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RESEARCH ARTICLE

Influences of Head and Torso Movement Before and During Affordance Perception

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ABSTRACT. Previous research has shown that body sway (both standing and seated) is related to the accuracy of affordance judgments. The authors investigated the influence of seated head and torso movement on the perception of a novel affordance for wheelchair locomotion. Healthy adults without prior wheelchair experience judged the lowest lintel under which they could roll in the wheelchair. Prior to judgments, participants were given brief (≈ 2 min) practice at self-controlled wheelchair locomotion. During practice, the participant's head either was or was not restrained within the wheelchair. During the subsequent judgment session, the participant's head was or was not restrained. The accuracy of affordance judgments was influenced by restraint during the practice session and also by restraint during the judgment session. The authors collected data on head movement during the judgment session (when participants were not restrained). These data revealed that movement during judgment sessions was influenced by whether or not participants were restrained during the practice session. Overall, the results reveal that the availability of head movements (i.e., being unrestrained) and the nature of head movements (during unrestrained judgment sessions) were causally related to the accuracy of affordance judgments.

Keywords: affordance, locomotion, perception, wheelchair

Affordances are potential behaviors that are available to a given animal in a given environment (J. J. Gibson, 1979/1986; Stoffregen, 2003). Because affordances influence human interaction with the environment, it would be adaptive for behaving organisms to perceive affordances, rather than inferring them through cognitive processing (J. J. Gibson, 1979/1986). Research has demonstrated perceptual performance consistent with predictions made by affordance-based theories (e.g., Adolph, 1995; Higuchi, Takada, Matsuura, & Imanaka, 2004; Stoffregen, Gorday, Sheng, & Flynn, 1999; Warren, 1984; Yonas & Hartman, 1993).

In the present study, our focus was on the role of movement in the perception of affordances. Infants use deliberate movements to obtain information about their ability to locomote across different surfaces (Adolph, Eppler, Marin, Weise, & Clearfield, 2000), and the accuracy of affordance judgments in adults is improved when they are permitted to move (Mark, Balliet, Craver, Douglas, & Fox, 1990; Oudejans, Michaels, Bakker, & Dolne, 1996). We sought to understand causal links between exploratory movement and the accuracy of affordance judgments.

Correspondence Between Movement and Judgment

Stoffregen, Yang, Giveans, Flanagan, and Bardy, (2009) examined relations between affordance judgments and movement. Healthy adults without prior wheelchair experience judged the lowest lintel under which they could roll while seated in the wheelchair. Before judgments, some participants were given brief (≈ 2 min) practice at self-controlled wheelchair locomotion. This practice took place in a hallway with a high ceiling, such that there were no overhead surfaces near their minimum passage height. In addition, during practice participants were not asked to judge or attend to their minimum passage height. There were two main results. First, participants who had this brief practice accurately judged their own minimum passage height (even when practice did not include passage under low lintels), whereas participants who had no practice gave relatively inaccurate judgments. Second, prejudgment practice influenced movement of the head and torso during judgment sessions.

The results demonstrate that affordance perception can be learned through brief, indirect practice, and suggest that such practice can inform exploratory movement that occurs during judgments. However, the results of Stoffregen et al., (2009) do not address the issue of whether there were causal relations between exploratory movement and the accuracy of affordance judgments. At least three relations are possible. First, the fact that prejudgment practice influenced both judgments and movement during judgments may have been coincidental. For example, changes in judgments and changes in movement may be independent consequences of some third factor, such as a change in some inferential cognitive process. Second, it may be that prejudgment practice influenced affordance judgments and that the change in judgments (relative to judgments made without prejudgment practice) caused participants to alter their movements. This type of causality would be consistent with the idea that the education of attention can lead to changes in exploratory activity (e.g., Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein, & Witherington, 2000; E. J. Gibson, 1988; E. J. Gibson & Rader, 1979). Finally, prejudgment practice may have produced changes in movement (during judgments) that, in turn, enabled increased accuracy in affordance judgments. These latter two explanations are not mutually exclusive: Changes in affordance perception could lead to changes in movement that, in turn, would lead to improvements in affordance perception. We expected that movement would have causal effects on the accuracy of affordance perception. Accordingly, we predicted that experimental manipulations of movement

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(before and during affordance judgments) would influence the accuracy of affordance judgments.

Locomotor and Nonlocomotor Movement

Mark (1987) asked participants to wear wooden blocks on their feet, which increased their maximum sitting height, that is, the tallest chair on which they could sit. While wearing the blocks, participants made a series of 24 judgments of maximum sitting height. Participants were not permitted to sit while wearing the blocks, and received no feedback about the accuracy of their judgments. In addition, participants could not see the blocks and, in fact, gave very poor estimates of block height. Despite these restrictions, the accuracy of affordance judgments improved over approximately 16 judgments and remaining stable thereafter. As noted, participants were not permitted to sit while wearing the blocks; however, they were permitted to walk between judgments. Mark et al., (1990) evaluated the possibility that walking while wearing the blocks may have lead to the observed improvement in judgment accuracy. In their Experiment 1, participants were required to walk after each judgment, whereas in their Experiment 2 participants were never permitted to walk while wearing the blocks. The results revealed that walking reduced the variability of judgments but did not affect the overall accuracy (i.e., the mean across participants for each trial).

In subsequent experiments, Mark et al., (1990) showed that when participants stood normally (as opposed to placing their feet in unusual positions) improvements in the accuracy of affordance judgments were dependent on the availability of normal body sway. Mark et al., required participants to stand with their head and back in contact with a wall, thereby eliminating body sway. In this condition, when participants wore blocks on their feet their judgments of maximum sitting height were grossly inaccurate and did not improve over trials (cf. Ramenzoni, Davis, Riley, & Shockley, 2010). Interestingly, the elimination of body sway also eliminated participants' ability to judge accurately their maximum sitting height when not wearing blocks. Thus, body sway appeared to be necessary for learning an unfamiliar affordance, and also for the perception of a stable, familiar affordance.

