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An account of the postural determinants of perceived reachability is proposed to explain systematic overestimations of the distance at which an object is perceived to be reachable. In this account, these errors are due to a mapping of the limits of prehensile space onto a person's perceived region of maximum stretchability, in the context of a whole-body engagement. In support of this account, 6 experiments on the judged reachability of both static and dynamic objects are reported. We tentatively conclude that the mental imagery of action is grounded and calibrated in reference to multiple skeletal degrees of behavioral freedom. Accordingly, this calibration is a source of systematic error in reachability judgments.

Systematic errors in the perceptual judgment of affordances do occur and appear to persist despite learning and development. Systematic errors, particularly underestimations, are reported in research on the perceptual discrimination of the height at which a stool can be sat on (Mark, 1987) and of the height at which an obstacle affords stepping onto or stepping over for children (Pufall & Dunbar, 1992). Pufall and Dunbar's results show that the underestimation of the critical upper limit of the stepping affordance tends to increase up to 10% as a function of the distance separating the observer and the obstacle (1, 3.5, or 7 m). These data indicate that although body-scaled information and the detection of objects' affordances might be perceived directly (Gibson, 1979), they sometimes are associated with systematic errors of judgment. In general, these systematic errors of judgment remain unexplained. The specific aim of the current experiments was to account for some of these errors—particularly errors in judged reachability—and to capture their underlying mechanism.

Recent research shows that the perceived critical limits of what is reachable, although body scaled, are associated with systematic biases in judgment. Carello, Grosofsky, Reichel, Solomon, and Turvey (1989) reported a systematic overestimation in adults' judgments of the distance at which an object was reachable. In different studies varying participants' reaching space and the way they were permitted to reach, Carello et al. reported overestimations produced in some experimental situations by more than 90% of the participants.

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Bootsma, Bakker, van Snippenberg, and Tdlohreg (1992) reported analogous overestimates in reachability judgments provided by adult participants about a dynamic object approaching in the frontoparallel plane and crossing the plane at various distances. Bootsma et al. found an average of 8.6% overestimation in reachability judgments. Because they viewed perception as being veridical, Bootsma et al. minimized the importance of this systematic overestimation. Because the standard deviation of the judgments was relatively small, they concluded that "the reachability of passing objects can be perceived quite accurately" (Bootsma et al., 1992, p. 13). However, it is unclear what they meant by "quite accurately" and whether they were suggesting that the perception of this affordance is "almost" veridical.

Errors in the perceptual judgment of what is reachable are certainly not attributable to a lack of learning opportunity, considering that, from the onset of development, objects' affordances for manual action are detected. Newborns tend to reach toward an object moving nearby in front of them (von Hofsten, 1982). From 2 months of age, infants systematically start using their hands, mouth, and eyes to explore novel objects (Rochat, 1989), and by 4 months of age they display systematic and successful attempts to reach and grasp objects they see (Piaget, 1952; Thelen et al., 1993; von Hofsten & Lindhagen, 1979) or objects they hear sounding in the dark (Clifton, Rochat, Litovsky, & Perris, 1991). From the onset of development, reaching behavior appears to be determined by the appreciation of a critical zone or distance at which the object is reachable (Clifton, Perris, & Bullinger, 1991; Field, 1976; Yonas & Hartman, 1993). In a recent study, Rochat and Goubet (1993) presented 4- to 7-month-old infants with an object placed either within reach, at the limit, or only 4 in. (10.16 cm) outside the limit of their prehensile space. They found a marked decrease in the frequency of reach attempts for the object when it was placed either at the limit of prehensile space or out of reach. Interestingly, infants appear to calibrate their attempts to reach to their relative ability to sit independently (Rochat & Goubet, 1993) or to lean forward with their trunk (Yonas & Hartman, 1993). The rapid development of these postural abilities determines the limits of prehensile space (Rochat & Bullinger, 1994; Rochat & Goubet, 1995).

These observations suggest that the perception of what objects afford for action is manifest from the onset of development. Infants seem to scale their perception of environmental resources to their own developing abilities and behavioral degrees of freedom (DFs). Furthermore, children aged 3+ years were found to scale their perception of what is reachable for themselves and for others (Rochat, 1995). When asked to judge what is reachable by an adult, they systematically and accurately attributed more reachability to the adult than to themselves. They also were accurate when asked to judge what was reachable by themselves or an adult when placed in an "imaginary" posture. In particular, young children's reachability judgments were commensurate with the actual reachability measures when asked to imagine either themselves or the adult experimenter standing on tiptoes under the object-target (Rochat, 1995). Thus, young children appear to detect and differentiate objects' affordances for themselves and for others and are capable of gauging these affordances on the basis of either perception itself or on a combination of perception and mental imagery. Although children were generally less accurate than adults, they also showed a significant and systematic overestimation of their own ability to reach for an object placed on a table in front of them (Rochat, 1995).

Within an ecological perspective, and in an attempt to explain the apparent disagreement between direct, veridical perception and the existence of systematic errors in the judgment of what is reachable, Heft (1993) introduced a distinction between two types of judgments: perceptual and analytical. According to Heft, perceptual judgments are based on skilled, unreflective perception–action processes and are accurate. These judgments are not focal tasks, but are a subsidiary means to achieve a larger goal. By contrast, analytical judgments are viewed as focal tasks, and, because they are reflective and explicit, they are a source of error. Heft presented the results of a study in which participants were asked to provide reachability judgments either as a focal task (analytical judgments) or in a condition minimizing analytical reflection, in which judgments were made as part of a larger focal task (i.e., picking up only reachable pieces to complete a puzzle). The results indicated that, in this latter condition, reachability judgments were more conservative and did not reflect the systematic overestimations of the focal task condition. These results and the theoretical distinction introduced by Heft leave open the question of the exact mechanisms underlying systematic errors in the perceptual judgment of what is reachable: when they occur and why they are systematic. If higher analytical processes are responsible for these errors, what is the nature of these processes? The specific aim of the current research was to address these questions and to test an account of the postural determinants of perceived reachability. We propose an account of the mechanisms underlying systematic overestimations in the perception of what is reachable. In general, the aim of the research was not merely to make a methodological point regarding the dependence of perceptual performance on the context of the task (i.e., analytical and reflective vs. direct and unreflective). Rather, it was aimed at reexamining the established theoretical framework of the perception of affordances. In particular, we argue that such perception may be influenced by particular biases at the level of mental imagery.

The Proposed Account

To account for the near-consistent finding of reachability overestimation (Bootsma et al., 1992; Carello et al., 1989), we propose that the judgment of what is reachable is calibrated in reference to more than one behavioral DF and hence involves the whole-body (i.e., multiple DFs) engagement of an actor. This general assumption leads to the prediction of a specific bias in reachability judgments: When in a restricted postural situation with constrained effectivities (i.e., the body's potential for action; Turvey & Shaw, 1978), the perceiver-actor will tend to overestimate the limits of prehensile space systematically because the limits are calibrated in reference to multiple behavioral DFs. This overestimation is thought to originate from people's everyday experience of reaching, which naturally requires multiple skeletal DFs. Constraints leading to overestimation could include the overall postural configuration of the actor (e.g., standing, sitting, or kneeling) or specific constraints dictated by the task (e.g., maintaining the body perpendicular to the ground while reaching).

