedness by means of action imagination tasks, in which left-handers and weak right-handers exhibited a smaller bias toward the right side of bodies compared with right-handers [45–48], the fact that no correlation between the degree of participants' handedness and the preference for perceiving right-limbed actions was observed in any of our previous studies with ambiguous human silhouettes [40–44] suggests that the latter involve considerably more visual than motor processes than the former. The studies with ambiguous human silhouettes also indicate that body configural information might include the implicit knowledge that the dominant limb of humans is usually placed on their right side, as specifically demonstrated by the fact that inversion—a manipulation that disrupts the configural processing of human bodies (e.g., [49,50])—abolishes the bias to perceive right-handed actions [43].

Two main hypotheses have been proposed in order to account for the left-handers' advantage in sports: (1) favorable predispositions inherent to left-handers (innate superiority hypothesis), and (2) the negative frequency-dependent selection hypothesis. As regards possible innate superior abilities, it has been proposed that left-handers' advantage in sports might arise from their greater spatial, visual, and motor abilities compared with right-handers (e.g., [51–54]). Several explanations have been suggested for such superior skills of left-handers, including better functioning or increased size of the right hemisphere, reduced hemispheric lateralization, and more bilateral representation of motor control [55–58], although some authors reject them and instead single out some sort of tactical advantage [59–61]. Based on the fact that only around 10% of the general population is left-handed (e.g., [62]), the negative frequency-dependent selection hypothesis [15] accounts for the overrepresentation of left-handers in several sports with the fact that left-handers would benefit from the limited experience and familiarity of right-handed players against left-handed ones. Actually, there is evidence that observers anticipate better the outcomes of right-handed and right-footed movements than those of left-handed and left-footed movements, likely because the visual system is more accustomed to right-limbed rather than left-limbed actions [37,38,63–66] (see also [14,40–44]), in agreement with

theories emphasizing the importance of visual experience in action recognition [67]. In this regard, the crucial role of perceptual processes is corroborated by the fact that a specific training consisting in the visual presentation of left- and right-handed actions can attenuate or intensify, respectively, the advantage in predicting the outcome of right- rather than left-handed actions [66].

In the present study, we focused on the second account. In particular, given that the prevalence of right-handedness is slightly larger than that of right-footedness, and given that hands provide more information than feet as regards both communicative and aggressive acts, we predicted that the perceptual/attentional bias toward the right side of human bodies should be stronger for the hand than for the foot. Specifically, the purpose of the current study was to examine whether the tendency to interpret ambiguous animated figures as right-handed was stronger than the bias to perceive them as right-footed. Moreover, given that task demand is positively related to the strength of lateral preferences (see [2] for a review), we expected that, compared to a simpler action, a more complex action would have been interpreted as right-handed more frequently. In order to test these hypotheses, we performed three experiments in each of which participants had to indicate, respectively, the rotating direction of: (1) ambiguous human figures, with either one arm or one leg extended, who were either acting on an object (a ball) or not; (2) ambiguous human figures with one arm and the contralateral leg extended; (3) ambiguous human figures with either one arm or one leg extended. With reference to the extended limb, the stimuli of Experiment 1 were represented as rotating inward (i.e., “palmward” when considering the hand movement and “en dedans”—a ballet term indicating a pirouette in which the dancer turns toward the supporting leg—when considering the foot movement), whereas the stimuli of Experiments 2 and 3 were represented as rotating either inward or outward (i.e., “backward” when considering the hand movement and “en dehors”—a ballet term indicating a pirouette in which the dancer turns away from the supporting leg—when considering the foot movement; see [40,43]). We point out that we required participants to indicate (by selecting one of two colored arrows; see Procedure section of Experiment 1) the rotating direction rather than the handedness or footedness of stimuli in order to prevent them from focusing overtly on our dependent variable of interest (i.e., limb laterality). It should be also noticed that, whereas the perceived rotating direction of ambiguous human figures such as those used in the present study can be easily reported (even by inexperienced observers) but no population bias has ever been found when controlling for the possible confounding variables ([40,43,68]), their perceived limb laterality is almost impossible to report (even by the authors themselves) but nonetheless exhibits a significant population bias in favor of the right limb [40,43]. This seems to be consistent with the fact that, although the limb laterality of observed individuals can often go unnoticed (e.g., see [69]), it exerts tangible effects at the behavioral level, as highlighted by the aforementioned sport studies. As recommended by Simmons, Nelson, and Simonsohn [70], we clearly describe how we determined our sample sizes, all manipulations, all data exclusions, and all measures in the study.

## 2. Experiment 1

### 2.1. Materials and Methods

#### 2.1.1. Participants

Seventy-four Italian-speaking participants (36 females and 38 males; age: 18–38 years) took part in the study. We scheduled the recruitment of 8 male participants and 8 female participants for each combination of response arrow spinning direction (CW or CCW), color (red or green), and position (above or below; see Procedure section). However, given that one experimenter allotted 10 participants of the same sex to some of such combinations by mistake, we remedied this by allotting at least 9 participants of the same sex to each condition. All participants had normal or corrected-to-normal vision. On the basis of the effect size ( $\eta_p^2 = 0.10$ ; unpublished data) observed for the main factor “perceived limb laterality” in our study with the most similar experimental design [40], we can predict

that the use of the desired sample size ( $N = 64$ ), with an alpha of 0.05, would entail a statistical power of at least 0.70. We point out that the statistical power would be 0.74 if the effect size were the same as in our previous work [40], but we expect increased effect size and statistical power here because of the inclusion not only of stimuli with one leg extended, but also of stimuli with one arm extended. We do not have previous data to make predictions about the effect size and statistical power of interaction effects.