In Stoffregen et al., (2009), prejudgment practice consisted of participants rolling up and down a hallway, under their own power, in the wheelchair. During this locomotion there would have been movement of the head and torso relative to the wheelchair. Movement of the wheelchair constituted locomotion, whereas movement of the head and torso was nonlocomotor. Either or both of these types of movement may have influenced the accuracy of affordance judgments. As previously noted, Mark et al., (1990) found that nonlocomotor movement (in their study, standing body sway) was necessary for perception of both familiar and altered affordances. One purpose of the present study was to evaluate the influence on affordance judgments of nonlocomotor movement during prejudgment practice and during judgment sessions. Following Mark et al., we used a method in which body sway (in our case, seated body sway) could be eliminated. Our method permitted us to eliminate sway during judgments, but also during the prejudgment sessions in which participants engaged in wheelchair locomotion.

The Present Study

We examined the influence of two different types of movement on the accuracy of affordance perception; nonlocomotor movements made before participants attempted to perceive an affordance, and nonlocomotor movements made during the act of affordance perception.

We studied perceptual judgments and body movement in a situation in which participants were asked to judge their ability to execute an act with which they had no prior experience. We recruited participants who had no experience using wheelchairs, and we asked them to judge PH_{Min}, the minimum height under which they could pass while rolling in a wheelchair. Before making judgments, participants were given brief practice of self-controlled locomotion in the wheelchair. During practice, participants either were restrained (restrained practice [RP]) or were not (unrestrained practice [UP]). Similarly, while making judgments participants either were restrained (restrained judgments [RJ]) or were not (unrestrained judgments [UJ]). Thus, we used a 2 × 2 design. Each individual participated in only one condition; thus, conditions was a between-participants variable. These manipulations allowed us to assess the influence of locomotion (which was always present during practice) and nonlocomotor movement (which was eliminated during restraint). The manipulation of restraint during judgments permitted us to assess directly relations between movement and judgment accuracy.

Logically, several effects were possible. The availability of nonlocomotor movement during practice may lead to more accurate judgments, to differences in movement during judgments, or to both. Similarly, the availability of nonlocomotor movement during judgments may lead to more accurate judgments.

We predicted that the most accurate affordance judgments would occur when there was no restraint, that is, in the UP–UJ condition. Mark et al., (1990) found that nonlocomotor body motion during judgments was necessary for affordance perception. Given this finding, we predicted that judgment accuracy would be reduced when movements were not available during judgments (i.e., in the UP-RJ and RP-RJ conditions). Separately, we predicted that the availability of nonlocomotor movement during the practice sessions would lead to improved judgment accuracy. One might expect that the worst (i.e., least accurate) judgments would occur in the RP–RJ condition, when participants were always restrained. Alternatively, judgment accuracy might reach its nadir in the UP–RJ condition, if during practice participants learned particular relations between nonlocomotor movement and affordance perception that were no longer available when restraint was imposed in the judgment session. Such an outcome would

