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Abstract Calibration of perception to environmental properties typically requires experiences in addition to the perceptual task, such as feedback about performance. Recently, it has been shown that such experiences need not come from an external source or from a different perceptual modality. Rather, in some cases, a given perceptual modality can train itself. In this study, we sought to expand on the range of experiences in which this can occur for perception of the length of a wielded occluded object. Specifically, in two experiments, we investigated whether the act of perceiving the length of a wielded object from a given grasp position could recalibrate the perception of length from a different grasp position. In both experiments, three groups of participants perceived the lengths of wielded rods in a pretest, practice, and a posttest. The practice included either (a) experimenter feedback, (b) changing the grasp position on the object (and again attempting to perceive length), or (c) no additional experiences. In Experiment 1, participants changed their grasp position from the middle to the end of each rod, and in Experiment 2, they did so from the end to the middle of each rod. In both experiments, the results showed that perceiving length from a different grasp position can recalibrate (i.e., provide self-training for) the perception of length.

Keywords Haptics · Perceptual learning · Perception and action

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In order for a person to successfully perform everyday behaviors, perception must be scaled to environmental properties. The process that establishes and maintains this scaling relationship is known as *calibration* (Withagen & Michaels, 2004, 2005). Recalibration of the perception of a property seems to require experiences in addition to the act of perception itself that allow a perceiver to make a series of comparisons between a detectable stimulation pattern and perceptual reports of that property (E. J. Gibson, 1969; Jacobs & Michaels, 2007; Withagen & Michaels, 2005). Among the important issues in developing a theory of calibration is establishing exactly what kinds of additional experiences are necessary and/or sufficient for recalibration to occur. This issue was the focus of the two experiments reported here.

In most laboratory experiments on the recalibration of perception, such experiences are typically in the form of feedback about performance, in some form or another. However, it is not necessary that such feedback be provided on every trial during a practice session (Wagman, McBride, & Trefzger, 2008), that the feedback be about perception of the same property (Wagman & Van Norman, 2011; Withagen & Michaels, 2007), or that feedback explicitly inform a perceiver about how a perceptual report differs from the actual metrical values of a given property (Wagman, Carello, Schmidt, & Turvey, 2009). Moreover, despite the theoretical and practical appeal of providing external feedback, it is also not necessary that feedback be provided by means of an external source (e.g., an experimenter) or by means of a perceptual modality other than that used to perceive the property (e.g., visual feedback on perception by touch). Alternatively, information generated by a perceiver him- or herself within the same perceptual modality used to perceive a given property can be sufficient to recalibrate perception of that property to the actual metrical values of that property. In other words, under certain circumstances, a given perceptual system can train itself (Stephen & Arzamarski, 2009). Such findings suggest that recalibration of perception

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may largely be a self-organized process (Jacobs & Michaels, 2007; see Van Orden, Holden, & Turvey, 2003). Moreover, such findings provide a challenge to accounts of perceptual organization in which the perceptual systems are specialized to pick up on particular ranges of information and in which the improvement of perception by means of one perceptual modality requires the support of another perceptual modality (e.g., Bahrick, Lickliter, & Flom, 2004).

In the two experiments reported here, we investigated self-training of perception by dynamic (or effortful) touch. Dynamic touch is the perceptual subsystem used when hefting or wielding objects by means of muscular effort, such as picking up a coffee mug or throwing a Frisbee (J. J. Gibson, 1966). A large body of research has shown that people can perceive many different geometric and functional properties of a hefted or wielded object, even when the object is out of view, and even when only a portion of the object is held in the hand. The perception of such properties of wielded objects is possible because wielding is an exploratory behavior that provides access to mechanical stimulation variables (e.g., mass and rotational inertia) that are informative about that object's geometric and functional properties (see Carello & Wagman, 2009; Turvey & Carello, 2011). For example, the major principal moment of inertia (i.e., the largest resistance to rotational acceleration about a rotation point in the wrist) provides information about (and constrains perception of) the length of a freely wielded object (van de Langenberg, Kingma, & Beek, 2006).