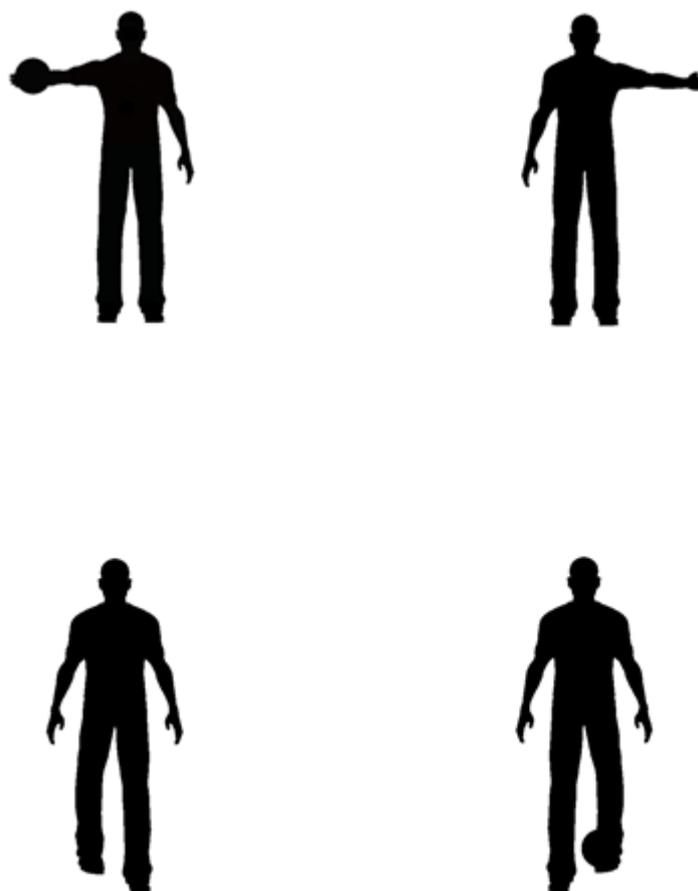
### 2.1.2. Stimuli

We obtained 256 stimuli from a set of original animations created with the software Poser Pro 2012 (Smith Micro Software Inc., Pittsburgh, PA, USA) and depicting the silhouette of a human male rotating inward (with respect to the extended limb) about his vertical axis while keeping a static posture. Specifically, the silhouette either stood on both legs with one arm close to the body and the other arm extended or stood on one leg with the other leg extended and both arms close to the body. In addition, the extended limb of the silhouettes was either free or acting on a ball. Therefore, four original animations were created: (1) a man with one arm extended, (2) a man with one arm extended and acting on a ball, (3) a man with one leg extended, and (4) a man with one leg extended and acting on the ball (Figure 1). The silhouettes were depicted in black against a white background, and no straightforward depth cue was available, so that the animations were ambiguous and could be interpreted as rotating either clockwise or counterclockwise. The first percept was consistent with an extended left limb and the second percept was consistent with an extended right limb. Adobe Photoshop CS6 (Adobe, San Jose, CA, USA) was used to decompose the four original animations in their 32 constituent frames. Then, for each original animation, we created 32 different versions, each depicting a complete rotation of the silhouette. Specifically, we rearranged the 32 frames by alternating the starting frame (i.e., from the 1st to the 32nd frame, from the 2nd to the 1st frame, and so on). Although we aimed to remove—as much as possible—potential perspective cues (e.g., relative size and relative height) by appropriately setting the Poser parameters (e.g., camera distance and elevation), we created a further set of 128 animations by horizontally mirroring each frame. This manipulation allowed us to compensate for any remaining uncontrolled depth cue or asymmetry which could have biased the perception of the extended limb (Figure 1). Therefore, the final set of 256 animations comprised each possible combination of extended limb (arm or leg), action complexity (with or without ball), mirroring, and starting frame. On average, the component frames of each stimulus measured around  $10.5^\circ$  vertically and around  $4.7^\circ$  horizontally at a viewing distance of 57 cm.

### 2.1.3. Procedure

The experiment, consisting of 256 trials, was carried out on a set of Windows (Microsoft Corporation, Redmond, WA, USA) notebooks with an Intel (Intel Corporation, Santa Clara, CA, USA) processor and a 15.4-inch monitor, and was run using SuperLab 4.0 (Cedrus Corporation, San Pedro, CA, USA). Participants, seated comfortably in a quiet room, and with their eyes approximately 57 cm from the computer screen, were invited to place their hands palm-down on the table and required not to cross their arms, legs, or fingers throughout the experiment.

In each trial, a black fixation cross was presented for 500 ms in the center of a white screen and followed by one of the previously described stimuli presented centrally. Then, a pair of colored arrows (indicating the two possible spinning directions of the silhouette) appeared, one slightly above and one slightly below the center of the screen. Participants were instructed to gaze at the fixation point and to report the perceived spinning direction of the silhouette by saying “VERDE” (the Italian word for “GREEN”) or “ROSSO” (“RED”) depending on which arrow corresponded to their percept. When the experimenter, positioned behind the participant, recorded her/his response by pressing the key “V” or “R” on a keyboard connected to the computer, the next trial started. Stimuli were presented in a random sequence.



