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Postural Determinants of Perceived Reachability

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Moving and acting in the environment require a constant monitoring of objects, obstacles, and their location. It is difficult to think of any action that does not require such monitoring which specifies the situation of the perceiver/actor in the environment and helps determine what objects afford for action. Reaching, for example, is an action that typically requires such monitoring. An object's reachability is detected in reference to the particular situation and characteristics of the perceiver/actor. Indeed, the detection of objects' affordances is a fundamental feature of perception (Gibson, 1979). The two experiments reported address the general issue of perceiving objects' affordances, and in particular, the determination of perceived reachability in terms of postural constraints, degrees of behavioral freedom, and the engagement of the whole body of the perceiver/actor. Two questions guide these experiments: How is reachability perceived, and what information specifies it?

General paradigm

Subjects 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 their arm only, keeping both feet parallel and the rest of the body perpendicular to the ground. Judgments were thus based on one skeletal degree of freedom. The paradigm required no physical reaching action from the subject, but merely a mental estimate. No feedback was given. Subjects' reachability judgments were obtained and compared in conditions where the ball was either pitched at various distances in the front of the subject as he or she stood sideways relative to the ball's trajectory (dynamic condition), or presented in front of the subject by the experimenter at various distances (static condition).

Experiment 1

The first experiment was designed to assess and compare subjects' perceived reachability in static vs. dynamic conditions, relative to three different locations of the ball in prehensile space (shoulder-height, 30 cm above, or 30 cm under).

Method. Twenty-four subjects, all college students (12 male and 12 female; 23 right handed, 1 left handed), participated in the experiment. Subjects stood sideways close to a large blackboard. A horizontal line corresponding to the subject's shoulder height was drawn on the board (middle location) with two parallel lines added, 30 cm above (top location) and 30 cm below (bottom location). In both static and dynamic conditions, balls were presented while subjects stood with the blackboard to either their left or right side. In all conditions, balls were presented on each side of the subject along the three lines in either an ascending or descending manner. Orders of 3 positions, 2 sides, and 2 manners of presentation were counterbalanced across subjects. Subjects provided judgments in the static condition first. Following the dynamic condition, the subjects' actual limits of prehensile space were measured for analysis of relative accuracy of their reachability judgments in terms of percent over- or underestimate.

Static Condition: Subjects were asked to judge ("yes" or "no" responses) whether or not 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. A "yes" judgment criterion consisted of being able to touch the ball with the arm closer to the blackboard extended and fingers outstretched, using the tip of the middle finger. For each judgment, the experimenter marked the ball's location on the blackboard, and later measured the distance in cm from the back of the subject's shoulder to the mark.

Dynamic Condition. After judgments in the static condition, subjects were asked to stand sideways, in between the blackboard and a pitching machine. The pitching machine (Ponzo Aztec Rookie) was located 4 meters away from the blackboard. Subjects stood 2 meters from both the blackboard and the pitching machine. The machine pitched soft-pressure tennis balls (Tretorn ST), which targeted fixed locations on the different position lines drawn on the blackboard. The balls crossed the fronto-parallel plan of the subject at a constant velocity of 6 m/sec. After each pitch, subjects were asked to move either closer to (descending) or away from (ascending) the perceived ball's trajectory, up to the location from which they thought they could have just touched the ball by raising the arm. The pitch was repeated as many times as necessary until subjects were confident of the distance in which they situated themselves in relation to the ball's trajectory. In an ascending presentation, subjects were initially placed close to the ball's trajectory (120 cm). They were required to move away to provide their judgments. In a descending presentation, subjects were initially placed far away (300 cm) from the ball's trajectory, and were required to move forward to provide their judgments. Once subjects situated themselves in relation to the ball, reachability judgments were

recorded by measuring the perpendicular from the ball's trajectory line to the extremity of the subject's back heel.

Scoring and analysis. Following the dynamic condition, the actual limits of the subject's prehensile space were measured for further analysis. These limits were mapped by asking subjects to draw an arc on the board while standing sideways against 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 repeated while standing to the other side of the blackboard. Differences in relative distance between perceived (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 underestimate (Perceived + Actual X 100). These calculations were based on measurements from the vertical line running through the subject's back heel, to either the middle finger tip (actual), or the ball's location/trajectory (perceived).

Results. Overall, subjects tended to overestimate the limits of their prehensile space. This trend was significantly greater in the dynamic condition compared to the static condition (average overestimate of 27.5% and 15% respectively, ($F(1,23)=9.889$, $p<.004$). Furthermore, in both conditions, the overestimate was significantly higher relative to the top and bottom ball's location compared to the middle location ($p < .0001$). Finally, a significant overall effect of side was found ($F(1,23)=76.69$, $p < .0001$). Overestimate was significantly greater when subjects had to judge reachability for their right hand (blackboard to the subject's right) .

