“What” versus “How” in Nonvisual Whole-Body Movement

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Abstract

Dissociable processes for conscious perception (“what” processing) and guidance of action (“how” processing) have been identified in visual, auditory, and somatosensory systems. The present study was designed to find similar dissociation within whole-body movements in which the presence of vestibular information creates a unique perceptual condition. In two experiments, blindfolded participants walked along a linear path and specified the walked distance by verbally estimating it (“what” measure) and by pulling a length of tape that matched the walked distance (“how” measure). Although these two measures yielded largely comparable responses under a normal walking condition, variability in verbal estimates showed a qualitatively different pattern from that in tape-pulling when sensory input into walking was altered by having participants wear a heavy backpack. This suggests that the “what” versus “how” dissociation exists in whole-body movements as well, supporting a claim that it is a general principle with which perceptual systems are organized.

Keywords: Perception; action; somatosensory system; vestibular sense; walking

Introduction

It has been well documented that perceptual systems contain two separable modes of information processing (Milner & Goodale, 1995; Ungerleider & Mishkin, 1982): One is to consciously recognize a stimulus (so-called “what” processing) and the other is to locate it in space and guide action toward it (so-called “how” or “where” processing). For example, a neurological patient who suffered from visual form agnosia was not able to verbally report the orientation of a slot presented in front of her, but was nevertheless able to put a card in the slot in a normal manner (Goodale, Milner, Jakobson, & Carey, 1991). Such dissociation between “what” and “how” (or “where”) has been most clearly established in the visual system, but similar distinctions have also been made in the auditory system (Anourova et al., 2001; Belin & Zatorre, 2000; Kaas & Hackett, 1999; Maeder et al., 2001; Rauschecker, 1998; Romanski et al., 1999) and somatosensory system (Aglioti, Beltramello, Bonazzi, & Corbetta, 1996; Halligan, Hunt, Marshall, & Wade, 1995; Kammers, van der Ham, & Dijkerman, 2006; Marcel, 2003; Paillard, 1999; Paillard, Michel, & Stelmach, 1983; Reed, Klatzky, & Halgren, 2005; Rossetti, Rode, & Boisson, 1995; Sathian et al., 2011; Sittig, Denier van der Gon, Gielen, & van Wijk, 1985; Van Boven, Ingeholm, Beauchamp, Bikle, & Ungerleider, 2005; Westwood & Goodale, 2003). These converging findings suggest that separate processing of conscious perception and action guidance (or stimulus location) is a general principle with which perceptual systems are organized. However, in virtually all of the previous studies concerning this dissociation within the somatosensory system, actions were carried out only with body parts, while the body itself remained stationary (e.g., hand or finger movement; for a review, see Dijkerman & de Haan, 2007). In the present study, we explored whether similarly dissociable processes underlie whole-body movements (i.e., walking).

Whole-body movements such as walking present a unique perceptual condition because they encompass not only somatosensory information about motion of each body part but also vestibular information about acceleration and velocity of the entire body. It has been shown that somatosensory perception can be altered in the presence of vestibular inputs (Bottini et al., 1995; Ferrè, Bottini, & Haggard, 2011), which may be due to the fact that somatosensory and vestibular information are processed in an integrated fashion in largely overlapping areas of the brain (Bottini et al., 1994; Fasold et al., 2002; Guldin & Grüsser, 1998; Schwarz & Fredrickson, 1971). For example, Ferrè et al. demonstrated that sensitivity to tactile stimuli can be increased by caloric vestibular stimulation, and they also showed that this perceptual enhancement was specific to the somatosensory system. Findings like this indicate that vestibular inputs affect the operation of the somatosensory system, suggesting that somatosensory processes underlying whole-body movements are not identical to those subserving partial-body actions. Thus, it should not be assumed that similar dissociation between conscious perception and action guidance would be found in whole-body movements as well. Rather, it is an open question that should be addressed empirically.