**Figure 1.** Examples of stimuli with an arm or a leg extended (with and without ball).

The first frame of each stimulus lasted 750 ms, and each of the remaining 31 frames lasted 36 ms (with this expedient, we aimed to reduce the possible response carry-over from one trial to the next; e.g., see [71]). Furthermore, we collected participants' responses by means of two colored arrows, each indicating a possible spinning direction, rather than by means of straightforward vocal responses such as "ORARIO" ("CLOCKWISE") and "ANTIORARIO" ("COUNTERCLOCKWISE"). We adopted this expedient because observers seem to exhibit some difficulty in labeling as clockwise or counterclockwise a rotation about an axis which is approximately parallel to their own body axis.

Before the experiment, participants were familiarized with the response modality by means of a pretest which used the two response arrows to indicate the spinning direction of a black human silhouette with clear perspective cues (e.g., the relative size of the hands in different positions). Such a pretest went on until the participant succeeded in matching each spinning direction with the corresponding arrow without fail, and led to the exclusion from the study of the few subjects who were not able to perform the task. After the experiment, participants were administered the Italian version [72] of the Edinburgh Handedness Inventory [73]. The study was carried out in accordance with the principles of the Declaration of Helsinki, and all participants provided written informed consent.

#### 2.1.4. Data Analysis

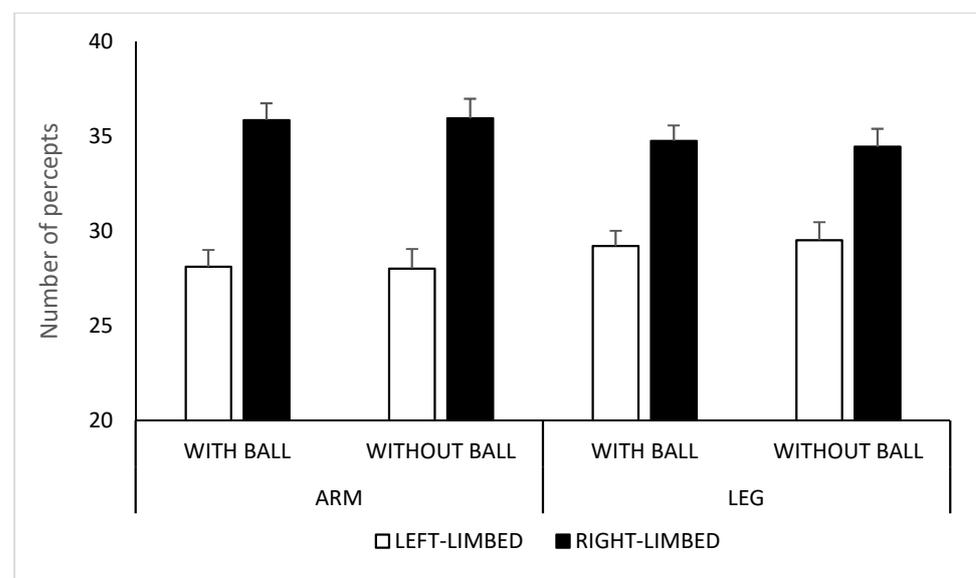
On the basis of the laterality score obtained in the Italian version [72] of the Edinburgh Handedness Inventory [73], 70 participants with a positive laterality score (range: 0.05/1.00;  $M = 0.66 \pm 0.03$  SEM) were classified as right-handers, and 4 participants with a negative laterality score (range:  $-1.00/-0.03$ ;  $M = -0.53 \pm 0.22$  SEM) as left-handers.

We examined whether the number of actions interpreted as right-handed differed as a function of the extended limb and/or the complexity of action. We excluded 6 female

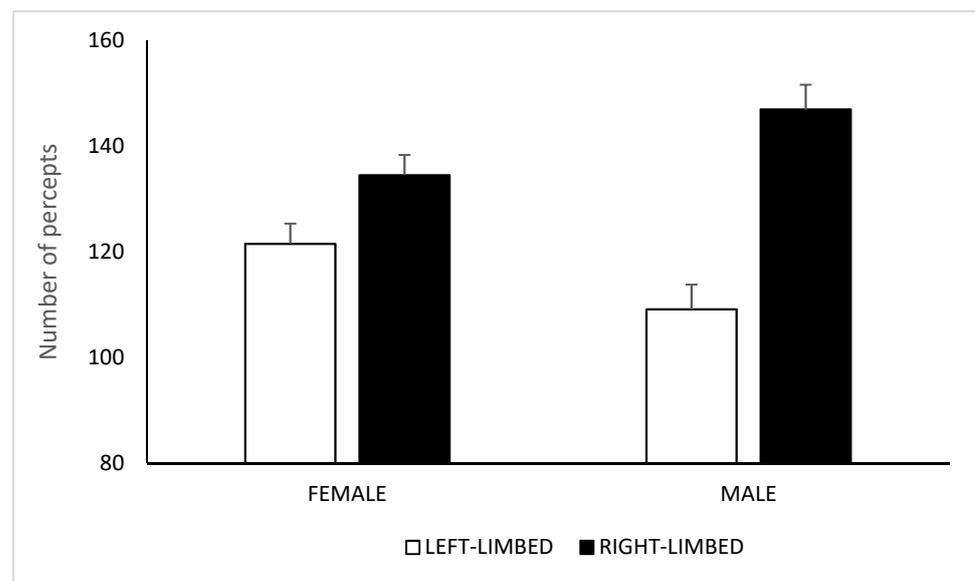
participants and 4 male participants scoring more than 2 standard deviations below or above the mean of their 'Sex' group in any combination of extended limb (arm or leg), action complexity (with or without ball) and perceived limb laterality (right or left). Then, a repeated-measures analysis of variance (ANOVA) was performed using participant's sex (female or male) as between-subjects factor and extended limb (arm or leg), action complexity (with or without ball), and perceived limb laterality (right or left) as within-subjects factors. Post-hoc two-tailed *t*-tests were performed when needed to specify the significant differences (within each set of post-hoc contrasts, *p*-values were adjusted using the Bonferroni correction for multiple comparisons). Laterality score was correlated with the number of actions perceived as right-limbed because—due to the limited number of left-handers—it was not possible to include handedness as an independent variable in the ANOVA.