Our account thus emphasizes the role of body posture as a determinant of perceived reachability. In the context of our experiments, the limits of the sphere of prehension are considered in relation to the region of "postural reversibility" (Carello et al., 1989). The outer boundaries of this region are the points of maximum stretch with hands toward the object-target, in a postural configuration that keeps the actor's center of gravity above the feet so that he or she can return to the initial posture without losing balance, or without making any major postural adjustments (see Figure 1). According to our account, perceived reachability is defined relative to the calibration and mapping of the region of postural reversibility.

We performed a series of experiments, first to assess errors in perceived reachability for static and dynamic objects and then to test the proposed account. All experiments were based on the same experimental paradigm. Participants were asked to judge, in varying postural conditions, the distance at which they thought either a static or dynamic object (i.e., a pitched ball) was just reachable.

General Experimental Paradigm

Participants were asked to judge the distance at which they could just touch a ball with the tip of the finger of their left or right hand, by extending only their arm, keeping both feet aligned with each other on the ground and the rest of the body perpendicular to the ground (Experiments 1–4, and 6), or with a full stretch (Experiment 5). Except for Experiment 4, participants were instructed to provide reachability judgments on the basis of one skeletal DF (shoulder joint). An

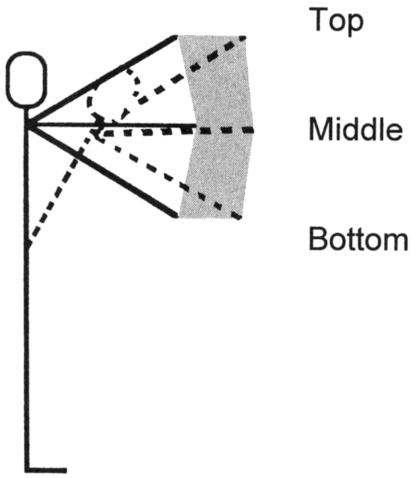

Figure 1. The region of reversibility is bounded by the points of maximum reach with the actor's hands toward an object in a postural configuration that keeps the actor's center of gravity above the feet so that he or she can return to the initial posture without losing balance or without making any major postural adjustments. The shaded area represents the reachability gain from a 1-DF reach to a multiple-DF reach within this region. DF = degree of freedom.

important feature of the paradigm is that it required no physical reaching action from the participant but merely a reachability judgment with no feedback either from the experimenter or from the outcome of an actual reach. Participants' reachability judgments were obtained in conditions in which the ball was either pitched at various distances from the participant as he or she stood in front or sideways relative to the ball's trajectory (dynamic condition), or the ball was presented statically in front of or sideways to the participant by the experimenter at various distances (static condition).

Experiment 1

The first experiment was designed to assess and compare participants' relative accuracy in perceiving the reachability of a ball in static and dynamic conditions, as well as in relation to three different locations in prehensile space (i.e., at shoulder height, 30 cm above, and 30 cm below). The specific aim of this experiment was to provide further assessment of the systematic overestimation of perceived reachability reported in the literature. In addition, we wanted to gather information about the magnitude of this overestimation relative to different locations of the object in prehensile space (Carello et al., 1989) in static or dynamic conditions.

Method

Participants

Twenty-four undergraduates (12 men and 12 women; 23 right-handed and 1 left-handed) participated in the experiment as part of a college research credit requirement.

Procedure

Participants stood with their backs against a large blackboard. A horizontal line corresponding to the participant's shoulder height was drawn on the board (middle position) with two parallel lines added, 30 cm above (top position) and 30 cm below (bottom position). In both static and dynamic conditions, balls were presented while participants stood with their backs against the blackboard. In all conditions, balls were presented to the right and left sides of the participants, in alignment with the three position lines, in either an ascending (i.e., increasingly farther from the participant) or descending (i.e., increasingly closer to the participant) manner. Orders of three positions, two sides, and two manners of presentation were counterbalanced across participants. Participants always provided judgments in the static condition first.

Static condition. Participants were asked to judge ("yes" and "no" responses) whether they could touch a tennis ball presented by the experimenter and moved by hand in increments of 2 cm along the position lines drawn on the blackboard. Participants stood with their backs against the blackboard and turned their heads to either the right or left side to see the ball and provide their judgment. In a descending presentation, the ball was moved until the participants provided a "yes" judgment, indicating that they judged they could touch the ball, with the ipsilateral arm (relative to the ball) extended and fingers outstretched, using the tip of the middle finger. At the point where participants expressed a transition from "no" to "yes" (descending presentation) and from "yes" to "no" judgments (ascending presentation), the experimenter marked the ball's location on the blackboard and later measured the distance in centimeters from the participant's sagittal midline to the mark.

Dynamic condition. After judgments in the static condition, participants stood with their backs against the blackboard facing a pitching machine. The pitching machine (Ponzo Aztec Rookie) was located 4 m away from the blackboard. Participants stepped 1 m away from the blackboard so they could not see the ball hitting its surface. The machine pitched soft-pressure tennis balls (Tretorn ST), which targeted fixed locations on the different position lines drawn on the blackboard. These pitching machine adjustments were made via precise angular and rotational adjustments out of sight of the participant. The balls passed by the side of the participant at a constant velocity of 6 m/s. They were required to keep their heads facing straight during the pitch but could follow the trajectory of the ball with their eyes. After each pitch, participants judged whether they thought they could have just touched the ball by raising the ipsilateral arm straight out to the side while maintaining the rest of the body perpendicular to the ground. Within a particular test trial, a pitch was repeated until the participants were able to provide a judgment. In an ascending presentation, the balls were first pitched close (80 cm) to the participant and were pitched progressively farther away in steps of approximately 5 cm. In a descending presentation, the balls were first pitched far (184 cm) from the participants and were pitched progressively closer in steps of approximately 5 cm. Once participants estimated that they could not (ascending condition) or were able to (descending condition) touch the ball, reachability judgments were recorded by measuring the distance from the participant's sagittal midline to the point of impact of the ball on the blackboard. The balls were dampened slightly before pitching so that an exact trace of their impact was left on the blackboard for measurements.

Scoring and Analysis

Participants made one reachability judgment for each position in the static condition and two successive judgments (averaged into one score) for each position in the dynamic condition. Following the dynamic condition, the actual limits of the participants' prehensile space were measured for analysis of relative accuracy of their reachability judgments in terms of percentages of over- or underestimation. For this measurement, they were asked to turn around and face the blackboard while holding a piece of chalk in their hands. The chalk was positioned in alignment with the tip of their right or left middle finger. Participants were required to trace on the blackboard, with arms extended, two arcs from 12 to 6 o'clock. Actual prehensile space was measured in reference to the distance from the participant's sagittal midline to the intersection of each arc with the three horizontal position lines drawn on the blackboard (top, middle, and bottom lines). Differences in distance between judged reachability and the actual limits of prehensile space at the different target locations on the position lines were converted into percentages of over- or underestimation (judged/actual × 100). These calculations were based on measurements from the vertical line running through the participant's back heel (sagittal midline) to either the middle finger tip (actual) or the ball's location and trajectory (judged).