In a typical experiment investigating the perception of length by dynamic touch, participants place their hand through a curtain, grasp an occluded object with their fist, wield the object about their wrist, and report the perceived length of that object by adjusting the distance between two visible markers. In a typical laboratory experiment investigating recalibration of the perception of length by dynamic touch, feedback is provided to a participant by one of three different methods. In the first method, the experimenter verbally informs the participant about how their perceptual report differs from the actual length of the object (e.g., "2 cm too short"; e.g., Cabe, 2010). In the second method, the experimenter readjusts the distance between the visible markers so that this distance corresponds to the actual length of the object (e.g., Wagman & Van Norman, 2011). In the third method, the experimenter instructs the participant to engage in a behavior that makes the actual length of the object perceptible by means of a different perceptual modality. For example, a participant could be instructed to look at the object or to touch a visible curtain with the distal tip of the object (e.g., Wagman et al., 2009; Withagen & Michaels, 2005).

Each of these methods provides perceivers with experiences in addition to the act of perceiving a given property that allow for comparisons between a detectable mechanical stimulation pattern and perceptual reports of that property. Thus, each method is an effective means by which to recalibrate perceived length to actual length. However, in each case, the information that allows for the requisite comparison comes either by means of an external source (i.e., the experimenter informs the perceiver of actual length) or by means of a different perceptual modality (i.e., vision informs touch of actual length). Recently, it has been shown that although such experiences are sufficient to recalibrate the perception of length to actual length, they are not necessary. Rather, the dynamic touch system may be capable of generating (or revealing) its own additional information about a given property of a wielded object sufficiently to recalibrate perception of that property. Stephen and Arzamarski (2009) found that striking a wielded object against an unseen surface was sufficient to recalibrate perceived length to actual length. In all likelihood, such recalibration occurred because striking is an exploratory behavior that provides access to a different set of mechanical stimulation variables that are informative about this property (e.g., variables related to elasticity) than does the exploratory behavior of wielding (i.e., variables related to mass and rotational inertia).

In the present study, we sought to expand on the range of experiences (i.e., the range of exploratory behaviors) that can serve as self-training for perception of the length of a wielded object. Striking an object against an unseen surface is one way for perceivers to further explore a wielded object so as to reveal mechanical stimulation variables that are informative about length. Another way for perceivers to do so would be to change their grasp position on the object. Whereas striking generally provides access to a different set of mechanical variables, changing grasp position generally provides access to different values of the same set of mechanical variables.[1] Changing grasp position changes the location of the point of rotation (i.e., the wrist) relative to the center of mass of the object, and thus changes the magnitudes of the moments of inertia (as well as other variables; see Wagman & Aspel, 2011; Wagman & Carello, 2003). Thus, just as wielding and striking an object provides more information about object length than does wielding alone, wielding an object at each of two different grasp positions provides more information about object length than does wielding that object from a single grasp position. Accordingly, grasp position on a wielded object can be thought of as a point of observation in an inertial array, in much the same way that the location of the eyes and head relative to environmental surfaces is a point of observation in an optic array (Wagman & Carello, 2003). Therefore, grasping an object at different locations should provide the touch system with additional information about that object, just as viewing an object from different points of observation does for the visual system (see J. J. Gibson, 1966, 1979).

The two experiments reported here were designed to investigate whether changing grasp position on a wielded object is

[1] In some cases, changing grasp position can also provide access to a different set of mechanical variables. For example, gravitational torque is not accessible when an object is grasped at its center of mass, but is accessible when the object is grasped at other locations.

sufficient to recalibrate perceived length to actual length. Specifically, in Experiment 1 we investigated whether the act of perceiving length when wielding a rod at the end could recalibrate perception of that length when that object was wielded at the middle. In Experiment 2, we investigated whether the act of perceiving length when wielding a rod at the middle could recalibrate perception of length when that object was wielded at the end.