## 2.2. Results and Discussion

The ANOVA showed a main effect of limb laterality ( $F_{1,62} = 17.06$ ;  $p < 0.001$ ;  $\eta_p^2 = 0.22$ ; Observed Power = 0.98) and a significant interaction between limb laterality and participant's sex ( $F_{1,62} = 4.07$ ;  $p = 0.048$ ;  $\eta_p^2 = 0.06$ ; Observed Power = 0.51). Participants perceived a larger number of right-limbed ( $M = 141.09$  [55.11%]) rather than left-limbed actions ( $M = 114.91$  [44.89%]). As shown in Figure 2, participants perceived a significantly larger number of right-limbed actions in each experimental condition, even after the Bonferroni correction for multiple comparisons (hand with ball:  $M_{\text{right}} = 56.05\%$ ;  $M_{\text{left}} = 43.95\%$ ;  $t_{63} = 4.34$ ;  $p < 0.001$ ; hand without ball:  $M_{\text{right}} = 56.20\%$ ;  $M_{\text{left}} = 43.80\%$ ;  $t_{63} = 3.83$ ;  $p < 0.001$ ; foot with ball:  $M_{\text{right}} = 54.35\%$ ;  $M_{\text{left}} = 45.65\%$ ;  $t_{63} = 3.42$ ;  $p = 0.004$ ; foot without ball:  $M_{\text{right}} = 53.86\%$ ;  $M_{\text{left}} = 46.14\%$ ;  $t_{63} = 2.60$ ;  $p < 0.05$ ). Male participants perceived a larger proportion of right- ( $M = 57.39\%$ ) rather than left-limbed actions ( $M = 42.61\%$ ;  $t_{33} = 4.03$ ;  $p < 0.001$ ), whereas no difference was observed in female participants (right-limbed:  $M = 52.54\%$ ; left-limbed:  $M = 47.46\%$ ;  $t_{29} = 1.70$ ;  $p = 0.20$ ). Moreover, the proportion of actions perceived as right-limbed was larger for male than for female participants ( $t_{62} = 2.02$ ;  $p < 0.05$ ; Figure 3). No significant correlation was observed between participants' laterality score and the number of actions perceived as right-limbed.



**Figure 2.** Number of actions perceived as right- and left-limbed in each experimental condition.



**Figure 3.** Number of actions perceived as right- and left-limbed in female and male participants.

This first experiment confirmed the presence of a bias toward the right side of observed bodies reported in previous studies [40–44], but not the predictions that such a bias would have been stronger for the hand compared with the foot and for a more complex compared with a simpler action. However, it is plausible that a difference between upper and lower limbs might emerge when the ambiguous stimulus depicts a human figure with one arm and the contralateral leg extended, given that hands could represent more salient stimuli compared with feet (e.g., see [74]). Moreover, whereas our previous studies [40,43] included stimuli rotating both inward and outward with reference to the extended limb, in this first experiment we included only stimuli rotating inward in order to use stimuli as realistic as possible (a ball is usually handled with the palm rather than the back of the hand). Another possible limitation of Experiment 1 was that, whereas the arm was extended laterally with reference to the figure’s body, the leg was extended frontally, which might have introduced some confound and could also account for why no difference was observed between upper and lower limbs. These issues were addressed in Experiment 2.

### 3. Experiment 2

#### 3.1. Materials and Methods

##### 3.1.1. Participants

Sixty-four Italian-speaking participants (32 females and 32 males; age: 18–30 years) took part in the study. We recruited 8 male participants and 8 female participants for each combination of response arrow spinning direction (CW or CCW), color (red or green), and position (above or below). All participants had normal or corrected-to-normal vision. For a discussion of anticipated effect size and statistical power, see the Participants section of Experiment 1.