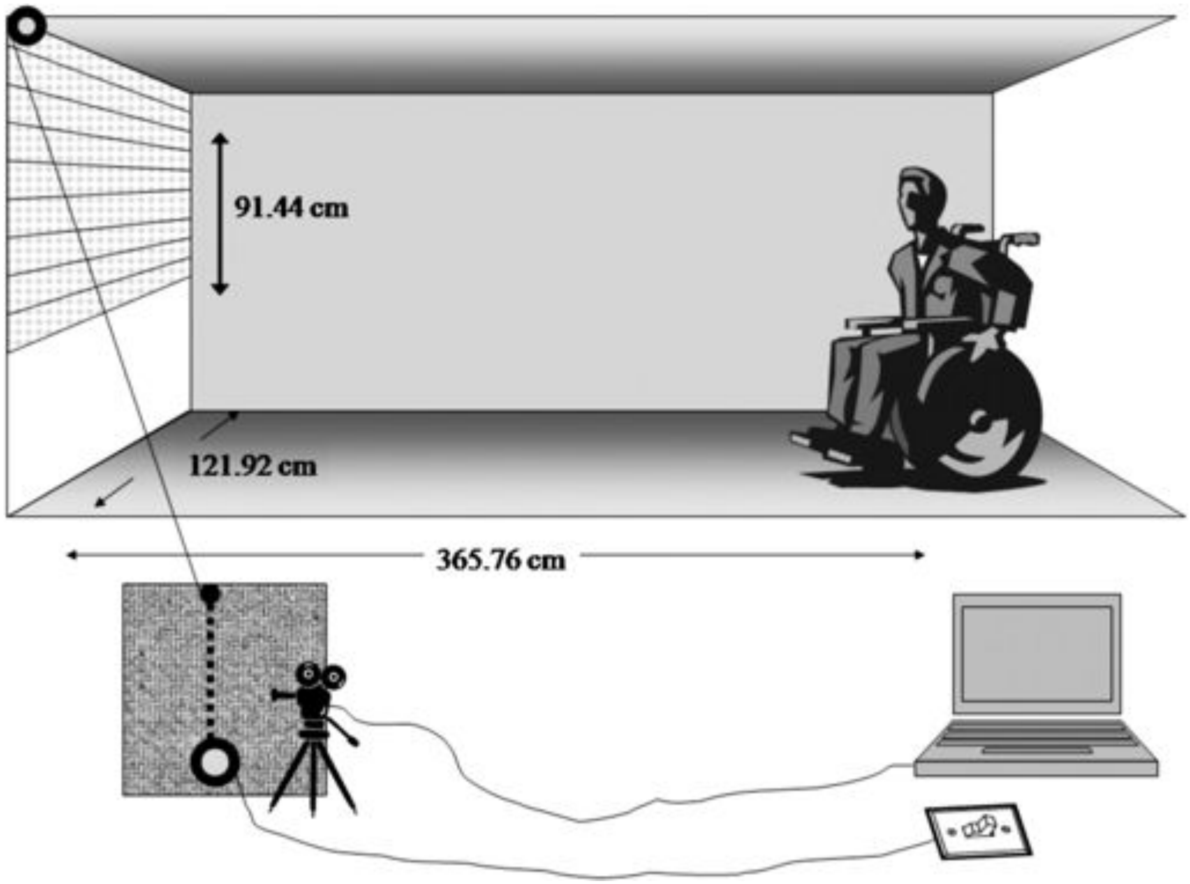

FIGURE 1. The experimental setup for PH_{Min} judgments.

strongly implicate a causal role for nonlocomotor movement in learning about affordances.

During judgment sessions, we measured movement of the head and torso. Our primary goal in gathering these data was to identify parameters of movement that could be related to judgment accuracy (i.e., differences across conditions) and to changes in accuracy (i.e., trial effects). Head and torso movement were measured only when the head was not restrainted during judgments, that is, in the UJ conditions (UP–UJ and RP–UJ). We predicted that movement during judgment sessions would differ between the UP and RP conditions. We attempted to relate these movement data to the accuracy of perceptual judgments; that is, we asked whether judgment error was related to exploratory movement during the judgment session, but also to differences between locomotor and nonlocomotor movement during the practice session.

Method

Participants

Participants were 48 individuals with no experience in wheelchair use. Participants varied in age from 18 to 32 years, and in height from 1.52 to 1.87 m. There were 18 men and 30 women. Each participant took part in only one experimental condition and all participants were naive to the hypotheses of the experiment. Informed consent was obtained from each participant before the experiment. Participants were treated in accordance with the “Ethical Principles of Psychologists and Code of Conduct” (American Psychological Association, 1992). The experimental protocol was approved by the Institutional Review Board of the University of Minnesota.

Apparatus

The experimental setting is depicted in Figure 1.

Wheelchair

We used a normal wheelchair (Stylus, Pride Mobility Corp., Exeter, PA). The wheelchair was with 41 cm seat depth, 49 cm seat height from floor, and 66 cm wide across the wheel rims. It had a soft seat and back, with padded armrests and metal footrests. The wheels could be securely locked so that the chair was fixed and stationary.

Judgment Apparatus

The experimental apparatus was the same as used by Stoffregen et al., (2009). It consisted of a height-adjustable window blind. The upper, fixed bar of the blind was attached to a horizontal cross bar 195 cm above the floor. The crossbar traversed a hallway that was 1.3 m wide. The lower bar was connected to an electric motor by a rope that ran up from the lower bar through a hook eye in the ceiling. The motor was remotely controlled by the experimenter, and could be used to raise and lower the lower bar from 65 to 190 cm above the floor. The blind moved at a velocity of 2 cm/s. A black curtain, 1.3 m wide and 2.5 m long, hung in front of the blind to prevent participants from seeing it prior to experimental trials. The curtain was opened when participants looked at the window blind.

The motor that moved the blind was attached to the bottom of a vertical plywood board that was 92 cm wide by 152 cm high. The rope that connected the motor to the window blind ran through a hook eye at the top of the board down to the motor. A tape measure was securely attached to the board next to the rope. A needle positioned horizontally through the rope passed in front of the tape measure, and could be used to read the height of the blind. A digital video camera placed on a tripod was used to record the position of the needle on tape for later analysis. During judgment sessions, the wheelchair was placed at a distance of 3.6 m from the window blind apparatus. The hallway extended 3.2 m beyond the window blind apparatus. Raising and lowering the blind disoccluded and occluded this portion of the hallway, respectively.

Movement Data

Movement of the head and torso were monitored during judgment sessions when the head was not restrained (i.e., the UP–UJ and RP–UJ conditions). Movement data were obtained using a magnetic tracking system (Fastrak, Polhemus, Inc., Colchester, VT). The emitter was placed on a stand at the approximate height of the participant's head, just behind the wheelchair. One sensor was attached to a bicycle helmet worn by participants, and another was affixed to the skin, using cloth medical tape, at the level of the seventh cervical vertebra (i.e., between the shoulder blades). A third sensor was attached to the arm of a large protractor that was securely affixed to a table adjacent to the experimenter, and was used by the experimenter to mark significant events in the movement data (described in the *Procedure* section). Data on the movement of each sensor in the anteroposterior (AP) and medialateral (ML) axes were sampled at 40 Hz, and were stored on disk for later analysis.

Procedure

Participants read and signed a consent form, after which the experimenter explained that they would be asked to sit in a wheelchair and give judgments of their minimum passage height. The experimenter, followed by the participant, pushed the wheelchair to a 25 m indoor hallway outside the experimental room. The participant was asked to sit up straight in the wheelchair. A commercial headrest with Velcro stripe could be used to restrain the participant's head. With eyes open, the participants used their hands to roll the wheelchair up and down a 25 m hallway. Wheelchair movement was self-paced, and lasted 2 min. When the participants were done with the prejudgment session, they were led back into the laboratory. The experimenter returned the wheelchair to the appropriate position in the laboratory, and locked the wheels, after which the participant sat in the wheelchair and began the judgment trials.

