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Haptic and visual matches for haptically perceived extent are equivalent

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Perception of the extent of hand-held rods was examined when the mode of exploration was dynamic touch and the mode of report was either a subsystem of the same mode (haptic touch) or a different mode (vision). Moment of inertia was manipulated by the position of an attached mass along the lengths of the rods. Results showed no difference between the report modes, with log of perceived length being a linear function of log of moment of inertia in both cases. This similarity between ipsemodal and cross-modal matches for perceived extent supports the generality of examinations of dynamic touch that use visual magnitude production (e.g., Solomon & Turvey, 1988; Solomon, Turvey, & Burton, 1989a, 1989b).

A number of experiments have shown that the extent of a hand-held implement can be perceived on the basis of effortful or dynamic touch (e.g., Solomon & Turvey, 1988). In the usual paradigm, a long cylindrical rod occluded from view is grasped firmly in one hand and wielded about rotations centered in the wrist. A subject indicates perceived extent by adjusting the position of a visible report surface so as to coincide with the felt location of the tip of the rod. Variations in rod characteristics (e.g., length, mass, center of oscillation, center of mass, moment of inertia), wielding style (e.g., underhand or overhand grip; in front of, to the side, or across the body; parallel or perpendicular to the direction of gravity), and wielding dynamics (variations in kinetic energy, torque) all point to the same conclusion: Perceived extent is a single-valued function of the rod's moment of inertia about an axis through the wrist parallel to the ground plane.

The fact that this method employs a cross-modal matching paradigm—the exploration mode is dynamic touch, and the report mode is visual—suggests caution with respect to the generality of this conclusion. Research dating to the 1800s comparing ipsemodal and cross-modal reports of object extent has revealed some differences. Jastrow (1886) compared perceptual accuracy of extent for objects presented visually (lines on a paper), haptically (finger-span method with wooden blocks), or kinesthetically (moving a stylus between two endpoints). Perceptual reports were obtained in one of the three modes. He found that when a single sense modality was responsible for both exploring an object and reporting a perceptual response, the task was easy and accurate (with vision being most accurate). However, when one sense modality explored the object and another reported extent, the task was difficult and less reliable. He concluded that the connection between modalities is loose and that cross-modal matches are inaccurate.

Although Kelvin (1954) reported no significant differences between cross-modal and ipsemodal conditions using a constant-method procedure for haptics (finger-span method) and vision, Kelvin and Mulik (1958) reported that differences arise when the standard is not the midpoint of the series—the point of subjective equality is displaced in the cross-modal conditions only. They concluded that cross-modal matching does not depend on the physical dimensions of the stimuli, but rather reflects an experimental artifact.

Others, however, have reported no difference between cross-modal and ipsemodal conditions. Davidon and Mather (1966) found that cross-modal judgments are comparable to ipsemodal judgments even when the standard is displaced from the midpoint of the series. Chan, Carello, and Turvey (1990) used the finger-span method to report visually and haptically perceived block size and found no difference between visual-haptic matches and haptic-haptic matches.

All of the foregoing examinations of cross-modal judgments are concerned with perceived extent via haptic touch. Gibson (1966) distinguished this perceptual subsystem from the subsystem he called dynamic touch. The former involves movement of the joints, whereas the latter requires muscular exertion (and both are distinct from the cutaneous-touch subsystem in which the skin and deep tissue are stimulated without either movement or muscular exertion). To date, cross-modal and ipsemodal conditions have not been compared when the exploring subsystem is dynamic touch. The experiment reported here examines perception of the extent of a wielded rod that is occluded from view—that is, the exploration mode is

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dynamic touch. Perceived extent is reported either with a visual match (the adjustment of a visible marker) or a haptic match (positioning the hand to the felt extent of the rod). Haptic touch was considered ipsemodal to dynamic touch because both are subsystems of the haptic perceptual system: "the sensibility of the individual to the world adjacent to his body by the use of his body" (Gibson, 1966, p. 97). That is, they are components of the same mode. For purposes of comparison with visually obtained magnitude productions, moreover, haptic touch is better suited than dynamic touch in that it, like vision, can be used to produce a length. Namely, the articulation of the joints (e.g., of the hand and arm relative to the knee) results in a gap of dimension L. Dynamic touch, in contrast, entails muscular exertions that have no straightforwardly isolable L component.