##### 3.1.2. Stimuli

We obtained 128 stimuli from an original animation created with the software Poser Pro 2012 (Smith Micro Inc.) and depicting the silhouette of a human male rotating about his vertical axis while keeping a static posture. Specifically, the silhouette stood on one leg, with the other leg and its contralateral arm extended (Figure 4). The silhouette was depicted in black against a white background and no straightforward depth cue was available, so that the animation was ambiguous and could be interpreted as rotating either clockwise or counterclockwise. Adobe Photoshop CS6 was used to decompose the original animation in its 32 constituent frames. Then, we created 64 different versions of the animation, each depicting a complete rotation of the silhouette. Specifically, we rearranged the 32 frames by

alternating the starting frame and order (i.e., from the 1st to the 32nd frame and vice versa, from the 2nd to the 1st frame and vice versa, and so on). The order manipulation allowed us to compensate for the association between spinning direction and extended limbs, because in the original order (which can be defined inward with regard to the hand movement and outward with regard to the foot movement) the clockwise rotation was congruent with an extended left arm and an extended right leg, whereas in the inverted order (which can be defined outward with regard to the hand movement and inward with regard to the foot movement) the clockwise rotation was congruent with an extended right arm and an extended left leg, and vice versa for the counterclockwise rotation. Although we aimed to remove—as much as possible—potential perspective cues (e.g., relative size and relative height) by appropriately setting the Poser parameters (e.g., camera distance and elevation), we created a further set of 64 animations by horizontally mirroring each frame. The mirroring manipulation allowed us to compensate for any remaining uncontrolled depth cue or asymmetry which could have biased the perception of the extended limb (Figure 4). Therefore, the final set of 128 animations comprised each possible combination of type of rotation (hand-inward/foot-outward or hand-outward/foot-inward), mirroring, and starting frame. On average, the component frames of each stimulus measured around  $10.3^\circ$  vertically and around  $4^\circ$  horizontally at a viewing distance of 57 cm.



**Figure 4.** Example of a stimulus with an arm and a leg extended.

### 3.1.3. Procedure

Except for the stimuli, the procedure was the same as in Experiment 1.

### 3.1.4. Data Analysis

On the basis of the laterality score obtained in the Italian version [72] of the Edinburgh Handedness Inventory [73], 59 participants with a positive laterality score (range: 0.13/1.00;  $M = 0.64 \pm 0.28$  SEM) were classified as right-handers, and 5 participants with a negative laterality score (range:  $-0.71/-0.11$ ;  $M = -0.54 \pm 0.11$  SEM) as left-handers.

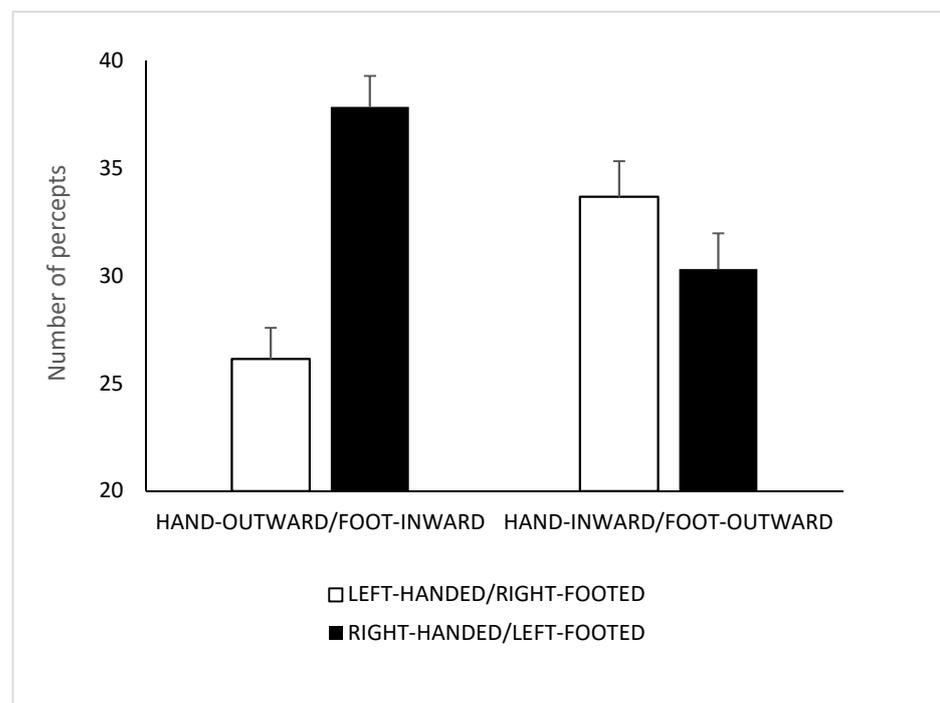
We examined whether the bias toward the right hand overcame the bias toward the right foot. As a first step, we excluded 2 male subjects giving the same response—‘VERDE’ or ‘ROSSO’—to all the 128 trials. We also excluded 4 female participants and 2 male participants scoring more than 2 standard deviations below or above the mean of their ‘Sex’ group in any combination of type of rotation (hand-inward/foot-outward or hand-outward/foot-inward), and perceived limb laterality (right-handed/left-footed or left-handed/right-footed). Then, a repeated-measures analysis of variance (ANOVA) was performed using participant’s sex (female or male) as a between-subjects factor, and type of rotation (hand-inward/foot-outward or hand-outward/foot-inward) and perceived limb laterality (right-handed/left-footed or left-handed/right-footed) as within-subjects factors. Post-hoc two-tailed *t*-tests were performed when needed to specify the significant differences (within each set of post-hoc contrasts, *p*-values were adjusted using the Bonferroni correction for multiple comparisons). The laterality score was correlated with the number of actions perceived as right-handed/left-footed because—due to the limited number of

left-handers—it was not possible to include handedness as an independent variable in the ANOVA.