After the participant finished all the judgment trials, his or her actual PH_{min} was measured. While seated in the wheelchair, participants' actual PH_{min} was measured from the top of the head to the ground. The participant was asked to sit up straight, and the measurement was taken using a cloth measuring tape from the rear of the wheelchair so that participants could not see the tape or the measurement process. During measurement of actual PH_{Min}, the wheels of the wheelchair were locked.

The procedure for making PH_{Min} judgments was identical for all conditions, and is illustrated in Figure 1. We used the method of continuous adjustment (Mark, 1987; Mark et al., 1990; Stoffregen, Gorday, et al., 1999). After a ready signal, the experimenter drew the curtain and began to move the window blind apparatus. The participant viewed the continuous motion of the blind and said "stop" when he or she judged that the lower bar was at his or her PH_{min}. Participants could, if they wished, request that the height of the blind be adjusted until they were satisfied it was at their PH_{min}. When the participant gave his or her approval of the blind setting, its height in centimeters was recorded on a data sheet by the experimenter (these data were later confirmed from the video recordings of the blind apparatus). The blind was then moved to the starting position for the next judgment, and the process was repeated. On alternate judgments, the blind rose or fell. After each judgment with the blind rising, the blind was set to a height of 165 cm in preparation for the next (falling) judgment. After each judgment with the blind falling, the blind was set to a height of 100 cm in preparation for the next (rising) judgment. Each participant completed 24 judgments, beginning with the blind descending.

Movement data were recorded continuously beginning at the ready signal for the first judgment, and ending when the participant indicated that he or she was satisfied with the last judgment. When the experimenter gave his ready signal at the beginning of each judgment, he also rapidly rotated the arm of the protractor through 180°. At the end of each judgment, when the participant indicated that he or she was satisfied with the position of the blind, the experimenter again rotated the protractor arm through 180°.

The head could be restrained using a device that could be attached to the back of the wheelchair (Plush, by Whitmyer Biomechanix, Inc.). The restraint device consisted of a headrest to which was attached a flexible band that passed around the forehead. The original purpose of the device was to support the head for individuals whose physical challenges make it difficult to balance or stabilize the head on the neck. This was achieved through passive stabilization, that is, the device restrained the head so that it was upright and facing forward. The restraint device did not directly limit movement of the torso, but torso movement was effectively limited due to the immobility of the head.

There were four experimental conditions. During wheelchair practice, the head was restrained, or was not restrained. During judgment sessions in the wheelchair, the head was restrained, or was not restrained. During unrestrained practice both locomotor and nonlocomotor movements were available, the former through self-generated translation of the wheelchair and the latter through movements of the head and torso in the wheelchair. During restrained practice only locomotor movements were available. During unrestrained judgment sessions there was no locomotion, but nonlocomotor movements of the head and torso were available. During restrained judgment sessions only eye movements were available.

Analysis

Judgment Data

Each trial consisted of one ascending judgment and one descending judgment. Following previous research (e.g., Mark, 1987; Mark et al., 1990; Stoffregen, Yang, & Bardy, 2005; Warren & Whang, 1987) we used the mean of these two judgments as the judgment value for each trial. To evaluate the accuracy and stability of judgments over trials, we computed the difference between the actual and perceived minimum passage heights (judged PH_{Min}—actual PH_{min}).[1]

Condition was a between-participants variable, whereas trial was a within-participants variable. We conducted 4 (Condition) × 12 (Trial) mixed repeated measures analyses of variance (ANOVAs) on the judgment data.

Movement Data

Movement data were collected during judgment sessions for the UP–UJ and RP–UJ conditions. Using recorded movements of the protractor arm, we divided movement data into judgment intervals and interjudgment intervals. Judgment intervals began with the experimenter's ready signal and ended when the participant indicated that he or she was satisfied that the blind was at his or her PH_{Min}. Interjudgment intervals included all remaining time. During interjudgment intervals participants were waiting for the next judgment to begin, and did not have an experimentally defined task. So long as they remained seated in the wheelchair, they were free to do whatever they wanted. Following Stoffregen et al., (2005, 2009), we reasoned that movement during interjudgment intervals could not aid perception of PH_{Min}, and may differ from movement during judgment intervals.

At the beginning of each judgment, the bottom rail of the blind was far from actual PH_{Min} (either at the top or bottom of the apparatus). As the blind moved, the bottom rail approached the participants' actual PH_{Min}. Participants might look more carefully as the blind approached actual PH_{Min}. If so, then head and torso movements used to stabilize vision might change from the beginning to the end of individual judgments. Stoffregen et al., (2009) reported that movement changed over time during the judgment process, that is, during individual judgments. Following that earlier study, we divided each interval (judgment and interjudgment intervals) into two nonoverlapping temporal windows, comprising the first 4 s and the final 4 s of each interval.

In our analysis of movement data, condition was a between-participants variable, whereas trial, interval, and temporal window were within-participants variables. We conducted 2 (Condition) × 12 (Trial) × 2 (Interval) × 2 (Temporal Window) mixed repeated measures ANOVAs on the movement data. Analyses were conducted separately on movement along the AP and ML axes.

In all ANOVAs, we estimated the effect size using the partial η^2 statistic. Cohen (1988) argued that values of partial $\eta^2 > 0.14$ indicate a large effect.

Results

Judgment Data

The data are summarized in Figure 2. The accuracy of judgments differed across conditions, as indicated by a main effect of conditions, $F(3, 44) = 4.412$, $p = .008$, partial $\eta^2 = .231$. Planned comparisons revealed that judgments were more accurate in the UP–UJ condition than in the UP–RJ condition. Other conditions did not differ from one another. In addition, judgments changed over trials, as indicated by a main effect of trial, $F(11, 34) = 3.419$, $p = .003$, partial $\eta^2 = .525$. Consistent with studies of perceived maximum sitting height (Mark, 1987; Mark et al., 1990; Stoffregen et al., 2005), the accuracy of judgments improved over trials. The Condition × Trial interaction was not significant, $F(33, 100.87) = 0.690$, $p > .05$.