To address this issue, we conducted two experiments in which blindfolded participants walked along a linear path and indicated the walked distance by using two types of measures: One was driven by a motoric response in which participants pulled a length of tape that matched the walked distance (Philbeck, Woods, Kontra, & Zdenkova, 2010). The other was verbal estimation of the walked distance, which required conscious awareness of how far they had walked. Although we hypothesized that these two measures are based on dissociable processes (i.e., “what” process for verbal estimation and “how” process for tape-pulling), we did not simply look for different patterns of response from them. Even if information about the walked distance was processed in a unified manner for verbal estimation and tape-pulling, they could still yield distinct patterns of data because the post-perceptual transformation required to translate the internal representation of the (already processed) distance information into a behavioral output might be carried out differently for each mode of response (Figure 1A). Thus, a stronger test on whether dissociable processes exist in whole-body movements can be done by altering sensory input into nonvisual walking and observing how the patterns of response are modulated relative to baseline patterns observed under a normal sensory condition (Foley, 1977; Philbeck & Loomis, 1997). If verbal estimation and tape-pulling were subserved by two separate processes (Figure 1B), it would be more likely that these processes were affected differently by the alteration of sensory input. As a consequence, patterns of response in the two measures would also change differently from the baseline. On the other hand, if a sole process underlay both verbal estimation and tape-pulling (Figure 1A), the altered sensory input would cause some common change in both measures (e.g., both verbal estimates and lengths of tape pulled doubled). These possible changes from the baseline can be observed even if responses in verbal estimation and tape-pulling were generated by different output transformations, because there is no logical ground to postulate that these post-perceptual transformations should also be modified by the sensory alteration; rather, it would be more reasonable to assume that they should remain unchanged.

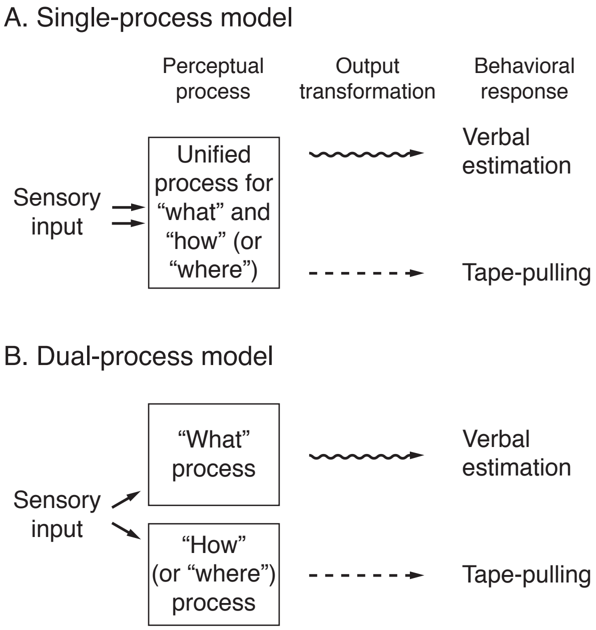

Figure 1: Schematic diagrams describing two theoretical models of perceptual processing for whole-body movements. (A) A unified process underlies whole-body movements. Responses in verbal estimation and tape-pulling are both controlled by the single process. Different shapes of the arrows representing output transformation indicate the possibility that the same output from the perceptual process can be transformed differently into verbal estimation and tape-pulling. (B) Two separate processes subserve whole-body movements. Responses in verbal estimation and tape-pulling are based on outputs from "what" and "how" processes, respectively.

Experiment 1

In Experiment 1, healthy adult participants walked without vision under a normal walking condition. It has been shown that verbal estimation of visually specified distance and motoric responses to indicate it (such as tape-pulling) tend to yield similar, if not identical, patterns of response when they are performed by neurologically intact individuals under a normal viewing condition (Philbeck & Loomis, 1997; Philbeck et al., 2010). Thus, it was predicted that similar patterns of data would be observed in the two response modes. They would form a basis with which changes caused by altering sensory input into nonvisual walking (implemented in Experiment 2) were evaluated.

Method

Participants Twelve students (6 males and 6 females, 18–27 years of age) at Cleveland State University volunteered in return for extra credit in psychology courses.

Materials and Design Participants walked linear distances of 1–6 m without vision at their own natural pace. A sighted experimenter walked with them while supporting their arm for safety reasons, but no assistance was provided for walking. Participants first walked 3- and 5-m distances, once apiece. They then walked distances of 1, 2, 4, and 6 m six times apiece in random order. These 26 trials were performed in one session. First two trials were used only to acquaint participants with the experimental procedure and therefore excluded from analyses. A long (at least 15 m) and loose measuring tape was used for tape-pulling. For each walked distance, participants made both a tape-pulling response and a verbal estimate. Thus, the experiment utilized a 2 (gender) × 2 (response mode) × 4 (walked distance) factorial design. Both response mode and walked distance were within-subject variables. Participants were run individually.