### 3.2. Results and Discussion

The ANOVA showed a main effect of limb laterality ( $F_{1,54} = 10.10$ ;  $p = 0.002$ ;  $\eta_p^2 = 0.16$ ; Observed Power = 0.88) and a significant interaction between type of rotation and perceived limb laterality ( $F_{1,54} = 7.11$ ;  $p = 0.01$ ;  $\eta_p^2 = 0.12$ ; Observed Power = 0.74). Participants perceived a larger number of right-handed/left-footed ( $M = 68.18$  [53.27%]) rather than left-handed/right-footed actions ( $M = 59.82$  [46.73%]).

Participants perceived a larger proportion of right-handed/left-footed ( $M = 59.15\%$ ) rather than left-handed/right-footed actions ( $M = 40.85\%$ ;  $t_{55} = 4.04$ ;  $p < 0.001$ ) in the hand-outward/foot-inward condition, whereas no difference was observed in the hand-inward/foot-outward condition (right-handed/left-footed:  $M = 47.38\%$ ; left-handed/right-footed:  $M = 52.62\%$ ;  $t_{55} = -1.01$ ;  $p = 0.63$ ). Moreover, the proportion of actions perceived as right-handed/left-footed was larger for the hand-outward/foot-inward condition than for the hand-inward/foot outward condition ( $t_{55} = 2.66$ ;  $p = 0.01$ ; Figure 5). A negative correlation was observed between participants' laterality score and the number of actions perceived as right-handed/left-footed ( $n = 56$ ;  $r = -0.41$ ;  $p = 0.002$ ).



**Figure 5.** Number of actions perceived as right-handed/left-footed and left-handed/right-footed in the hand-outward/foot-inward and hand-inward/foot-outward conditions.

This second experiment provided some support for our hypothesis, given that participants' interpretations clearly favored the right hand rather than the right foot, corroborating the idea that hands could provide more relevant information compared with feet during human interactions. The fact that a significant advantage of the right hand over the right foot was observed only when hand and foot movements were presented together could be due to the limited difference (about 5%) in the prevalence of right-handed versus right-footed actions in the real world [8], which might be too small to modulate the perceptual frequency effect likely responsible for the preference to interpret ambiguous human bodies as right-handed and right-footed when their limbs move separately. Indeed, such a difference should act on a very narrow range, given that the actual proportions of right-handed (about 90%) and right-footed (about 85%) actions are reflected in a very smaller

proportion of ambiguous human bodies perceived as right-limbed (in most cases, about 53%) [40–44]. Similar argumentations could account for the absence of significant effects of action complexity in Experiment 1. On the other hand, it cannot be ruled out that any difference between the stimuli of Experiment 1 (in which the arm was extended laterally and the leg frontally and all stimuli rotated inward) and Experiment 2 (in which both limbs were extended frontally and when the hand rotated inward the foot rotated outward and vice versa) could account for the discordant results. Moreover, in Experiment 2 we found two unpredicted results: (1) the perceptual bias for the right hand overcame that for the right foot only in the hand-outward/foot-inward condition, possibly indicating that the bias for the right hand, foot, or both is larger for outward rather than inward rotations; (2) participants' laterality score correlated negatively (positively) with the tendency to perceive right-handed/left-footed (left-handed/right-footed) actions, possibly indicating either that the more right-lateralized the participant, the more (the less) her/his bias to perceive right-footed/left-handed (right-handed/left-footed) actions, or that less right-lateralized participants were more likely to attend to the upper limbs of stimuli, which in turn might increase the likelihood to perceive right-handed actions. However, it should be stressed how, being unexpected, these findings must be considered with caution. Experiment 3 addressed the further issues raised by Experiment 2.

#### 4. Experiment 3

##### 4.1. Materials and Methods

###### 4.1.1. Participants

Sixty-four participants (16 Italian-speaking females, 16 Italian-speaking males, 16 Polish-speaking females, and 16 Polish-speaking males; age: 20–36 years) took part in the study. We recruited 8 (4 Italian-speaking and 4 Polish-speaking) male participants and 8 (4 Italian-speaking and 4 Polish-speaking) female participants for each combination of response arrow spinning direction (CW or CCW), color (red or green), and position (above or below). All participants had normal or corrected-to-normal vision. For a discussion of anticipated effect size and statistical power, see the Participants section of Experiment 1.

###### 4.1.2. Stimuli

We obtained 256 stimuli from two original animations created with the software Poser Pro 2012 (Smith Micro Inc.) and depicting the silhouette of a human male rotating about his vertical axis while keeping a static posture. Specifically, the silhouette either stood on both legs with one arm close to the body and the other arm extended or stood on one leg with the other leg extended and both arms close to the body (Figure 6). The silhouettes were depicted in black against a white background, and no straightforward depth cue was available, so that the animations were ambiguous and could be interpreted as rotating either clockwise or counterclockwise. Adobe Photoshop CS6 was used to decompose the four original animations into their 32 constituent frames. Then, for each original animation, we created 64 different versions, each depicting a complete rotation of the silhouette. Specifically, we rearranged the 32 frames by alternating the starting frame and order (i.e., from the 1st to the 32nd frame and vice versa, from the 2nd to the 1st frame and vice versa, and so on). The order manipulation allowed to compensate the association between spinning direction and extended limb, because in the original order (which can be defined inward with regard to the limb movement) the clockwise rotation was congruent with an extended left limb, whereas in the inverted order (which can be defined outward with regard to the limb movement) the clockwise rotation was congruent with an extended right limb, and vice versa for the counterclockwise rotation. Although we aimed to remove—as much as possible—potential perspective cues (e.g., relative size and relative height) by appropriately setting the Poser parameters (e.g., camera distance and elevation), we created a further set of 128 animations by horizontally mirroring each frame. The mirroring manipulation allowed to compensate any remaining uncontrolled depth cue or asymmetry which could have biased the perception of the extended limb (Figure 6).