Movement Data

We analyzed the positional variability of movement, which we defined as the standard deviation of position, and the velocity of movement, which we defined as the change in position per unit time.

There were no significant main effects of condition or trial on any movement variables. The main effect of interval was significant. Head movement differed during judgment intervals, relative to interjudgment intervals. There were significant effects of interval on the variability of head position in the ML axis, $F(1, 22) = 4.672$, $p = .042$, partial $\eta^2 = .175$, and in the AP axis, $F(1, 22) = 5.218$, $p = .032$, partial $\eta^2 = .192$. These effects are presented in Table 1. Interval influenced the velocity of head motion in the ML axis,

TABLE 1. Main Effects of Intervals on Movement of the Head

		Interval			
		Judgment		Interjudgment	
Measure	Axis	*M*	*SD*	*M*	*SD*
Positional variability (cm)	ML	0.145	0.032	0.189	0.050
	AP	0.240	0.063	0.308	0.089
Velocity (cm/s)	ML	0.537	0.057	0.599	0.071
	AP	0.508	0.080	0.591	0.106

Note. AP = anteroposterior; ML = medialateral.

$F(1, 22) = 6.195$, $p = .021$, partial $\eta^2 = .220$, and in the AP axis, $F(1, 22) = 5.522$, $p = .028$, partial $\eta^2 = .201$. These effects are illustrated in Table 1. There were no significant main effects of interval on torso motion.

Main Effect of Temporal Windows

In the AP axis, the velocity of head movement during the first temporal window ($M = 0.507$ cm/s, $SD = 0.086$ cm/s) was less than during the last temporal window ($M = 0.592$ cm/s, $SD = 0.100$ cm/s), $F(1, 22) = 6.204$, $p = .021$, partial $\eta^2 = .220$. There were no significant main effects of temporal windows on torso movement.

Interval × Temporal Window Interactions

We found significant Interval × Temporal Window interactions. This interaction was significant for the positional variability of head motion in the AP axis, $F(1, 22) = 4.581$, $p = .044$, partial $\eta^2 = .172$ (Figure 3). The interaction was significant for the velocity of head motion in the ML axis ($F(1, 22) = 8.251$, $p = .009$, partial $\eta^2 = .273$; Figure 4). It was significant for the velocity of torso movement of in the ML axis ($F(1, 22) = 7.903$, $p = .010$, partial $\eta^2 = .264$; Figure 5), and in the AP axis, ($F(1, 22) = 5.152$, $p = .033$, partial $\eta^2 = .190$; Figure 6).

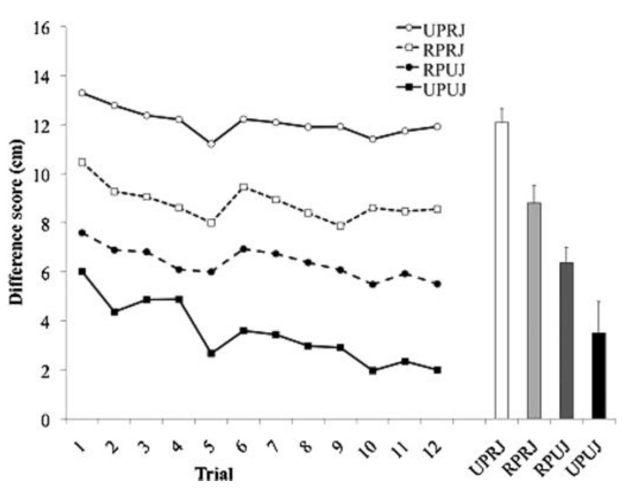

FIGURE 2. Mean difference scores (judged—actual PH_{Min}) as a function of trials and conditions. RJ = restrained judgments; RP = restrained practice; UJ = unrestrained judgments; UP = unrestrained practice.

Trial × Interval × Temporal Window Interaction

We found a significant three-way interaction on the velocity of torso motion in the ML axis, $F(11, 12) = 3.122$, $p = .031$, partial $\eta^2 = .741$ (Figure 7), and in the AP axis, $F(11,12) = 3.377$, $p = .024$, partial $\eta^2 = .756$ (Figure 8). From Cohen's (1988) perspective, the effect sizes for these interactions were large, which is unusual for three-way interactions.

Condition × Interval × Temporal Window Interaction

As predicted, we found that the presence of absence of restraint during prejudgment practice influenced movement during subsequent judgment sessions. There was a significant three-way interaction on the velocity of head motion in the AP axis ($F(1, 22) = 4.659$, $p = .042$, partial $\eta^2 = .175$). From

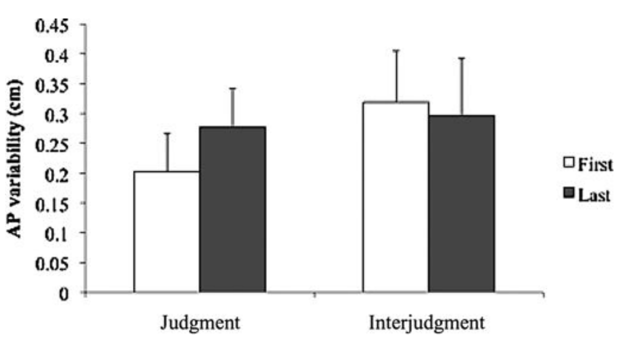

FIGURE 3. Positional variability of head movement in the anteroposterior (AP) axis as a function of temporal window and interval. The error bars represent standard error.