Results

As shown in Table 1, participants systematically tended to judge the object's reachability at farther distances than it actually was. This was the case at all locations and across both conditions. An analysis of variance (ANOVA) comparing actual and judged reachability measures across all conditions yielded a highly significant effect of reachability, $F(1, 23) = 39.32, p < .0001$. For simplicity of presentation, the remaining detailed analyses are based on judged/actual reachability ratios. When transformed to mean ratios of judged/actual reachability, the data indicate that participants tended to overestimate the limits of their prehensile space more in the dynamic condition (23%) than in the static condition (13%). A 2 (condition) × 2 (side) × 3 (location) ANOVA with repeated measures performed on the ratios yielded a significant main effect of condition, $F(1, 23) = 10.54, p < .004$, and a significant main effect of location, $F(2, 46) = 20.23, p < .0001$. The overestimation was greater for the top and bottom ball's location than the middle location ($p < .01$, based on a post hoc Tukey test). A marginally significant effect of side ($p < .09$) and no significant interactions were found.

To assess whether the increased overestimation of judged reachability found in the dynamic condition was attributable to a general difficulty in performing that task, we analyzed individual variability. We calculated the absolute value of the difference between Judgments 1 and 2 for each dynamic side and location and performed a 2 (side) × 3 (location) repeated measures ANOVA. No significant effects were found.

Discussion

The results of the first experiment confirmed the existence of a systematic overestimation of judged reachability. This overestimation was significantly greater for a dynamic than a static object, and it also varied with the location of the object in prehensile space: The overestimation increased for objects located above or below participants' shoulder height.

One possible explanation for the systematic errors in judged reachability that we found is that they might have been caused by the ball's trajectory not being in the participants' frontoparallel plane, forcing them to imagine a reach to the side. To provide their judgments, they either had to turn their head sideways (static condition) or use their peripheral vision (dynamic condition). Thus, participants were placed in an awkward, unusual posture for planning a reach. This unusual posture might have led to the observed error in reachability judgments. Experiment 2 was performed to control for this possibility and to test for the generalization of the observed overestimation to situations in which the ball crossed the participants' frontoparallel plane. These situations were considered to be more familiar and thus to be possibly associated with less error because

Table 1
Means and Standard Deviations (in cm) of Actual Reachability, Judged Reachability, and Judged/Actual Ratios in the Static and Dynamic Conditions of Experiment 1 Relative to the Three Locations and to Right- and Left-Hand Side Presentation

	Static condition				Dynamic condition			
	Right hand		Left hand		Right hand		Left hand	
Location	Actual	Judged	Actual	Judged	Actual	Judged	Actual	Judged
Top								
M	76.8	87.5	75.7	84.0	76.8	98.2	75.7	88.1
SD	7.1	11.7	7.4	12.1	7.1	13.6	7.3	16.5
Middle								
M	85.9	94.7	84.5	91.4	85.9	101.6	84.4	96.7
SD	6.7	11.5	7.1	13.1	6.7	18.9	7.1	16.9
Bottom								
M	82.1	96.7	79.9	93.4	82.1	107.1	79.9	101.5
SD	8.0	10.9	7.8	12.0	8.6	21.0	7.8	23.0

they entailed the imaging of a forward reach in a less awkward posture.

Experiment 2

Like Experiment 1, Experiment 2 tested reachability in static and dynamic conditions and relative to three different locations in prehensile space (i.e., shoulder height, 30 cm above, and 30 cm below). However, participants were situated differently relative to the ball's trajectory.

Method

Participants

A new group of 24 undergraduates (12 men and 12 women; 23 right-handed and 1 left-handed) participated in the experiment as part of a college research credit requirement.

Procedure

The general procedure of Experiment 1 was replicated in the second experiment, with the same counterbalancing of variables. However, two procedural modifications were introduced: (a) Participants stood sideways in relation to the blackboard and the pitching machine and (b) in the dynamic condition, they provided their reachability estimates by moving closer to or farther away from the ball, which was always presented or pitched to the same location in space.

Static condition. The static condition was identical to that of Experiment 1, except that participants stood sideways to the blackboard, facing the ball (frontoparallel plane), which was presented at each position line and was moved either toward (descending) or away from (ascending) the participant by the experimenter.

Dynamic condition. After judgments in the static condition, participants stood sideways to the blackboard and the pitching machine. The pitching machine was located 4 m away from the blackboard. Participants stood 2 m from the blackboard. The machine pitched soft-pressure tennis balls, which targeted fixed locations on the different position lines drawn on the blackboard. The balls crossed the frontoparallel plane of the participants at a constant velocity of 6 m/sec; the participants were required to look straight ahead during this process. After each pitch, participants were asked to move either closer to (descending) or away from (ascending) the perceived ball's trajectory to the location from which they thought they could have just touched the ball by raising the arm closer to the blackboard. Within a particular trial presentation, the pitch was repeated until participants provided their judgments. In an ascending presentation, participants were initially placed close to the ball's trajectory (70 cm). They were required to move away to provide their judgments. In a descending presentation, participants were initially placed far away (184 cm) from the ball's trajectory and were required to move forward to provide their judgments. Once the participants situated themselves in relation to the ball, reachability judgments were recorded by measuring in centimeters on the floor the perpendicular from the ball's trajectory line to the extremity of the participants' sagittal midline.

Scoring and Analysis

Participants made one reachability judgment for each position in the static condition and two successive judgments (averaged into one score) for each in the dynamic condition. At the end of the experiment, the actual limits of the participants' prehensile space were measured for further analysis by having them draw an arc on the board while standing sideways to the blackboard, with their right or left arm fully extended, holding a piece of chalk in alignment with the tip of their right or left middle finger. This procedure was carried out for their right and left sides. Differences in relative distance between judged reachability and the actual limits of prehensile space at the different target locations on the position lines were converted into percentages of over- or underestimation (judged/actual × 100). These calculations were based on measurements from the vertical line running through the participants' back heel (sagittal midline) to either the middle finger tip (actual) or the ball's location and trajectory (judged).