Discussion. To account for these results, we hypothesize that in general, the source of systematic overestimate comes from the difficulty to perceive and judge reachability based on one skeletal degree of freedom. Although this constraint was required by the task, subjects tended to perceive and judge reachability in relation to a maximum stretch of the whole body. If perceived reachability is based on an overall body engagement, the systematic overestimate could be linked to the difficulty in accurately judging the ball's reachability within the context of the postural constraints imposed by the task. This hypothesis is further supported by the fact that subjects' overestimates tended to increase significantly when the ball was positioned at the top or bottom location. Indeed, a whole body engagement at the top and bottom locations affords increased reachability for the subject without losing balance, assuming that subjects take into account at least the constraint of maintaining both feet parallel on the ground. Based on this hypothesis the following model is proposed.

Proposed Model. The distance at which an object is reachable depends on the perceived limits of maximum stretchability when engaging the whole body, and in particular the perceived "point of postural reversibility" (the point from which the subject can come back to the initial posture without losing balance). Experiment 2 was designed to test this model further.

Experiment 2

To test the viability of the proposed model, subjects 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 point 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 reaching task. Indeed, with increasing weight, the point of postural reversibility is brought back towards the subject's center of mass, thus reducing the distance at which an object is reachable without losing balance. According to the hypothesis, subjects' judgments should take into account the fact that additional weight on the reaching wrist affords less reachability. Therefore, a reduced overestimate should occur, in direct proportion to the increased amount of weight on the reaching arm.

Method. Subjects were 48 college students (37 female and 11 male), tested in the same dynamic condition as in Experiment 1, but with the machine on their left side only, and with balls pitched at the middle position only. Subjects were asked to provide reachability judgments for their right (reaching) arm only. The experimental paradigm and procedure was otherwise identical to Experiment 1, except that subjects were required to wear Softworks exercise weights on one of their wrists while making judgments. In particular, subjects provided judgments under four conditions:

1. No weights on either wrists (same as in Experiment 1);
2. 2 pounds of weights on the right (reaching) wrist and none on the left;
3. 7 pounds of weights on the right (reaching) wrist and none on the left;
4. 7 pounds of weights on the left (nonreaching) wrist and none on the right.

Note that Conditions 1 and 4 are *control* conditions in which the right (reaching) arm is not weighted.

Scoring and Analysis. Subjects provided two successive reachability judgments in each of the four conditions. Judgments were recorded in the same manner as in the dynamic condition of Experiment 1. Manner of presentation (ascending or descending) and order of conditions were counterbalanced across subjects. Judgments were always made relative to the right arm and hand, regardless of which arm was weighted. Because subjects were tested exclusively for the middle position, only the line corresponding to the subjects' shoulder height was created on the blackboard. After subjects provided their reachability judgments in all conditions, they were required to stand sideways to the blackboard, and measurement of the actual reachability of their right arm was recorded for further calculations of over- or underestimate (see Experiment 1 above). Again, these calculations were based on measurements from the vertical line running through the subject's back heel, to either the middle finger tip (actual), or the ball's trajectory at the middle position (perceived).

Results. Similar to the results obtained in Experiment 1, subjects demonstrated a marked overestimate of the distance at which they thought they could reach and contact the ball (33% overestimate on average). Results demonstrate a significant effect of the various weight conditions in the anticipated direction. Compared to the experimental conditions where subjects had weights attached to their right (reaching) arm, overestimate was greater in the control conditions (35% in the control conditions versus 31.5% in the experimental conditions on average). Regarding the two experimental conditions, the overestimate was reduced in Condition 3, where subjects wore 7 pounds on their right arm, compared to Condition 2, where they wore only 2 pounds (30% versus 33% on average). An analysis of variance yielded a significant effect of condition ($F(3,47)=3.975$ $p<.009$). Out of the 48 tested subjects, 36 showed the overall trend predicted by the hypothesis (i.e., overestimate in Condition 1 = Condition 4 > Condition 2 > Condition 3). These results support the model that the point of postural reversibility determines the perception of the distance at which an object is reachable.

General conclusions

The reported experiments demonstrate that postural constraints determine the perceived reachability of an object. The distance at which an object is judged "just reachable" tends to be based on a whole-body engagement. In particular, the determination of this distance appears to depend on both the point of postural reversibility and the basic constraint of maintaining body balance while reaching out in full stretch for the object.

Reference

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton-Mifflin.