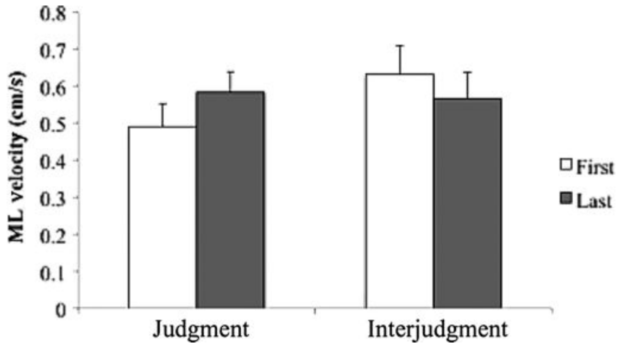

FIGURE 4. Mean velocity of medialateral (ML) head movement as a function of temporal window and interval. The error bars represent standard error.

Cohen's (1988) perspective, the effect size for this interaction was large, which is unusual for three-way interactions. Figure 9 illustrates the interaction effect.

Discussion

We asked participants to judge a novel affordance, PH_{Min}, the minimum height under which they could pass while rolling in a wheelchair. We manipulated the availability of movement of the head and torso. Before the judgment session, participants were given brief practice controlling their own locomotion in the wheelchair, either with or without head restraint. During judgment sessions (seated in the wheelchair) the head also was or was not restrained. Judgment accuracy was influenced by head restraint in the judgment sessions, but also by head restraint during prejudgment locomotion. Judgments were least accurate when the availability of head movements during locomotion was followed by head restraint during judgments. Across conditions, judgment accuracy improved over the course of the judgment session.

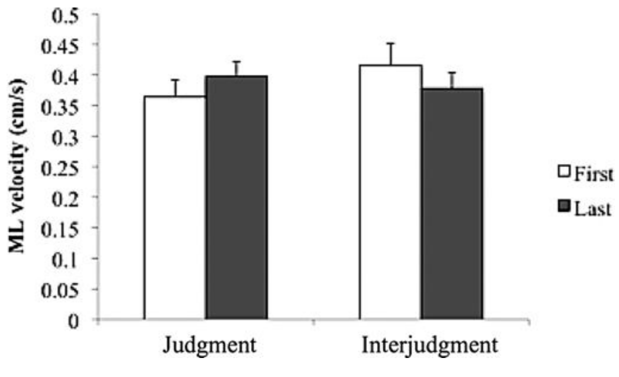

FIGURE 5. Mean velocity of medialateral (ML) torso movement as a function of temporal window and interval. The error bars represent standard error.

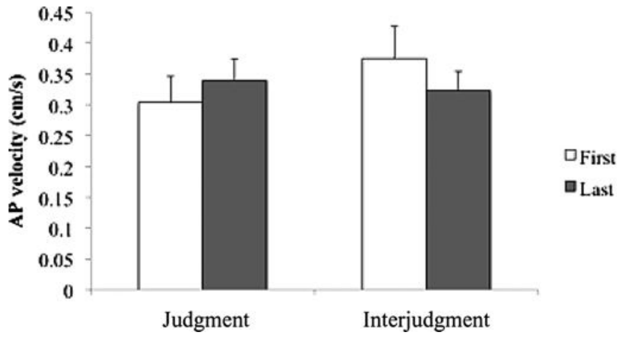

FIGURE 6. Mean velocity of anteroposterior (AP) torso movement as a function of temporal window and interval. The error bars represent standard error.

We collected data on movement of the head and torso during judgment sessions, for the two conditions in which the head was not restrained. Using these data we found four types of effects. First, participants moved differently when they were making judgments (judgment intervals) than between judgments (interjudgment intervals). Second, movement changed over time within individual judgments, that is, across temporal windows. Third, movement varied as a function of trials, in a three-way interaction with intervals and temporal windows. Fourth, in another three-way interaction, we found effects of prejudgment head restraint on movements during judgment session. These effects are discussed below.

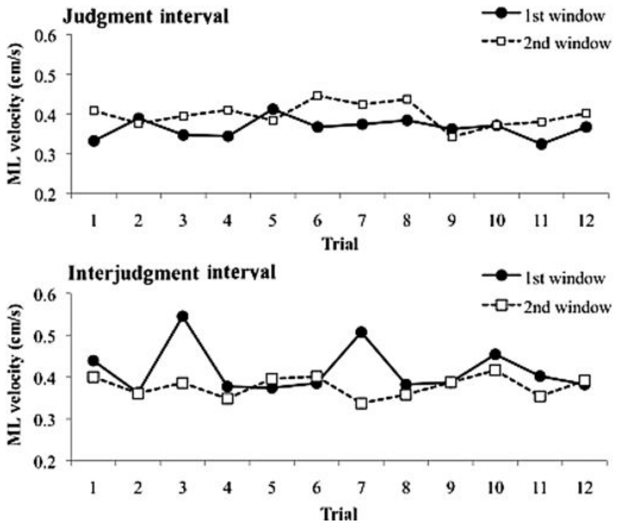

FIGURE 7. Mean velocity of medialateral (ML) torso movement as a function of trial, interval, and temporal window: **(A)** judgment, **(B)** interjudgment.