Procedure Prior to the experiment, participants were given an opportunity to practice pulling the tape. While standing still, they held one end of the measuring tape and the experimenter extended it so that it was parallel to the floor. A paper clip was attached to the tape at an arbitrary distance (generally in the range of 1–6 m) and participants pulled the tape until the paper clip reached their hands. They used a hand-over-hand motion to pull the tape, rather than pulling it by one hand while holding accumulated tape by the other hand. Participants viewed how the paper clip approached them as the tape was reeled in. This was repeated a few more times with different distances to the paper clip until participants felt acquainted with the tape-pulling procedure.

Following the practice session, participants wore a blindfold and hearing protectors (noise reduction rating: 21 dB) to obscure their vision and hearing. They were then guided to a nearby hallway in which the experiment was conducted. They were disoriented before taken to the hallway, and thus had no clear idea about where they were in the building during the experiment. This manipulation was included because prior

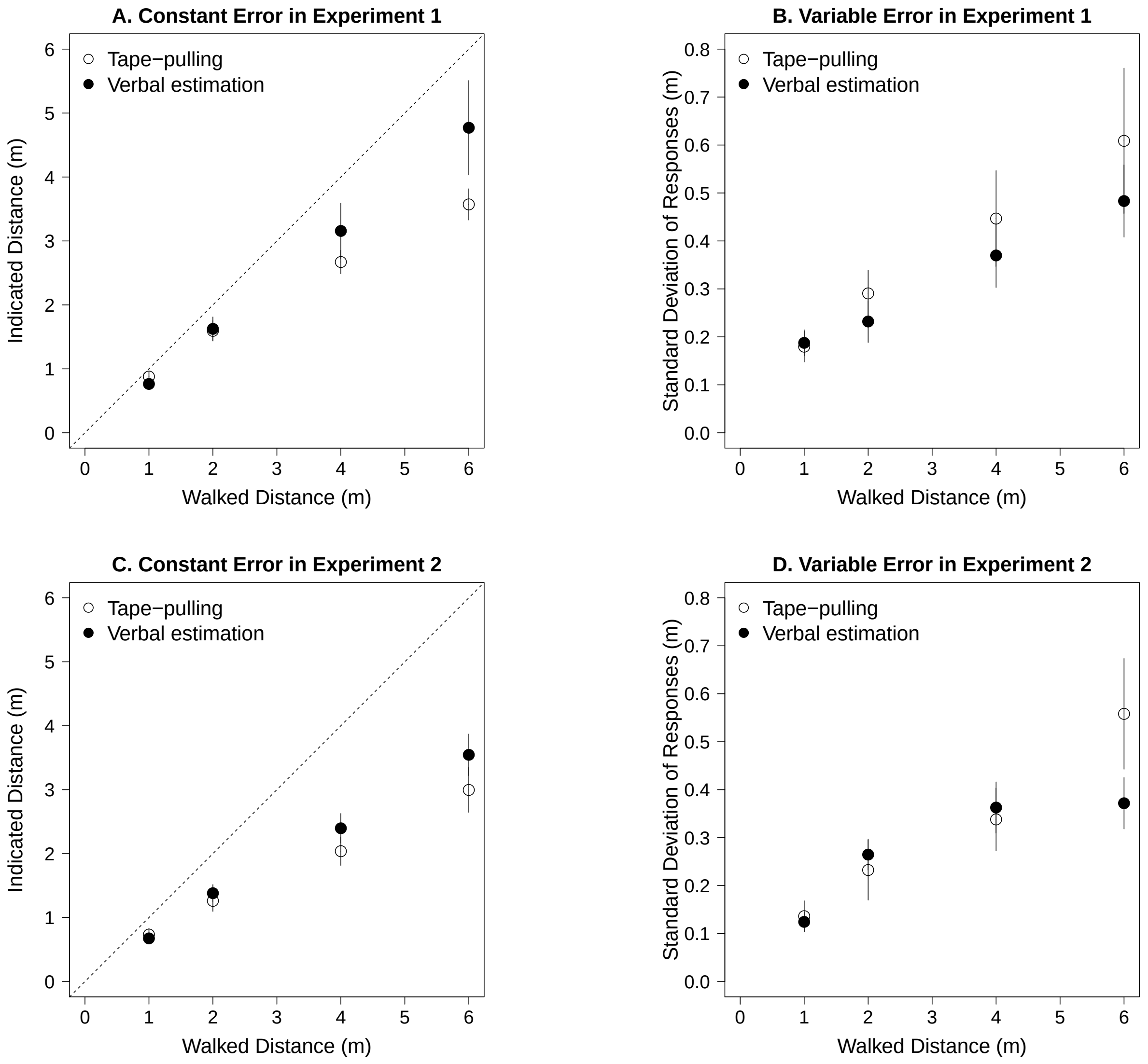

Figure 2: Mean constant and variable errors in estimation of walked distances in Experiments 1 and 2. They are shown as a function of response mode and walked distance. The dashed diagonal lines in panels A and C indicate accurate estimation of the walked distances (i.e., constant error = 0). Error bars represent ±1 standard error of the mean.

knowledge about the environment could influence nonvisual distance perception (Philbeck & O'Leary, 2005).