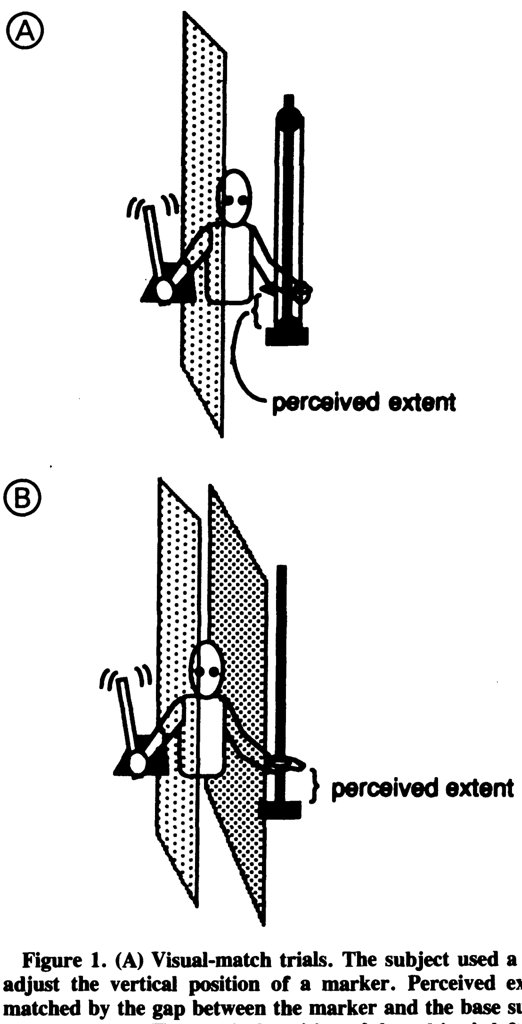

Figure 1. (A) Visual-match trials. The subject used a pulley to adjust the vertical position of a marker. Perceived extent was matched by the gap between the marker and the base supporting the report rod. (The vertical position of the subject's left hand remained more or less the same.) (B) Haptic-match trials. The subject adjusted the vertical position of his/her left hand by sliding it up from the base supporting the report rod. Perceived extent was matched by the gap between the hand and the base. (The base was at seat height.)

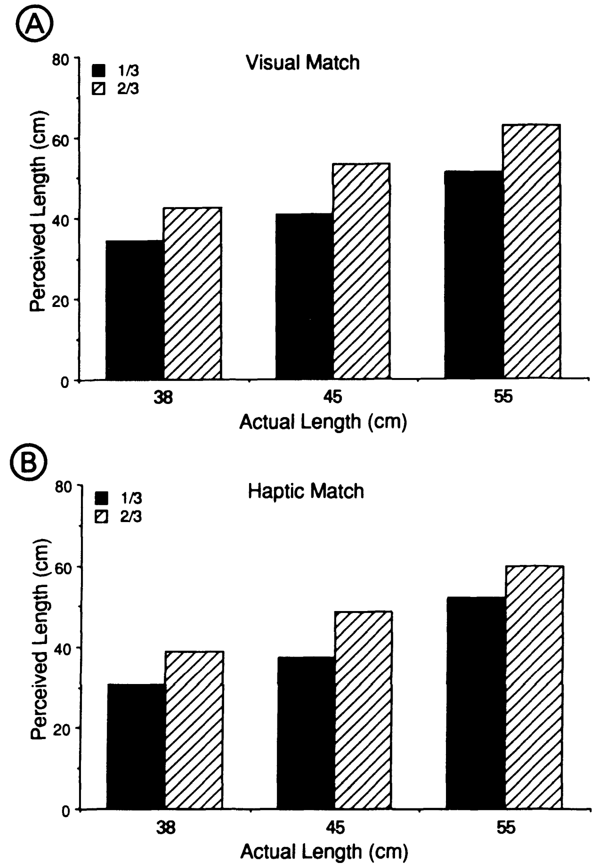

Figure 2. Perceived length as a function of actual length and position of an attached mass for (A) visual-match trials and (B) haptic-match trials.

METHOD

Subjects

Fourteen undergraduates at the University of Connecticut participated in partial fulfillment of a course requirement.

Materials

Three wooden dowels 1.25 cm in diameter and 38, 45, and 55 cm in length were used. Moment of inertia was manipulated by attaching a 30-g mass along the rod at one third or two thirds of its length.

Apparatus

For visual matches, the position of a pointer was adjusted by a line-and-pulley system along the length of a vertically oriented dowel 150 cm in length. For haptic matches, the pulley system was removed and the hand itself was raised along the report rod (which was occluded by an opaque curtain) to the felt position of the rod tip (Figure 1). Length (in centimeters) was read off the indicator by the experimenter.