Therefore, the final set of 256 animations comprised each possible combination of extended limb (arm or leg), type of rotation (inward or outward), mirroring, and starting frame. On average, the component frames of each stimulus measured around  $10.3^\circ$  vertically and around  $3.6^\circ$  horizontally at a viewing distance of 57 cm.

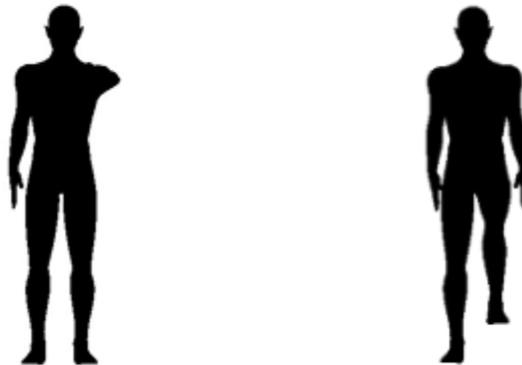


Figure 6. Example of a stimulus with an arm or a leg extended.

#### 4.1.3. Procedure

Except for the stimuli and, for the Polish-speaking participants, the response words in Polish (“ZIELONY” and “CZERWONY” for “GREEN” and “RED”, respectively) and the Polish version (short form translated by Przemysław Zdybek) of the Edinburgh Handedness Inventory [73], the procedure was the same as in Experiments 1 and 2.

#### 4.1.4. Data Analysis

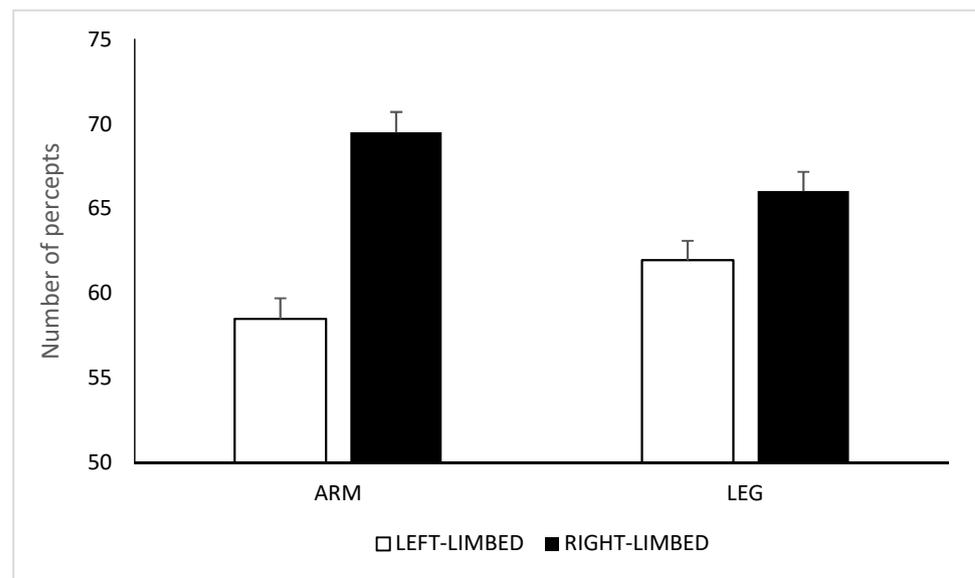
On the basis of the laterality score obtained in the Italian or Polish (short form translated by Przemysław Zdybek) version [72] of the Edinburgh Handedness Inventory [73], 54 participants with a positive laterality score (range: 0.05/1.00;  $M = 0.61 \pm 0.031$  SEM) were classified as right-handers, 9 participants with a negative laterality score (range:  $-1.00/-0.06$ ;  $M = -0.49 \pm 0.13$  SEM) as left-handers, and 1 participant with a null laterality score as ambidextrous.

We examined whether the bias toward the right hand overcame the bias toward the right foot. As a first step, we excluded 1 female participant and 1 male participant giving the same response—‘VERDE/ZIELONY’ or ‘ROSSO/CZERWONY’—to all the 256 trials. We also excluded 3 female participants and 4 male participants scoring more than 2 standard deviations below or above the mean of their ‘Sex’ group in any combination of extended limb (arm or leg), type of rotation (inward or outward), and perceived limb laterality (right or left). Then, a repeated-measures analysis of variance (ANOVA) was performed using the participant’s sex (female or male) as between-subjects factor and extended limb (arm or leg), type of rotation (inward or outward), and perceived limb laterality (right or left) as within-subjects factors. Post-hoc two-tailed *t*-tests were performed when needed to specify the significant differences (within each set of post-hoc contrasts, *p*-values were adjusted using the Bonferroni correction for multiple comparisons). Laterality score was correlated with the number of actions perceived as right-limbed because—due to the limited number of left-handers—it was not possible to include handedness as an independent variable in the ANOVA.