Experiment 1

Three groups[2] of participants attempted to perceive the length of a set of occluded rods when grasping those rods at the middle in a pretest, a practice session, and a posttest. One group of participants received feedback during the practice session by the experimenter readjusting the report apparatus to match the actual length of the object. A second group of participants received self-training during the practice session by regrasping the object at the end and again attempting to perceive the length of the object. A third group did not receive any kind of additional experience during the practice session. We assessed (changes in) recalibration by comparing the ratios of perceived length to actual length in the pretest and posttest. We expected that recalibration of perceived length to actual length would occur for participants receiving either experimenter feedback or self-training during practice (and would not occur for participants receiving no additional experience during practice).

Method

Participants

A group of 45 right-handed undergraduate students (40 women, five men) from Illinois State University participated in this experiment. All of the participants received extra credit in their psychology courses in exchange for their participation. Participants were assigned to one of three conditions: experimenter feedback (n = 15), change grasp$_{M-E}$ (n = 15), or control (n = 15).

Materials and apparatus

Fifteen wooden rods (1.2-cm diameter), ranging in length from 20 to 125 cm in 7.5-cm increments, were used as the stimuli in this experiment (see Table 1). Participants sat in a right-handed student desk and placed their right forearm on the desk and through a curtain that occluded both the hand and rod. The report apparatus consisted of an adjustable horizontal marker along a 240-cm wooden track at a height of 70 cm. Participants adjusted the distance of the marker toward or away from themselves using a pulley system, such that the distance between the marker and the zero point of the apparatus corresponded to the perceived length of the rod. A tape measure secured to the floor allowed the experimenter to read reports of perceived length (in centimeters, measured from the wrist of the participant). The tape measure was not visible to participants.

Procedure

The experiment consisted of four blocks of trials—a pretest, two training sessions, and a posttest.

Block 1: ***Pretest*** A participant was seated and placed his or her right arm on the armrest and his or her hand through the curtain, such that the wrist aligned with the zero point of the report apparatus. On a given trial, a participant was handed one of the rods such that he or she grasped it at its midpoint. Specifically, the midpoint of the rod was placed in the middle of the palm, and the participant closed the hand and fingers around the rod such that equal portions of the rod extended on either side of the fist. The participant was not explicitly informed that he or she was holding the rod at this location. The participant then attempted to perceive the entire length of the rod (from one end to the other) by wielding it about the wrist and reported the perceived length by adjusting the report apparatus as described above. Wielding was not restricted in any way, except that the participant was instructed not to lift the forearm off the desk or to touch the curtain or floor with the wielded object. The participant was allowed to wield each rod as long as necessary and was allowed to continually adjust the report apparatus until satisfied with the perceptual report. After reporting the perceived length for a given rod, the participant returned the marker to the zero point of the apparatus. Each participant reported perceived length once for each rod, and the rod order was randomized within each block of trials. The pretest block was identical for participants in all three conditions.

Block 2: ***Practice$_1$*** Following the pretest, each participant completed two practice blocks (practice$_1$ and practice$_2$). As in the pretest, on a given trial, a participant was handed one of the rods by the experimenter such that he or she grasped it at its midpoint and reported perceived length by adjusting the report apparatus as described above. Participants in the experimenter feedback and change grasp$_{M-E}$ conditions received (different kinds of) additional experiences after every trial in the practice session. Participants in the control condition did

[2] This experiment originally consisted of five between-participants conditions—the three conditions reported here, as well as two analogues of the experimenter feedback and change grasp$_{M-E}$ conditions in which participants were provided with false (i.e., inflated) feedback. The patterns of results of these two additional conditions were comparable to those from the feedback conditions.

Table 1 Length, mass, and principal moment of inertia for the objects used in Experiments 1 and 2

Length (m)	Mass (kg)	Principal Moment of Inertia When Grasped at End (kg m^2)	Principal Moment of Inertia When Grasped at Middle (kg m^2)
0.200	0.011	0.019	0.008
0.275	0.017	0.049	0.017
0.350	0.023	0.100	0.032
0.425	0.029	0.190	0.054
0.500	0.038	0.330	0.093
0.575	0.035	0.400	0.110
0.650	0.044	0.640	0.170
0.725	0.058	1.040	0.270
0.800	0.062	1.350	0.350
0.875	0.055	1.420	0.370
0.950	0.081	2.470	0.640
1.025	0.072	2.520	0.650
1.100	0.076	3.090	0.790
1.175	0.078	3.620	0.930
1.250	0.089	4.670	1.190

The magnitudes of principal moments of inertia were multiplied by 100

not receive any kind of additional experience during the practice session.