Results

As shown in Table 2, participants again tended to judge the object's reachability at farther distances than it actually was. This was systematically the case at all locations and across both conditions. An ANOVA comparing actual and judged reachability measures across all conditions yielded a

Table 2
Means and Standard Deviations (in cm) of Actual Reachability, Judged Reachability, and Judged/Actual Ratios in the Static and Dynamic Conditions of Experiment 2 Relative to the Three Locations and to Right- and Left-Hand Side Presentation

	Static condition				Dynamic condition			
	Right hand		Left hand		Right hand		Left hand	
Location	Actual	Judged	Actual	Judged	Actual	Judged	Actual	Judged
Top								
M	59.3	72.6	63.8	70.0	72.3	96.3	76.8	94.9
SD	6.6	11.8	6.7	11.2	6.5	13.8	6.7	13.2
Middle								
M	67.4	78.0	71.6	75.8	80.4	100.3	84.6	100.3
SD	6.2	11.9	6.6	9.3	6.2	12.5	6.6	14.7
Bottom								
M	62.2	77.2	65.0	74.3	75.2	100.4	78.0	100.8
SD	6.7	12.3	6.0	9.9	6.7	15.7	6.0	15.9

highly significant effect of reachability, $F(1, 23) = 62.15$, $p < .0001$. Again, for simplicity of presentation, the remaining detailed analyses are based on judged/actual reachability ratios. When converted to ratios of judged/actual reachability, the data indicate that participants tended to overestimate more in the dynamic condition than in the static condition (average overestimates of 28% and 16%, respectively). A 2 (condition) × 2 (side) × 3 (location) ANOVA with repeated measures performed on the ratios yielded a significant main effect of condition, $F(1, 23) = 9.89$, $p < .005$, a significant main effect of side, $F(1, 23) = 76.69$, $p < .0001$, and a significant main effect of location, $F(2, 46) = 25.72$, $p < .0001$. No significant interactions were found. In both conditions, the overestimation was significantly greater when participants had to judge reachability for their right hand (i.e., the hand closest to the blackboard). Furthermore, in both conditions, the overestimation was significantly greater for the top and bottom ball's location than the middle ball's location ($p < .01$, based on a post hoc Tukey test).

To assess individual variability in the dynamic condition, we calculated the absolute value of the difference between Judgments 1 and 2 for each sublevel and performed a 2 (side) × 3 (location) repeated measures ANOVA. No significant effects were found.

Discussion

The results of Experiment 2 are remarkably similar to those obtained in Experiment 1. The systematic overestimation of perceived reachability again was significantly greater in the dynamic than in the static condition. This pattern of reachability error appeared to be pervasive across postural and perceptual contexts and thus could not be accounted for merely by the awkward posture of the participants (Experiment 1). One possible explanation for this finding is that the static and dynamic conditions in our experiments yielded different perceptual experiences despite the fact that both tasks required the same number of skeletal DFs. In the dynamic condition, participants made reachability judgments only after the ball had passed before them. In the static condition, participants provided their judgments while in constant visual contact with the ball. The dynamic condition created a perceptual context that is commonly accompanied by rapid motor responses (i.e., catching), usually performed with a whole-body engagement. By contrast, the constant presence of the ball in the static condition gave participants more time and opportunity to take into consideration the planning of a reach with 1 skeletal DF and hence more opportunity to potentially inhibit their inclination to calibrate the reach with a whole-body engagement. However, this hypothetical inhibition is only partial because participants also persisted in overestimating reachability of the object in the static condition. Note that this interpretation differs from that of Heft (1993), who proposed that perceptual errors should be commensurate with the degree of analytical processing required by the task.

Results of both experiments also reveal a significant effect of location. Errors in judged reachability were affected similarly by either the top, bottom, or shoulder line location of the object in prehensile space: An explanation of this finding is offered later relative to the proposed account. Regarding the effect of side found in Experiment 2, it was marginally significant in Experiment 1 ($p < .09$). In both experiments, participants tended to overestimate their reachability more when the ball was presented to their right side. This result might have been because the vast majority of participants in both experiments were right-handed. Thus, they were less conservative in planning their reach to this dominant side.

Our account of the consistent errors of judged reachability in Experiments 1 and 2 states that, in general, this systematic overestimation results from a difficulty in perceiving and judging reachability on the basis of limited skeletal DFs. According to this account, individuals tend to perceive and judge an object's reachability in relation to an engagement of the whole body within the region of postural reversibility or the region from which they can come back to the initial posture without losing balance (see Figure 1). In other words, the systematic overestimation is linked to the difficulty in accurately judging the ball's reachability within the context of the postural constraints imposed by the task (i.e., 1 DF).

The proposed account is supported by the finding that, in both Experiments 1 and 2, participants' overestimations tended to increase significantly when the ball contacted the board above and below their shoulder line. Indeed, in actuality, a whole-body engagement in reaching to the top and bottom locations permits contact with the object at farther distances relative to the vertical line running through the participants' back heel (sagittal midline) than at the middle location, assuming that they take into account at least the constraint of keeping both feet aligned with each other and of not losing balance. For the top position, a whole-body engagement extends the reach because the actor can stand on tiptoes. For the bottom position, lowering the trunk (via knee bending) effectively lowers the center of mass, which allows further displacement from the sagittal midline.

To directly test this proposal, we performed a follow-up experiment to Experiment 2. In addition to obtaining judged and actual reachability measures for the required task, we also obtained actual measures of reachability, as predicted by our account of the overestimations. Thus, direct comparisons between judged reaches and actual reaches in different postural configurations were possible.

Experiment 3

In a simplified experimental paradigm, Experiment 3 tested participants' reachability judgments for one side (right) in only the dynamic condition. The same task constraints as in Experiments 1 and 2 were imposed, but, in addition to obtaining actual measurements based on reaches of 1 DF, we obtained actual measurements based on a whole-body engagement. On the basis of our account, we predicted that participants' judged reaches in all three locations would more closely approximate multiple-DF rather than 1-DF measures of actual reachability.

Method

Participants

A new group of 12 undergraduates (6 women and 6 men; all right-handed) participated in the experiment as part of a college research credit requirement.

Procedure

Participants were tested in the same dynamic condition as in Experiment 2, for the three locations in space, but the pitching machine was located only to their left side; thus, the participants provided reachability judgments for their right (reaching) arm only. The experimental paradigm and procedure were otherwise identical to those of Experiment 2, except that two sets of actual reaches were obtained.

Scoring and Analysis

Participants provided two successive reachability judgments for each of the three locations; mean scores were used for analysis. Judgments were recorded in the same manner as in the dynamic condition of Experiment 2. The manner of presentation (ascending and descending) and location (top, middle, and bottom) were counterbalanced across participants. After all judgments were made, two sets of measurements of actual reachability were obtained. The first (straight: 1 DF) was exactly as described in Experiment 2. The second set measured actual reachability for the three locations but according to a whole-body (multiple-DF) engagement: Participants were required to stretch forward as far as possible while maintaining both feet parallel to each other. They were allowed to bend their knees or raise their heels but could not step forward. Calculations for both sets were based on measurement from the vertical line running through the participants' back heel to either the middle finger tip (actual) or the ball's trajectory (judged).

Results

As shown in Table 3, participants generally tended to overestimate reachability at all locations. When converted to ratios of judged (1-DF)/actual (1-DF) reachability, the data revealed a trend of overestimation comparable to those of Experiment 1 and 2, in which overestimation for the top and bottom locations was greater than for middle. Figure 2 shows the mean judgments of reachability, together with actual 1-DF and actual multiple-DF measurements as a function of location.

A 3 (location) × 3 (reachability: judged, actual 1-DF, and actual multiple-DF) ANOVA performed on the data yielded significant effects of location, $F(2, 22) = 70.90, p < .0001$, and reachability, $F(2, 22) = 84.10, p < .0001$, and a significant Location × Reachability interaction, $F(4, 22) = 4.03, p < .007$. A post hoc Tukey test yielded significant differences for all reachability measures at all locations ($p < .05$). These results indicated that, overall, judged reachability was significantly different from both 1-DF and multiple-DF actual measurements.