Procedure

A subject sat with his/her right forearm supported to the wrist. A rod was placed in his/her hand so that the bottom of the rod was flush with the bottom of the subject's fist. The subject was instructed to grip the rod firmly so that it did not twirl in his/her hand. The rod was occluded from the subject's view by an opaque curtain that extended up from his/her elbow to approximately 30 cm above his/her head. On a given trial, the subject was instructed to wield the rod about motions in his/her wrist in order to perceive the rod's length. At the same time, the subject was to adjust the report apparatus to indicate the rod's extent. The apparatus was located to the subject's left, 20 cm below the height of the armrest (Figure 1). For visual-report trials, the subject adjusted the position of the marker so that its distance above its base matched the felt length of the rod. For haptic-report trials, the subject slid his/her left hand up from the base to a height that matched the felt length of the rod. In neither condition, therefore, did the indicator coincide with the location of the tip of the wielded rod. This was done so that the subjects would not have to stretch in order to indicate the lengths of long rods on haptic-report trials.

There were three observations at each combination of rod length and mass position, randomized within report condition, which was blocked and counterbalanced over subjects. The 36 trials took approximately 40 min.

RESULTS

Means of perceived extent as a function of actual extent for visual and haptic matches are shown in Figure 2. A 2 (mode) × 3 (rod length) × 2 (mass position) analysis of variance revealed main effects of rod length [$F(2,26) = 177.20$, $p < .0001$] and mass position [$F(1,13) = 69.17$, $p < .0001$]. Neither the main effect of mode nor its interaction with other variables was significant [all Fs < 1 except mode × mass position, $F(1,13) = 1.71$, $p > .20$]. Lengths were discriminated (the 38-, 45-, and 55-cm rods were perceived as 39.1, 48.4, and 60.8 cm, respectively), and rods with larger moments of inertia (i.e., far position of attached mass) were perceived as longer than rods with smaller moments of inertia (i.e., near position of attached mass); this was the same for visual and haptic reports of perceived length.

A regression of the log of perceived length on the log of moment of inertia is shown in Figure 3. As in previous research on dynamic touch, perceived length was accounted for by variations in the moment of inertia of the rod. Again, this was true for both the usual visual matches and for haptic matches ($p < .0001$).

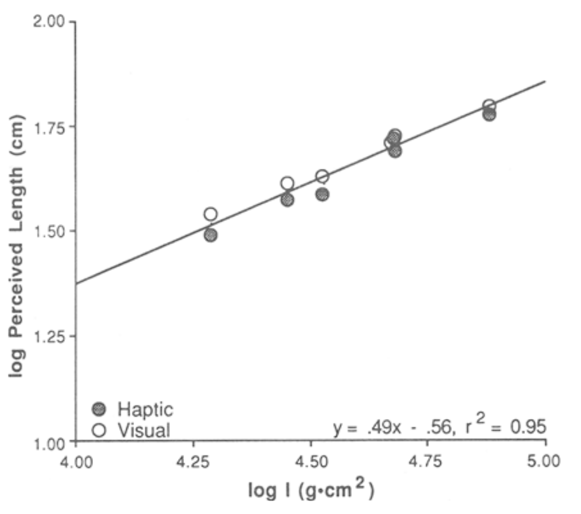

Figure 3. Log of perceived length is the same linear function of log of moment of inertia for both visual and haptic matches.

DISCUSSION

The response measures employed here allowed the subjects to report a geometric property, perceived extent, in terms of the dimension L. Adjusting the position of the marker produced a visible gap that the subjects matched to the extent of the wielded rod. Similarly, adjusting the position of the left hand produced an articulation of joints—a felt gap—that the subjects matched to the extent of the wielded rod. Regardless of the mode in which length was reported, the perceived extent of a wielded rod was the same. The magnitude-production response used in combination with dynamic touch corroborates the findings of Chan et al. (1990) with respect to haptic touch: Ipsemodal and cross-modal matching do not differ.

But L per se is not a mechanical variable; it cannot affect the tissues while dynamic touch is being used to explore the rod. That perceptual subsystem is stimulated by kinetic quantities based on the dimension mass, M. The general conclusion of research on dynamic touch (e.g., Solomon & Turvey, 1988; Solomon, Turvey, & Burton, 1989a, 1989b; Turvey, Solomon, & Burton, 1989), and the conclusion of the research reported here is that perceived extent—however indicated—is a function of the mass distribution of the object. This mass distribution is best characterized by the inertia tensor, a quantification of the rod's resistances to rotation in different directions.

Solomon and his colleagues discussed the mapping of perceived length onto inertial properties in terms of operators. These are embodiments of physical principles or laws that describe what must be done to one thing in order to get another. For example, the operator that takes t into x (namely, $x = at + b$) embodies Newton's second law of motion. In principle, then, we are after what must be done to a wielded rod in order to perceive its extent. In practice, nested operators may be required to describe systems of this sort: Rigid body motions of the hand-rod system act on the tissues of the haptic subsystem in a way that yields a deformation pattern for which there is an invariant specific to the kinetic property on which perception of extent is based. Presumably, whether extent is reported visually or haptically, these operators are the same. That is, the mapping of perceived length onto inertial properties of the hand-rod system is the same whether indexed visually or haptically.

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