In the experimenter feedback condition, after a participant reported the perceived length, the experimenter repositioned the marker such that the distance between the marker and the zero point corresponded to the actual length of the rod. After the marker was repositioned, the participant wielded the rod and compared the perceived length to the length specified by the feedback. The participant then returned the marker to the zero point before the next trial.

In the change grasp$_{M–E}$ condition, after a participant reported the perceived length, the experimenter completely removed the rod from the participant's hand and repositioned it such that the participant was holding it at the "bottom." Specifically, the rod was placed in the palm such that the end of the rod was flush with the bottom of the fist. The participant then closed the hand and fingers around the rod, such that all but the portion of the rod in the hand extended away from the participant. The participant was informed that he or she would be grasping the same rod at a different location, but not that they would be grasping the rod at this particular location. After the rod was repositioned, the participant freely wielded the rod about the wrist and (again) attempted to perceive the entire length of the rod. He or she reported perceived length by readjusting the distance of the marker (if necessary). The participant then returned the marker to the zero point before the next trial. Participants in this condition received no explicit feedback about object length.

In the control condition, trials in the practice sessions were identical to those in the pretest. That is, a participant was handed one of the rods by the experimenter such that he or she grasped it at its midpoint and reported perceived length by adjusting the report apparatus as described above. After reporting the perceived length for a given rod, the participant returned the marker to the zero point of the apparatus.

Block 3: ***Practice$_2$*** In all conditions, the second practice block (Block 3) was identical to the first practice block (Block 2).

Block 4: ***Posttest*** The posttest was identical to the pretest and was identical for participants in all three conditions.

Results

To assess the calibration of perceived length to actual length, we compared the ratios of perceived length to actual length in the pretest and posttest for each participant in each of the three conditions (cf. Stephen & Hajnal, 2011). A 3 (condition: experimenter feedback vs. change grasp$_{M–E}$ vs. control) × 2 (test: pre vs. post) mixed-design analysis of variance (ANOVA) was performed on the mean ratio values. A main effect of test [$F(1, 42) = 38.94$, $p < .001$, $\eta_p^2 = .48$] showed that ratios increased from pretest ($M = 0.68$) to posttest ($M = 0.92$), and a main effect of condition [$F(2, 42) = 4.31$, $p < .05$, $\eta_p^2 = .17$] showed that ratio values differed across the three conditions. However, these effects were superseded by an interaction of these factors [$F(2, 42) = 5.46$, $p < .01$, $\eta_p^2 = .21$]. Follow-up tests with Bonferroni corrections revealed that the ratio values increased from pretest to posttest in both the experimenter feedback condition ($p < .001$) and the change grasp$_{M–E}$ condition ($p < .01$), but not in the control condition ($p = .24$) (see Fig. 1).

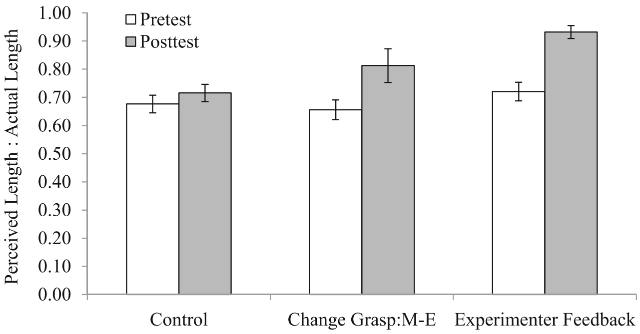

Fig. 1 Ratios of perceived length to actual length in the pretest and posttest of the three conditions for Experiment 1. Error bars indicate standard errors

To assess whether ratio values changed to different degrees in the experimenter feedback and change grasp$_{M–E}$ conditions, we calculated difference scores by subtracting the ratio values in the pretest from ratio values in the posttest for each participant in these conditions. A *t* test showed no difference in the changes in ratio values in the experimenter feedback (M = +.21) and change grasp$_{M–E}$ (M = +.16) conditions, $t(28) = 0.94$, $p = .35$.