Table 3
Means and Standard Deviations (in cm) of Actual (1-DF) Reachability, Judged (1-DF) Reachability, Judged (1-DF)/Actual (1-DF) Ratios, and Actual Multiple-DF Reachability for the Three Locations in Experiment 3

Variable	Top	Middle	Bottom
Actual (1-DF)			
M	71.76	82.38	80.76
SD	11.29	10.72	10.41
Judged (1-DF)			
M	93.95	104.95	108.45
SD	16.11	13.68	16.09
Judged (1-DF/actual)(1-DF)			
M	1.32	1.28	1.35
SD	0.21	0.15	0.17
Actual (multi-DF)			
M	106.17	112.32	118.49
SD	10.42	9.19	8.73

Note. DF = degree of freedom.

As Figure 2 indicates, reachability judgments were closer in value to actual multiple DF reaches than to actual 1-DF reaches. To assess the validity of this trend, we calculated difference scores between judged and 1-DF actual and between judged and multiple-DF actual measures. We performed a 2 (difference score) × 3 (location) ANOVA on the absolute value of the difference scores. This yielded a main effect of difference score, $F(1, 11) = 5.71, p < .035$, a main effect of location, $F(2, 22) = 6.17, p < .008$, and no significant interaction. A post hoc Tukey test confirmed that difference scores obtained from judged and actual 1-DF measures were significantly larger than those from the judged and actual multiple-DF measures for each location (top, $p < .05$; middle, $p < .01$; and bottom, $p < .01$). Finally, two separate ANOVAs were performed to compare the fit of judged reachability measures with each set of actual measures across location. Comparison of judged reachability measures with 1-DF actual measures yielded a significant Measure × Location interaction, $F(2, 22) = 3.83, p < .03$. By contrast, no interaction was found when judged reachability and actual multiple-DF measures were compared, $F(2, 22) = 1.57, p < .23$, demonstrating a better fit.

Discussion

The results of Experiment 3 supported our predictions. Like Experiments 1 and 2, Experiment 3 yielded a robust, systematic overestimation of judged reachability. In support of our account, judged reachability approximated actual multiple-DF measures. Although actual multiple-DF performance was not perfectly matched, the magnitude of this mismatch was significantly reduced compared with that of judged versus actual 1-DF measures. Furthermore, in relation to location, a superior fit between judgment data and

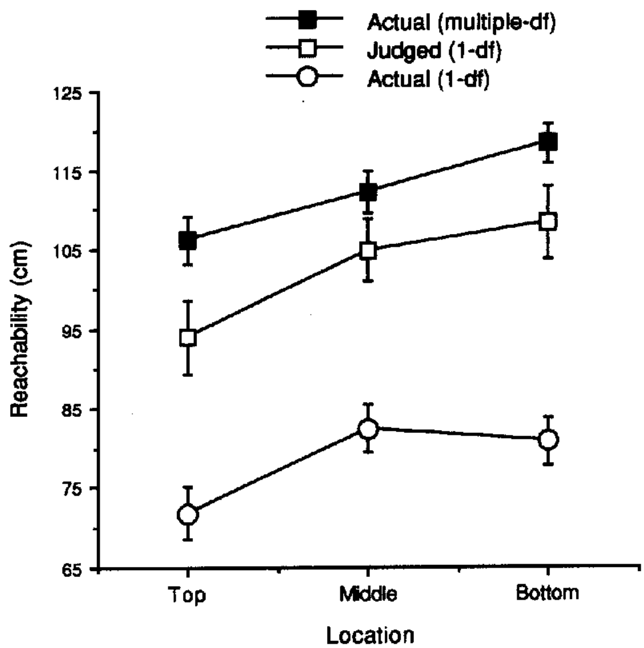

Figure 2. Mean values for 1-DF reachability judgments and 1-DF and multiple-DF actual measurements for the top, middle, and bottom locations in Experiment 3. DF = degree of freedom (df on figure).

actual multiple-DF data was found. These findings suggest that although participants are inclined to judge reachability in reference to multiple skeletal DFs, they may compromise between this inclination and the postural constraints dictated by the task.

Taken together, the results of Experiments 1–3 support the proposition that the distance at which an object is reachable depends on a multiple-DF, whole-body engagement within the perceived region of postural reversibility. Experiment 4 was designed to provide even stronger support of this hypothesis.

Experiment 4

To further test the viability of the proposed account, participants in Experiment 4 were asked to provide reachability judgments while wearing various weights attached to one or both of their wrists. The rationale for this experiment was that if the region of postural reversibility plays a role in the determination of perceived reachability, then judgments should vary in relation to the weights attached to the arm "engaged" in the imagined reaching task despite the fact that the constraints of the task dictate otherwise. In the context of a reach that requires only one skeletal DF, the addition of moderate amounts of weight to the reaching arm do not affect the distance at which an object is reachable. However, in the context of a whole-body engagement, increasing the weight on the reaching arm brings the region of postural reversibility back toward the participant's center of mass. Thus, the distance at which an object is reachable without losing balance is reduced. According to our model, participants' judgments should take into account the fact that additional weight on the reaching wrist affords less reachability. Therefore, we predicted a reduced overestimation of reachability in direct proportion to the increased amount of weight on the reaching arm.

Method

Participants

A new group of 48 undergraduates (37 women and 11 men; 44 right-handed and 4 left-handed) participated in the experiment as part of a college research credit requirement.

Procedure

Participants were tested in the same dynamic condition as in Experiment 3, but only for balls pitched at the middle (shoulder line) position. The experimental paradigm and procedure were otherwise identical to Experiment 3, except that participants were required to wear exercise weights on one of their wrists while making judgments. They were instructed to shake the weighted arm vigorously several times before beginning judgments of each condition to "get a feel" for the amount of weight on the arm. In particular, participants provided judgments under four conditions:

1. no weights on either wrist (same as in Experiments 2 and 3).
2. 2 lb (0.906 kg) of weights on the right (reaching) wrist and none on the left.
3. 7 lb (3.171 kg) of weights on the right (reaching) wrist and none on the left.
4. 7 lb (3.171 kg) of weights on the left (nonreaching) wrist and none on the right.

Note that Conditions 1 and 4 were control conditions in which the right (reaching) arm was not weighted.

Scoring and Analysis

Participants provided two successive reachability judgments in each of the four conditions. Mean scores were used for analysis. Judgments were recorded in the same manner as in the dynamic condition of Experiment 3. The manner of presentation (ascending or descending) and order of conditions were counterbalanced across participants. Judgments always were made relative to the right arm and hand regardless of which arm was weighted. Because participants were tested exclusively for the middle position, only the line corresponding to their shoulder height was created on the blackboard. After participants provided their reachability judgments in all conditions, they were required to stand sideways to the blackboard and measurements of the actual reachability of their right arm were recorded. Again, these calculations were based on measurements from the vertical line running through the participants' back heel to either the middle finger tip (actual) or the ball's trajectory at the middle position (judged).