#### 4.2. Results and Discussion

The ANOVA showed a main effect of limb laterality ( $F_{1,53} = 16.34$ ;  $p < 0.001$ ;  $\eta_p^2 = 0.24$ ; Observed Power = 0.98) and a significant interaction between extended limb and limb laterality ( $F_{1,53} = 5.66$ ;  $p = 0.02$ ;  $\eta_p^2 = 0.10$ ; Observed Power = 0.65). Participants perceived a larger number of right-limbed ( $M = 135.55$  [52.95%]) rather than left-limbed actions ( $M = 120.45$  [47.05%]).

Participants perceived a larger proportion of right-limbed ( $M = 54.30\%$ ) rather than left-limbed actions ( $M = 45.70\%$ ;  $t_{54} = 4.53$ ;  $p < 0.001$ ) in the arm-extended condition, whereas no difference was observed in the leg-extended condition (right-limbed:  $M = 51.59\%$ ; left-limbed:  $M = 48.41\%$ ;  $t_{54} = 1.77$ ;  $p = 0.16$ ). Moreover, the proportion of actions perceived as right-limbed was larger for the arm-extended condition than for the leg-extended condition ( $t_{54} = 2.38$ ;  $p = 0.02$ ; Figure 7). No significant correlation was observed between participants' laterality score and the number of actions perceived as right-limbed.



**Figure 7.** Number of actions perceived as right- and left-limbed in the arm-extended and leg-extended conditions.

This third experiment further confirmed the presence of a bias toward the right side of observed bodies reported in previous studies [40–44], although such a bias was observed only for the upper limbs, which in turn generalizes the findings of Experiment 2 (indicating that the bias for the right hand is stronger than that for the right foot) to stimuli with only one limb extended. However, neither the effect of the type of rotation (inward or outward) nor the positive correlation between participants' laterality score and the number of actions perceived as right-footed were confirmed.

## 5. Discussion

On the whole, the present results corroborate the notion that body configural information includes the implicit knowledge that the dominant limb of humans is usually placed on their right side [43]. Indeed, each of the three experiments confirmed the presence of a bias toward the right hand (Experiments 1, 2, and 3) and/or foot (Experiment 1) of observed bodies, as already shown in previous studies [40–44]. In Experiment 1 (in which ambiguous human figures with either one arm or one leg extended, who either were acting on an a ball or not, were presented), participants were more likely to perceive the silhouette spinning consistently with an action performed with the right rather than the left limb, regardless of the extended limb (hand or foot) and complexity of action (with and without ball). In both Experiment 2 (in which ambiguous human figures with one arm and the contralateral leg extended were presented) and Experiment 3 (in which ambiguous human figures with either one arm or one leg extended were presented), the hypothesized advantage of the right hand over the right foot was also found, although the bias toward the right side was observed only for the upper limbs in Experiment 3.

As we already proposed [40–44], the larger proportion of actions perceived as right-limbed could be due to a perceptual frequency effect [14,15] and could explain the increased ability to predict the outcome of sport actions when observing right- rather than left-limbed

movements [37,38,63–66]. Accordingly, the findings of Experiments 2 and 3 that the bias for the right hand is stronger than that for the right foot might be due to the fact that the prevalence of right-handedness is larger than that of right-footedness [8], corroborating the role of visual experience in action recognition [66,67]. On the other hand, such findings might also be ascribed to the fact that hands represent more relevant body parts compared with feet (e.g., see [74]), the former providing more information than the latter as regards both communicative and aggressive acts (which could also account for why a preference to perceive right-handed rather than right-footed actions is observed when silhouettes with one arm and the contralateral leg extended are shown). Future studies should assess whether attentional and perceptual asymmetries toward the right side of human bodies are phylogenetically (because of the evolutionarily adaptive advantage of directing attention toward the dominant limbs of others) or ontogenetically (because of prolonged exposure to right-limbed individuals) determined.

Although an overall bias toward the right side of human bodies was found across the three experiments, some minor inconsistencies (both among their results and in comparison with the results of previous studies) were observed. For example, a significant bias to perceive right-footed actions was observed in Experiment 1, but not in Experiment 3, and this might be due to a combination of various factors (such as the different sets of stimuli used in the two experiments or unwanted differences between participant samples) which could have reduced the statistical power of Experiment 3. In this regard, it should also be stressed that a significant bias toward the right foot was observed in a previous study including a larger sample of participants than Experiment 3 [40]. Moreover, in Experiment 1, only male participants perceived a larger proportion of right- rather than left-limbed actions, and the proportion of actions perceived as right-limbed was larger for male than for female participants, which seems to suggest a stronger bias for the right hand in male rather than female individuals and would be in line with the observation that the advantage of left-handed players is larger for males than for females [18,29,31]. However, this result must be considered with caution, because it was neither confirmed by Experiments 2 and 3 nor observed in our previous studies [40–44], and future research specifically aimed at testing whether males exhibit a larger perceptual and attentional bias toward the right side of others' body compared with females is warranted. Finally, the unexpected findings of Experiment 2 that (1) the bias for the right hand, foot, or both was larger for outward rather than inward rotations and (2) participants' laterality score correlated negatively with the tendency to perceive right-handed/left-footed actions were observed neither in Experiments 1 and 3 nor in our previous studies [40–44]. Although such significant results in Experiment 2 might simply represent instances of type I errors, further studies could be designed in order to examine these issues in more detail.

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