As expected, the analyses showed that recalibration of perceived length to the actual length of a wielded rod occurred when the experience in addition to the act of perception itself consisted of either explicit feedback from an experimenter or the act of perceiving the same property from a different grasp position. Moreover, the degrees of recalibration did not differ in each case. Recalibration of perceived length to actual length did not occur when such additional experiences were not provided.

Experiment 2

In Experiment 1, we found that the act of perceiving length while wielding a rod at the end was sufficient to recalibrate perceived length to actual length while wielding the rod at the middle. Thus, Experiment 1 provided preliminary evidence that this behavior can serve as self-training for perception of the length of a wielded object (cf. Stephen & Arzamarski, 2009). Providing stronger evidence for this claim would require demonstrating that changes in grasp position in the reverse order (from the end to the middle) are also sufficient to recalibrate perceived length to actual length. This is particularly important because, in general, perception of the length of a wielded object is better calibrated to actual length when an object is grasped at the end than when it is grasped at the middle (e.g., Wagman & Van Norman, 2011). In part, this is due to the fact that grasping a homogeneous cylindrical object (such as the wooden rods used in Exp. 1) at one end maximizes the major principal moment of inertia, whereas grasping that same object at its midpoint minimizes this value (and makes gravitational torque inaccessible). Therefore, the recalibration observed for participants in the change grasp$_{M–E}$ condition could have been due to these particular changes in mechanical variables across grasp positions during the practice session, rather than to the act of perceiving length from a different grasp position per se. In Experiment 2, we investigated this possibility. Specifically, we investigated whether a recalibration of perceived length to actual length would also occur following changes in grasp position that served to *decrease* the value of the major principal moment of inertia and make gravitational torque inaccessible.

As in Experiment 1, three groups of participants attempted to perceive the length of a set of occluded rods in a pretest, practice, and posttest. The conditions were analogous to those in Experiment 1, except that participants initially grasped the rods at the end rather than at the middle. One group of participants received feedback during practice by the experimenter readjusting the report apparatus to match the actual length of the object. A second group of participants received self-training during practice by regrasping the rod at the middle and again attempting to perceive length. A third group did not receive any kind of additional experience during practice. As in Experiment 1, we assessed (changes in) recalibration by comparing the ratios of perceived length to actual length in the pretest and posttest. We expected that recalibration of length perception would occur for participants receiving either experimenter feedback or self-training during practice (and would not occur for participants receiving no additional experience during practice).

Method

Participants

Another group of 45 right-handed undergraduate students (35 women, ten men) from Illinois State University participated in this experiment. All of the participants received extra credit in their psychology courses in exchange for participation. Participants were assigned to one of three conditions: experimenter feedback (n = 15), change grasp$_{E–M}$ (n = 15), or control (n = 15).

Materials and apparatus

The materials and apparatus were the same as in Experiment 1 (see Table 1).

Procedure

The procedure was the same as in Experiment 1, except as noted.

Block 1: ***Pretest*** On a given trial, the participant was handed one of the rods such that he or she grasped it at the end.

Specifically, the rod was placed in the palm such that one end of the rod was flush with the bottom of the fist. The participant closed the hand and fingers around the rod, such that all but the portion of the rod in the hand extended away from the participant. He or she then reported perceived length as in Experiment 1.

Block 2: ***Practice₁*** On a given trial, a participant was handed one of the rods by the experimenter such that he or she grasped it at the end and reported perceived length as described above. In the experimenter feedback condition, after a participant reported the perceived length, the experimenter provided feedback as described in Experiment 1. In the change $grasp_{E–M}$ condition, after a participant reported the perceived length, the experimenter completely removed the rod from the participant's hand and then handed it back to the participant such that he or she was now holding it at its midpoint. Specifically, the midpoint of the rod was placed in the middle of the palm and the participant closed the hand and fingers around the rod, such that equal portions of the rod extended on either side of the fist. In the control condition, trials in the practice session were identical to those in the pretest.