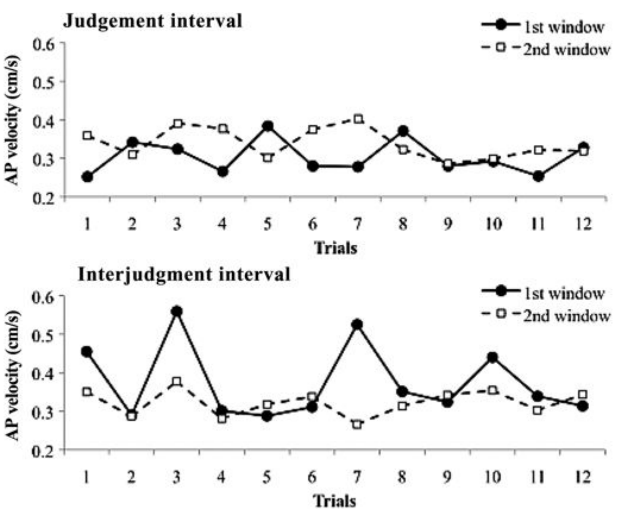

FIGURE 8. Mean velocity of anteroposterior (AP) torso movement as a function of trial, interval, and temporal window: **(A)** judgment, **(B)** interjudgment.

Head Restraint and Judgment Accuracy

In four conditions, participants made a series of judgments of PH_{Min}. We expected that judgment accuracy would be affected by the availability of head movements during judgment sessions, but also by the availability of head movements during prejudgment sessions. This prediction was confirmed: Judgment accuracy was influenced by head restraint both prior to and during judgment sessions. Planned comparisons revealed that head restraint during judgments (UP–RJ condition) reduced the accuracy of judgments relative to when the head was never restrained (UP–UJ condition). Interestingly, Figure 2 suggests that judgment accuracy may have been greater when the head was always restrained (RP–RJ condition) than when the head was restrained only during judgments (UP–RJ condition). At a minimum, the results indicate that head restraint during both prejudgment and judgment sessions did not yield the least accurate judgments.

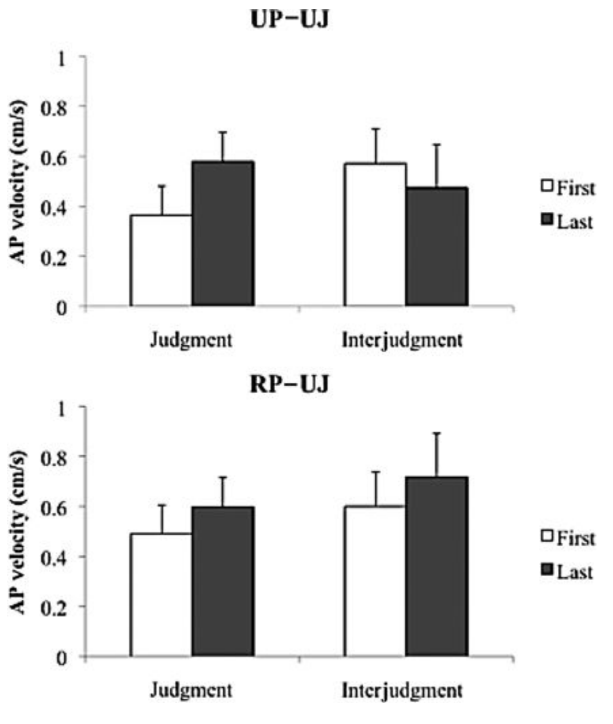

FIGURE 9. Mean velocity of anteroposterior head movement a function of temporal window and interval: **(A)** UP–UJ, **(B)** RP–UJ. The error bars represent standard error. RJ = restrained judgment; RP = restrained practice; UJ = unrestrained judgment; UP = unrestrained practice.

In the present study, judgments when the head was always restrained (RP–RJ condition) were not less accurate than when the head was restrained only during the prejudgment session (RP–UJ condition) or only during the judgment session (UP–RJ condition). One implication of this finding is that judgment accuracy was not related to the simple quantity of movement that was available to participants. It may be that restraint would reduce judgment accuracy through a generic reduction in the amount of movement (cf. Stoffregen et al., 2009). Although we did not measure movement during the prejudgment sessions it seems certain that the magnitude of head and torso movements was greater in the UP conditions (UP–UJ and UP–RJ) than in the RP conditions (RP–UJ and RP–RJ). Thus, the fact that judgment accuracy did not differ between the RP–RJ condition and the UP–RJ condition indicates that judgment accuracy did not scale with movement magnitude in any simple fashion.

Following previous studies (Mark, 1987; Mark et al., 1990; Stoffregen et al., 2005), we predicted that the accuracy of judgments would improve over trials, despite the absence of feedback about judgment accuracy. This prediction was confirmed: Across conditions, judgment accuracy improved over trials. Head restraint reduced the overall accuracy of judgments but did not influence the increase in accuracy over trials, as shown by the fact that the Condition × Trial interaction was not significant. These results may be interpreted as indicating that movement was not causally related to trial-related improvements in judgment accuracy. An alternative interpretation, which we prefer, is that trial-related improvements might have been facilitated by different types of movement in different conditions.

Stoffregen et al., (2009) provided some participants with prejudgment locomotor experience in the wheelchair, whereas other participants had no such experience. They found that prejudgment experience improved the accuracy of PH_{Min} judgments. It makes sense that practice with locomotion would improve an individual's ability to judge his or her own locomotor abilities (e.g., Oudejans et al., 1996). In the present study, head movements were irrelevant to the affordance being judged: Movement of the head did not alter PH_{Min}. Thus, the influence of head restraint (in both the prejudgment and judgment sessions) on judgment accuracy indicates that judgments were influenced by movements that, nominally, were irrelevant to the capability being judged.

Ramenzoni et al., (2010) had observers watch an actor performing actions that were relevant to a to-be-judged affordance, or actions that were irrelevant to that affordance. Watching the relevant actions lead to improved judgments, whereas watching the irrelevant acts did not improve judgment accuracy. In our case, nonlocomotor movements were nominally irrelevant to passage under the lintel, but they clearly influenced the accuracy of affordance perception. Many differences exist between the present study and that of Ramenzoni et al.: judgments of self versus others, judgments of jumping ability versus locomotor ability, and so on. Taken together, the two studies suggest many questions about relations between movement and affordance perception that can be addressed in further research.