Results

Similar to the results obtained in the previous three experiments, participants demonstrated a marked overestimation of the distance at which they thought they could reach and contact the ball (a 33% overestimate on average). As shown in Table 4, in all conditions judged reachability was systematically greater than actual reachability. When converted to ratios of judged/actual reachability, an effect of the various weight conditions occurred in the predicted direction. Compared with the experimental conditions, in which participants had weights attached to their right (reaching) arm, overestimation was greater in the control conditions (35% in the control conditions vs. 31.5% in the experimental conditions on average). Regarding the two experimental conditions, the overestimation was reduced in Condition 3, in which participants wore 7 lb (3.171 kg) on their right arm, compared with Condition 2, where they wore only 2 lb (0.906 kg; 31% vs. 33% on average). A 4 (condition) × 2 (reachability: actual vs. judged) ANOVA with repeated measures yielded significant effects of condition, $F(3, 141) = 4.026$, $p < .008$, and reachability, $F(1, 47) = 251.16$, $p < .0001$; more important, there was a significant Condition × Reachability interaction, $F(3, 141) = 3.95$, $p < .009$. A post hoc Tukey test performed on judged reachability data yielded significant contrasts between Conditions 1 and 3 ($p < .01$) and between Conditions 3 and 4 ($p < .01$). Of the 48 participants tested, 36 showed the overall trend predicted by the model (i.e., an overestimate in Condition 1 = Condition 4 > Condition 2 > Condition 3). This proportion of participants was significant, as determined by a binomial test ($p < .02$).

Discussion

The results of Experiment 4 provide additional support for the general idea that the region of postural reversibility plays a role in the determination of perceived reachability. Although participants were asked to provide their judgments while maintaining their body perpendicular to the ground (i.e., 1 skeletal DF), they seemed to base their judgments on a whole-body engagement. With increasing weight on the reaching arm of an actor engaged in a multiple-DF reach, the region of postural reversibility was brought back toward the participants' center of mass, thus reducing the distance at which an object was reachable without losing balance. As predicted by the model, the results demonstrate that reachability judgments indeed varied in relation to the weights attached to the arm engaged in the reaching task. Despite the required 1-DF reaching task, respondents' judgments indicated that they took into account the fact that additional weight on the reaching wrist affords less reachability; thus, their systematic overestimation decreased as a function of the weight attached to the reaching arm. The fact that post hoc tests revealed a significant decrease in overestimation between only the control conditions and Condition 3 (0 weight on the left wrist and 7 lb [3.171 kg] on the right wrist [OL-7R]) indicates that the effect depends on a load to the reaching arm greater than 2 lb (0.906 kg).

Considering the relatively light weights attached to the participants' wrists and the fact that before each trial they were asked to move their weighted arm vigorously, a task that was easily performed by all participants, it is unlikely that the observed effect was linked to the amount of effort that would be expended during an actual reach in a particular weight condition. However, to assess the precise role of perceived effort as a potential control variable, future experiments should test participants in analogous weight conditions while they are in a supine posture. This postural change would eliminate the effect of weight in relation to balance, which is the main factor proposed here.

A fifth experiment was designed to provide additional direct support for our account. We asked participants to provide reachability judgments with fewer postural restrictions (i.e., more than one skeletal DF). In this experiment, participants were asked to provide judgments about the maximum distance at which they could still contact the pitched ball in a whole-body engagement. On the basis of our account, we predicted that a comparison between actual and perceived reachability in this condition would reveal a significant decrease and potentially a disappearance of the systematic error because the task required fewer postural restrictions.

Table 4
Means and Standard Deviations (in cm) of Actual Reachability, Judged Reachability, and Judged/Actual Ratios in the Four Weight Conditions of Experiment 4

Variable	0L-0R	0L-2R	0L-7R	7L-0R
Actual				
M	83.1	83.1	83.1	83.1
SD	6.8	6.8	6.8	6.8
Judged				
M	112.2	110.3	108.3	112.6
SD	14.2	13.5	14.1	12.3
Judged/actual				
M	1.35	1.33	1.31	1.36
SD	0.18	0.17	0.18	0.16

Note. 0L-0R = 0 weight to the left wrist and 0 weight to the right; 0L-2R = 0 weight to the left and 2 lb (0.906 kg) to the right; 0L-7R = 0 weight to the left and 7 lb (3.171 kg) to the right; 7L-0R = 7 lb (3.171 kg) to the left and 0 weight to the right.

Experiment 5

Method

Participants

Twenty new undergraduates (15 women and 5 men; 19 right-handed and 1 left-handed) were tested as part of a college research credit requirement.

Procedure

As in Experiment 4, the pitching machine was placed only on the participants' left side, and balls were pitched at the middle (shoulder line) position only. Participants provided reachability judgments only for their right (reaching) arm. In contrast to Experiment 4, they did not wear any weights while making judgments. They provided reachability judgments in two conditions: (a) with the instruction to maintain their body perpendicular to the ground with feet aligned together (straight condition) or (b) with the instruction to provide their judgments on the basis of a multiple-DF stretch (whole-body condition). The latter reach was defined as the maximum forward leaning from the hips with arm outstretched while maintaining both feet parallel to each other on the ground. The manner of presentation (i.e., ascending vs. descending) and order of conditions were counterbalanced across participants.

Scoring and Analysis

Participants provided two successive reachability judgments in each of the two conditions, and the means of these scores were used for analysis. Judgments were recorded in the same manner as in the dynamic condition of Experiments 2–4. Because participants were tested exclusively for the middle position, only the line corresponding to the participants' shoulder height was created on the blackboard. After they provided their reachability judgments in all conditions, the participants were required to stand sideways to the blackboard, and measurement of the actual reachability of their right arm with either a multiple-DF posture or with only their arm raised and the rest of the body perpendicular to the ground was recorded for further calculation of over- or underestimation (see the earlier experiments). Again, these calculations were based on measurements from the vertical line running through the participants' back heel to either the middle finger tip (actual) or the ball's trajectory at the middle position (judged).

Results

The data in Table 5 show that, as in the first four experiments, in Condition 1 (straight: 1 DF) participants demonstrated a marked overestimation in the distance at which they thought they could reach and contact the ball (actual vs. judged reachability difference of 19 cm, or a 28% overestimation, on average). By contrast, this overestimation was markedly reduced in Condition 2 based on a multiple-DF reach (8 cm, or a 6% overestimation, on average). A 2 (condition) × 2 (reachability) ANOVA with repeated measures yielded significant effects of condition, $F(1, 19) = 249.95$, $p < .0001$, and reachability, $F(1, 19) = 29.75$, $p < .0001$, and a significant Condition × Reachability interaction, $F(1, 19) = 42.87$, $p < .0001$. A post hoc Tukey test revealed that the differences between actual and judged reaches in both conditions were significant ($p < .01$).

Table 5
Means and Standard Deviations (in cm) of Actual Reachability, Judged Reachability, and Judged/Actual Ratios in the 1-DF and Multiple-DF Conditions of Experiment 5

Variable	Straight	Full stretch
Actual		
M	80.2	116.6
SD	5.7	10.8
Judged		
M	99.5	124.1
SD	16.3	16.8
Judged/actual		
M	1.28	1.06
SD	0.13	0.13

Note. DF = degree of freedom.