Block 3: ***Practice₂*** In all conditions, the second practice block (Block 3) was identical to the first (Block 2).

Block 4: ***Posttest*** The posttest was identical to the pretest and was identical for the participants in all three conditions.

Results

As in Experiment 1, a 3 (condition: experimenter feedback vs. change $grasp_{E–M}$ vs. control) × 2 (test: pre vs. post) mixed-design ANOVA was performed on the mean ratio values. A main effect of test [$F(1, 42) = 35.91$, $p < .001$, $\eta_p^2 = .46$] showed that ratios increased from pretest ($M = 0.72$) to posttest ($M = 0.86$). This main effect was superseded by a Test × Condition interaction [$F(2, 42) = 8.16$, $p = .001$, $\eta_p^2 = .28$]. Follow-up tests with Bonferroni corrections revealed that the ratio values increased from pretest to posttest in both the experimenter feedback condition ($p < .001$) and the change $grasp_{E–M}$ condition ($p = .025$), but not in the control condition ($p = .187$) (see Fig. 2). We found no main effect of condition, $p > .05$.

As in Experiment 1, to assess whether the degree of recalibration differed in the experimenter feedback and change $grasp_{E–M}$ conditions, we calculated difference scores by subtracting the ratio values in the pretest from ratio values in the posttest. A t test showed that the change in ratio values was larger in the experimenter feedback condition ($M = +.26$) than in the change $grasp_{E–M}$ ($M = +.09$) condition, $t(28) = 2.84$, $p < .01$.

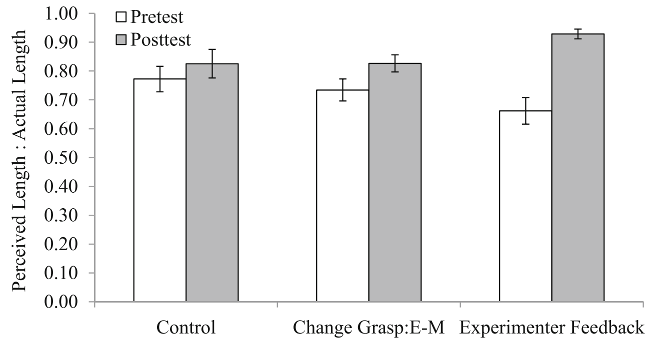

Fig. 2 Ratios of perceived length to actual length in the pretest and posttest of the three conditions for Experiment 2. Error bars indicate standard errors

As expected, the analyses showed that recalibration of perceived length to the actual length of a wielded rod occurred when the experience in addition to the act of perception itself consisted of explicit feedback from an experimenter or the act of perceiving the same property from a different grasp position. In particular, the act of perceiving length when wielding a rod at the middle recalibrated perception of length when that object was wielded at the end. However, a greater degree of recalibration was present when participants were provided with feedback from an experimenter than when they changed grasp positions. The recalibration of perceived length to actual length did not occur when such additional experiences were not provided.

General discussion

Previous research has shown that experience in addition to the act of perceiving a given property is necessary for recalibration of the perception of a given property to the actual metrical values of that property. However, it is not necessary that such experience consist of feedback provided by means of an external source (e.g., an experimenter) or by means of a perceptual modality other than that used to perceive the property. Along these lines, Stephen and Arzamarski (2009) found that the act of striking a wielded object against an unseen surface recalibrated (i.e., served as self-training for) the perception of object length. In the present study, we sought to expand on the range of experiences that can serve as self-training for perception of the length of a wielded object. Specifically, in two experiments we investigated whether the act of perceiving length from one grasp position is sufficient to recalibrate perceived length to actual length when that object is wielded from a different grasp position. In both experiments, we found that the ratios of perceived length to actual length increased (i.e., approached 1.0) from pretest to posttest following practice in which participants were provided with explicit feedback from an experimenter and in which participants changed their grasp position and again attempted to perceive length. To this end, the results show that changing grasp position on a wielded object can recalibrate (i.e., serve as self-training for) perception of the length of a wielded object, and they provide further evidence that (re)calibration may largely be a self-organized process (Jacobs & Michaels, 2007; see Van Orden et al., 2003).