Overall, the judgment data suggest that judgment accuracy was affected by factors within judgment sessions (as indicated by the trial effects and the influence of head restraint during judgment sessions), but also by factors prior to the judgment sessions (as indicated by the influence of prejudgment head restraint).

Movement During Judgment Sessions

Movement data were collected only during judgment sessions, and only when the head was not restrained during judgments. Thus, the results of our analysis of head and torso movement can apply directly only to these conditions. Within that limited context, the movement data revealed several interesting effects. Our main interest was on possible relations between movement and the accuracy of affordance judgments. However, several additional effects are noteworthy: We begin with these.

The multiple main effects of Interval (judgment interval vs. interjudgment interval) indicate that movements of the head were organized as a function of the suprapostural task in which participants were engaged; judging PH_{Min} versus waiting between judgments. With one exception, movement was reduced during judgment intervals, relative to movement during interjudgment intervals. During judgment intervals, participants needed carefully to stabilize their visual system relative to the experimental apparatus, whereas during interjudgment intervals the stability of the visual system was less important (cf. Stoffregen, Hove, Bardy, Riley, & Bonnet, 2007; Stoffregen et al., 2009). For example, during interjudgment intervals, participants might have spent more time thinking or ruminating and less time looking at their surroundings. At the same time, it may be that head movements were more prominent during interjudgment intervals than during judgment intervals due to the fact that during interjudgment intervals participants were free to look around the room.

Replicating effects reported by Stoffregen et al., (2009), we found significant interactions between interval and temporal window (Figures 3–6). These interactions confirm the influence of the suprapostural task (judging vs. waiting) on movement of both the head and torso, as well as the fact the task effect can be modulated by time: The temporal structure of movement differed depending upon the task (judging PH_{Min} vs. waiting for the next judgment). Following Stoffregen et al., (2009), we interpret these interactions as indicating that participants' modulation of their movements over time (within intervals) was task-specific (e.g., Stoffregen, Smart, Bardy, & Pagulayan, 1999; Wulf, Mercer, McNevin, & Guadagnoll, 2004; Wulf, Weigelt, Poulter, & McNevin, 2003).

The three-way interactions between interval, temporal window, and trial are difficult to interpret. Interpretation is difficult not only due to the obvious nonlinearity of the effects (Figures 7 and 8) but also due to the nature of the relation between these effects and the effect of trials on the accuracy of judgments. Judgments improved over trials in a more or less linear fashion that does not appear to correspond with trial-related changes in movement.

In collecting data on body movement our main purpose was to identify parameters of movement that may be related to the accuracy of affordance judgments. We predicted that movement during judgment sessions would differ as a function of whether participants were or were not restrained during the practice session. This prediction was confirmed, in a three-way interaction between conditions (UP–UJ and RP–UJ), intervals, and temporal windows. Figure 9 suggests that participants who were not restrained during practice learned to differentiate the temporal structure of their movements between the act of judging PH_{Min} and the intervals of waiting between judgments. Participants who had been restrained during practice do not appear to have acquired this differentiation. The effect size is unusually large for a three-way interaction, which underscores the importance of prejudgment restraint on movements during the judgment session.

The effects of trials on movement (as modulated by intervals and temporal windows) were independent of the effect of conditions on movement (as modulated by intervals and temporal windows). This independence corresponds with the judgment data, in which effects of conditions and trials were also independent.

Conclusion

Stoffregen et al., (2009) showed that brief locomotor practice was associated with greater accuracy in judgments of PH_{Min}. In that study, participants were not subjected to any form of passive restraint. Thus, during prejudgment practice sessions they enjoyed both locomotion, that is, self-controlled movement of the wheelchair relative to their surroundings, and nonlocomotor activity, that is, movement of the head and torso relative to the wheelchair and the surroundings. In the present study, our primary purpose was to evaluate the hypothesis that nonlocomotor movement exerted a causal influence on the accuracy of PH_{Min} judgments. Participants in all groups engaged in locomotor practice prior to making a series of PH_{Min} judgments. For some participants, prejudgment locomotor practice included nonlocomotor movement of the head whereas for others the head was restrained. In an independent manipulation nonlocomotor movement of the head either was or was not available to participants as they made their PH_{Min} judgments.

The results of the present study demonstrate that nonlocomotor movement of the head (and, presumably, of the torso) was causally related to our participants' perception of their own abilities. This conclusion derives from the main effect of conditions on judgment accuracy. Overall, head restraint tended to reduce judgment accuracy. In two conditions, we were able to analyze movements of the head and torso during the judgment sessions. In these two conditions, movement was influenced by a variety of factors. With respect to the motivation of the present study, the most interesting of these effects was that movement during the judgment session was influenced (in a three-way interaction with interval and temporal window) by whether the head had been restrained during prejudgment locomotor practice. Taken together, these findings are consistent with the hypothesis that affordance perception was influenced by nonlocomotor movement during judgments (cf. Mark et al., 1990), but also by nonlocomotor movement prior to judgments. In further research it will be interesting to examine the role played by active control of locomotion in the prejudgment session, both on the accuracy of judgments and on the nature of nonlocomotor movements made during judgment sessions.

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NOTE

1. Our analyses of quantitative accuracy are approximate, and may not be related to levels of accuracy that would be sufficient for the control of behavior. Judgment accuracy might be evaluated relative to performance in terms of the height (of the blind) at which participants would duck their head when actually passing under it (cf. Oudejans et al., 1996).

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