Discussion

As predicted by the proposed account, perceived reachability errors in Experiment 5 were markedly reduced when participants provided their judgments in reference to a multiple-DF posture. However, although errors were significantly reduced, they did not in fact disappear. We propose that the residual 6% average overestimation was probably linked to the remaining restriction of keeping both feet parallel and flat on the floor. Future research could determine the validity of this interpretation by testing participants in a situation in which they would be asked to provide reachability judgments in postures that varied the position of the feet (e.g., flat vs. tiptoe position; aligned vs. staggered feet).

Similar to Experiment 3, the average judged reachability in the straight condition fell short of the actual reachability in a multiple-DF stretch (see Table 5). Again, it appears that even though participants' judgments were systematically biased toward the planning of a reach in a multiple-DF stretch, they still took into consideration the postural constraints dictated by the task. This might have mitigated the amount of observed overestimation in the straight condition.

We performed a sixth experiment with a new static condition as a final test of our account. The experimental paradigm remained basically the same, but the context of the judgment task was changed. Participants were placed in a situation in which the object to be reached was either the image of themselves reflected in a large mirror or a point on a wall. The mirror and wall conditions were designed to test the relative dependence of our account on the amount of visual information provided to participants (i.e., rich mirror image of the body vs. small dot on a white wall; see the *Procedure* section in Experiment 6). In addition to this novel context, participants also provided their judgments in different postural conditions (i.e., standing or kneeling), which varied their region of postural reversibility for reaching in a multiple-DF posture. The rationale was that, in a kneeling posture, the region of postural reversibility would be pushed back compared with in a standing posture. Therefore, on the basis of the model, we predicted more conservative reachability judgments in the kneeling posture.

Experiment 6

Method

Participants

A new group of 36 individuals was tested (18 men and 18 women aged 18–49 years). They were paid to participate in the experiment and were recruited at the Physical Education Center of Emory University, where they exercised.

Procedure

The experiment was run at the dance studio of the Physical Education Center using a large mirror covering one of its walls. Participants stood facing either the large mirror, made of 12 panels 10 ft (3.048 m) high and 30 ft (9.144 m) wide, or a concrete wall. They were instructed either to move away from (ascending presentation) or to move toward (descending presentation) either their own reflection or the wall, up to the point where, by raising only their right arm forward, perpendicular to their torso, they could either just touch the tip of their reflected right index finger in the mirror (mirror condition) or a blue dot glued on the wall at their right shoulder height (wall condition).

In the mirror condition, the exact meeting point of the participants' right index finger and its reflection corresponded to the actual surface of the mirror. No mention of the mirror surface was made to the participants. Rather, they were instructed to situate themselves in relation to their reflection in the mirror. Participants also were told that they were to provide their reachability judgments while maintaining their body perpendicular to the ground (1 DF).

Participants were tested successively in four conditions: (a) while standing in front of the wall, (b) while kneeling in front of the wall, (c) while standing in front of the mirror, and (d) while kneeling in front of the mirror. In each condition, participants provided two reachability judgments, which were averaged for later statistical analyses. In the ascending presentation, participants were first placed close either to the wall or to the mirror (70 cm), and in the descending presentation, far from it (184 cm). Once participants situated themselves where they thought they could just touch the wall or their reflected index finger, the experimenter recorded the judgment by measuring in centimeters on the ground the distance from the participants' toes (standing condition) or knees (kneeling condition)[1] to either the wall or the mirror. The manner of presentation (ascending or descending) and order of conditions were counterbalanced across participants.

Scoring and Analysis

Once participants provided their judgments in the four conditions, their actual reachability was measured. For this measurement, they were asked either to stand or to kneel in front of the mirror. They raised their right arm and just touched the mirror surface while maintaining the rest of the body perpendicular to the ground. As in the other experiments, the participants' relative accuracy was assessed on the basis of the ratio of judged/actual reachability.

Results

As in the other five experiments, the data in Table 6 shows that participants demonstrated a tendency to overestimate the distance at which they thought they could reach and contact the object. When converted to judged/actual ratios, the data indicate that there was a marked overall reduction of overestimation in the kneeling conditions compared with the standing conditions. A 2 (condition) × 2 (posture) ANOVA with repeated measures performed on the ratios yielded a highly significant main effect of posture, $F(1, 35) = 31.86$, $p < .0001$, but no effect of condition and no interaction.

Table 6
Means and Standard Deviations (in cm) of Actual Reachability, Judged Reachability, and Judged/Actual Ratios in the Kneeling and Standing Conditions of Experiment 6 Relative to the Wall or Mirror Situation

	Wall		Mirror	
Variable	Kneeling	Standing	Kneeling	Standing
Actual				
M	68.5	59.5	68.6	59.6
SD	5.6	5.6	5.6	6.0
Judged				
M	74.8	70.6	71.5	67.6
SD	10.7	11.2	12.7	15.0
Judged/actual				
M	1.09	1.18	1.04	1.17
SD	0.13	0.18	0.17	0.28

Discussion

The results of Experiment 6 demonstrate that in a frontal static condition, participants persisted in overestimating what they perceived to be reachable. These results confirm the results obtained in the static condition of Experiment 1. Furthermore, the results demonstrate that the particular posture of the participant determines the amount of the systematic error. As predicted by the proposed account, the amount of overestimation was significantly reduced in the kneeling posture, where the region of postural reversibility was pushed back. Pilot observations indicated that actual multiple-DF reaches in a standing compared with a kneeling posture increased by 16% on average. This increase is comparable to the difference in overestimation between these two postural configurations found in Experiment 6. Thus, although they were asked to judge their reachability on the basis of 1 skeletal DF, participants tended to respond in reference to multiple DFs within the constraints of a particular postural configuration (i.e., kneeling or standing). These results indicate that perceived reachability is mapped onto the perceived region of postural reversibility corresponding to the particular postural condition in which participants find themselves.

General Discussion

The results of the six experiments confirm the existence of a systematic error in the judgment of what is reachable. In all experiments, for both static and dynamic objects, participants systematically tended to overestimate reachability judgments. This systematic error was not attributable to a difficulty in understanding the judgment task. In all experiments, participants demonstrated little variability between the two responses required for each dynamic judgment, and, most of the time, one pitch of the ball was sufficient for participants to judge whether they could reach

[1] These distance measures were chosen as convenient approximations of the most outward point of the body for each respective postural configuration.

it. Furthermore, posttest interviews with participants did not reveal any apparent difficulty in performing the task.