Changing grasp position and recalibration of perception

Two distinct processes are generally responsible for improvement of perception with practice—attunement and calibration. *Attunement* is the detection of a stimulation variable that is (more) informative about a given environmental property, and *calibration* is the scaling of perceptual reports of that property to this informative stimulation variable. The two experiments reported here show that changing grasp position on a wielded object was sufficient to recalibrate perceived length to actual length. Moreover, it is likely that such calibration is due to attunement to a mechanical stimulation variable accessed by wielding that is informative about the length of a freely wielded object (e.g., the moments of inertia). Striking generally provides access to a different set of mechanical variables than does wielding (e.g., elasticity vs. mass and rotational inertia). Changing grasp position generally provides access to different values of the same set of mechanical variables (e.g., moments of inertia) but, under some circumstances, can also provide access to a different set of mechanical variables (e.g., gravitational torque). Importantly, the results of the experiments showed that the act of perceiving the length of a wielded object from one grasp position recalibrated the perceived length from a different grasp position, regardless of whether the change in grasp position served to increase or decrease such inertial magnitudes, and regardless of whether the change in grasp position rendered gravitational torque (in)accessible. This suggests that changing grasp position served an exploratory rather than a corrective (or supportive) function in calibrating perceived length to actual length. In other words, it does not seem to be the case that perceived length at one grasp position was somehow derived from perceived length at another grasp position, or that a particular grasp position provides more privileged information about length than does another grasp position. Rather, it seems more likely that changing grasp position on a wielded object provided the opportunity to (further) explore a detectable stimulation pattern that provided information about object length from any grasp position (see Wagman & Van Norman, 2011).

Incidental feedback, indirect practice, and recalibration

Although experience in addition to the perceptual task seems necessary for recalibration of the perception of a given property, it is somewhat unclear exactly what kinds of additional experiences are sufficient for this to occur. The results of the two experiments reported here help to shed some light on this issue. The finding that explicit feedback is not necessary for improvements in perceptual accuracy is consistent with the finding that explicit practice at performing a given behavior is not necessary for improvements in perception of the possibilities for that behavior (e.g., Mark, Balliet, Craver, Douglas, & Fox, 1990; Stoffregen, Yang, Giveans, Flanagan, & Bardy, 2009). Rather, improvements in the perception of affordances can occur so long as experience performing the perceptual task is accompanied by the opportunity to explore a stimulation pattern that is informative about performance of that behavior (e.g., Hirose & Nishio 2001; Ramenzoni, Riley, Shockley, & Davis, 2008). Such additional experience is particularly effective if the relevant stimulation pattern is not available (or is less salient) in the absence of such exploration. In some cases, such exploration is quite subtle. For example, visual perception of whether a surface can be sat upon improves when experience perceiving is accompanied by postural sway, but it does not improve when postural sway is restricted (see Mark et al., 1990; Stoffregen, Yang, & Bardy, 2005). In other cases, exploration is less subtle but still does not include explicit practice performing the behavior. For example, brief practice using a wheelchair is sufficient to improve perception of whether that wheelchair can be rolled under a barrier (Stoffregen et al., 2009).

In the present experiment, changing grasp position improved the perception of length because it is an exploratory behavior in addition to the perceptual task that allowed the perceiver to further explore a detectable mechanical stimulation pattern that provided information about length. In this way, changing grasp position on a wielded object is an exploratory behavior analogous to changing one's point of observation in the optic array when visually perceiving environmental properties (Wagman & Carello, 2003). As a result, grasping an object at multiple locations should provide the touch system with additional information about that object, just as viewing an object from multiple points of observation does for the visual system (see J. J. Gibson, 1966, 1979).

Author note Experiment 1 was part of a master's thesis conducted at Illinois State University by D.H.A. D.H.A. is now at the School of Social Sciences, Humanities and Arts, University of California, Merced. We thank Ray Bergner for comments on an earlier draft of the manuscript, and Craig Taheny for help with data collection.

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