Aside from simply confirming the existence of such error, the analysis of both its magnitude and direction in relation to the various experimental conditions demonstrated that the distance at which an object is judged as "just reachable" tends to be based on a whole-body engagement and is relatively independent of the particular postural constraint configurations dictated by the task. The research results suggest that the determination of what is reachable depends in part on the region of postural reversibility (i.e., the region from which participants can come back to an initial posture) while reaching out in a multiple-DF stretch for the object while either standing or kneeling. In all experiments, the systematic error in perceiving the object's reachability was linked to a difficulty in judging its affordance while taking into consideration the postural constraints of maintaining the body perpendicular and with feet aligned with each other on the ground. Thus, despite the postural constraints dictated by the task, participants in all six experiments seemed to judge the object's reachability in reference to a whole engagement of the body, with more than one skeletal DF and without losing balance. Interestingly, these postural constraints tended to be only partially factored into the perceptual judgment. The result was an overestimation that reflected a compromise between the tendency to imagine an action with a less restricted, whole-body engagement and the postural constraint configuration dictated by the task.

We propose that this explanation also can account for the results of other research reporting systematic overestimation of judged reachability, in which the relative amount of overestimation varies in relation to the particular postural constraint configurations in which participants are placed. For example, in Experiment 2 of Carello et al. (1989), participants sat at tables of various heights. Carello et al. reported significant overestimations in judged reachability only when participants sat at low tables (48- and 76-cm table heights as opposed to 104 cm). These lower tables afforded more stretchability in reaching toward the object-target. Recently, Peper, Bootsma, Mestre, and Bakker (1994) observed that participants overestimated by approximately 12% the critical distance at which a passing ball was judged reachable while maintaining the body perpendicular to the ground (no sideward leaning). Peper et al. suggested that the overestimation was due to the "unnatural aspect of the task" (p. 596) and in particular to the fact that participants were asked to provide their judgment on the basis of a simple arm stretch with no leaning of the trunk. We propose that if participants calibrate their reachability judgments in relation to the posture they are placed in, they tend to do so in reference to a multiple-DF stretch whether sitting at a particular table, standing, or kneeling. Accordingly, this tendency plays a major part in the pervasive and systematic overestimation in judged reachability.

However, the fact remains that, although robust and consistent across many experiments, the reported judged reachability overestimation in our experiments was substantially greater than those reported in the aforementioned studies. We think that this difference may be attributable to methodological differences. For example, in the experimental setup of Bootsma et al. (1992) and Peper et al. (1994), participants' feet were rigidly strapped to a thin platform. This physical strapping of the feet provided direct tactile–kinesthetic feedback of the task constraint itself—a variable that was not present in our experimental setup—and may have inhibited participants' tendency to overestimate judged reaches. Further experiments should be performed to address this issue.

Beyond the methodological point that the performance of perceiving affordances depends greatly on the constraints dictated by the task, what do our results indicate about the mechanisms underlying judged reachability? Moreover, to what extent is the systematic error reported in all experiments perceptual? Of interest is the finding that the reachability overestimation was significantly greater for a dynamic than for a static object (see the results of Experiments 1 and 2). As already mentioned in the discussion of Experiment 2, the static and dynamic conditions corresponded to different perceptual contexts. Perception in the dynamic condition is commonly associated with and accompanied by rapid motor responses (i.e., catching) and is usually performed with a whole-body engagement. By contrast, in our static condition the ball was always present, which gave participants more time and opportunity to imagine a reach within the particular constraint of the task (i.e., 1 skeletal DF). An obvious conclusion to be drawn is that judged reachability depends on the context of the task and on the type of body engagement a reach would normally entail if performed (i.e., contacting a moving or a static object). In other words, the judgment of what is reachable is linked to the way an actual reaching action is normally planned and executed.

Overall, the difficulty of our task resided in requiring the participants to imagine themselves reaching for the object and not actually to perform the action. Although the task was perceptually based (situating oneself in relation to a perceived object), it required some mental imagery to the extent that there was no performed action: The reachability judgments provided by the participants referred to an imagined action. Because there was no performed action in the context of the tasks, and considering that perception was supporting only imagined reaching, the observed systematic errors might have corresponded to errors in imaging rather than to errors in perceiving and acting. Bootsma (1989) indirectly provided further support for this interpretation, with evidence that the accuracy of perceptual judgments depends on the participants' active involvement. In different conditions, Bootsma asked participants either to hit a moving ball with their own arm (natural arm condition) or simply to indicate when they thought the ball reached a particular point of contact. Participants' accuracy was significantly greater in the natural arm condition than in the other. Bootsma concluded that accuracy depends on the tight coupling between perceiving and acting systems. When participants are asked merely to verbalize whether they think they can do something, the probability of their inaccuracy increases. On the basis of our findings, this inaccuracy stems from a difficulty in imagining an action outside of a familiar (prototypical) calibration.

The fact that participants tended to imagine their reach in the context of a less constrained, whole-body engagement indicates that there is a biased format to the mental imagery of action. This bias is probably shaped by participants' past experience in perceiving and acting in the environment. We did not directly test for this; however, on the basis of Bootsma's (1989) findings, it is probable that within a different task requiring a tight coupling between perception and the planning and execution of an actual reach, postural restrictions would not affect the degree of accuracy in perceiving what is reachable. The embodiment of perceived reachability in the planning and actual execution of a reach act is a source of supplementary visual, proprioceptive, and kinesthetic information that is not available in the imaging of the same act. This information forms the basis of fine adjustments and less error in the detection of the limits of what is reachable.

Among the participants tested in the six experiments, some were good athletes, and in particular good tennis and baseball players, who evidently should have been capable of accurately detecting the affordance for reaching in the context of their sport. However, these participants showed as much systematic error when asked to judge the reachability of moving objects; an action with which they were seemingly familiar. In general, all participants expressed great surprise on learning of their systematic overestimation. To further test this notion, future researchers should compare the performance of participants required either to verbalize what is reachable with no actual reaching action (as in the current experiments) or to plan and execute an actual reach only when they judge that the object is just reachable (e.g., see Heft, 1993).

Considering that detecting an object's affordances is inseparable from an observer's actions, a legitimate question to raise is whether mental imagery is relevant to this process. This question addresses the general issue of the relation between perception, action, and mental imagery. Numerous studies dealing with this issue have demonstrated a perceptual and action analog of mental imagery, whether it refers to the search of an object in a mentally imagined landscape (Kerr & Neisser, 1983; Kosslyn, 1980), the mental rotation of an object (Shepard & Metzler, 1971), or the effects of mental practice on expert action systems (National Research Council, 1991). Our results provide further evidence that there is a perceptual and action analogue of mental imagery. Participants had no difficulty in providing reachability judgments on the basis of an imagined action. However, the perception–action analogue of mental imagery appears to be only partial because the imaging of the reaching action is a source of systematic overestimation of the limits of prehensile space.

In conclusion, the results of our experiments demonstrate that systematic errors in the judgment of what is reachable come from the fact that it is based on the imaging of a reach with a multiple-DF stretch of the body despite the fact that participants were required to remain perpendicular to the ground with both feet or knees aligned with each other. This finding suggests that the mental imagery of an action depends on familiar, prototypical experiences, which are not adjusted precisely to whatever particular constraints underlie that action. Our experiments demonstrated that participants have a propensity to calibrate the mental imagery of the reach in reference to a whole-body engagement. Thus, the mental imagery of reaching appears to be calibrated in reference to multiple skeletal DFs. This calibration provides the framework for an obligatory format of imagined action. As illustrated in our experiments, it also is the source of systematic errors in the detection of an affordance.

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