In the beginning of each trial, participants stood at a fixed starting position and held one end of the measuring tape in their preferred hand. The rest of the tape was untangled and placed on the floor. In addition, participants were given a 5-digit random number and asked to remember it until they completed the trial. Because this number was typically retained in memory by rehearsal, this concurrent task was intended to interfere with subvocal counting of steps in walking and draws in tape-pulling that could otherwise be used to aid distance judgement. By discouraging participants from utilizing this counting strategy, their distance perception and its indicators were more based on somatosensory and vestibular information acquired during walking. Participants' accuracy in recalling this number ranged from 54.17% to 91.67% in both experiments (mean = 80.03%), suggesting that they attempted to memorize the numbers and it was sufficiently challenging to make the counting difficult. When participants were ready to start the trial, they proceeded straight ahead until they were told to stop at an appropriate distance. They then turned to face the starting position and pulled a length of the measuring tape so that it matched the walked distance. They marked the end of the pulled tape with their fingers and handed it to the experimenter. Subsequently, they gave a verbal estimate of the walked distance by using a distance unit of their choice. Most participants used ft, and a few used m or cm. They were encouraged to be as accurate as possible by using fractions (e.g., .25 m) when necessary. They were also instructed to derive the verbal estimate from the walked distance, not from the length of tape they just pulled. Finally, participants repeated the 5-digit number, and were guided back to the starting position for the next trial. Participants walked in the same direction in all trials. No feedback was given to participants during the experiment.

Data Analysis Lengths of tape pulled and verbal estimates of walked distances were analyzed by calculating constant and variable errors. Constant errors represent how accurately participants indicated the walked distances by tape-pulling and verbal estimation. They were obtained by computing the mean amount of tape pulled and the mean verbal estimate for each walked distance. Variable errors characterized participants' consistency in responding to the same walked distance and were defined by standard deviations of six responses to each walked distance. Constant and variable errors were analyzed separately by split-plot analyses of variance (ANOVAs) with participants' gender as a between-subject factor and response mode (tape-pulling and verbal estimation) and walked distance (1, 2, 4, and 6 m) as within-subject factors. All F-tests conducted in this study were corrected for nonsphericity by using Greenhouse–Geisser epsilon when appropriate. Generalized eta squared ($\eta_G{}^2$) values are reported as effect size statistics (Bakeman, 2005; Olejnik & Algina, 2003).

Results

Constant Error Figure 2A shows mean constant errors in Experiment 1 as a function of response mode and walked distance. Participants generally made larger errors as they walked farther. In addition, tape-pulling tended to yield increasingly larger errors than verbal estimation as the walked distance increased. These observations were supported statistically by the main effect of walked distance, $F(3,30) = 68.01, p < .001, \eta_G{}^2 = .60$, and the interaction between response mode and walked distance, $F(3,30) = 4.82, p = .049, \eta_G{}^2 = .056$. A post-hoc contrast comparing the difference between the two response modes at 6 m against those at other distances had a large effect, $F(1,11) = 5.17, p = .044, \eta_G{}^2 = .32$, suggesting that tape-pulling and verbal estimation produced similar patterns of errors for the most part, except at the longest distance (6 m). Other effects and interactions did not reach statistical significance in the ANOVA.

Variable Error Figure 2B shows mean variable errors in Experiment 1 as a function of response mode and walked distance. Participants responded less consistently as the walked distance became longer. Although tape-pulling responses tended to be more variable than verbal estimates, the difference between them was not substantial. Consistent with these observations, only the main effect of walked distance was significant, $F(3,30) = 16.45, p < .001, \eta_G{}^2 = .24$.

Discussion

As predicted, when participants walked under a normal condition and attempted to specify walked distance, largely comparable responses were yielded from tape-pulling and verbal estimation. These data constituted a baseline against which findings from Experiment 2 would be evaluated: We manipulated sensory input into nonvisual walking in Experiment 2 to create an altered walking condition and investigated how constant and variable errors would change compared to those observed in Experiment 1.

Experiment 2

To change sensory input into nonvisual walking, we asked participants to wear a heavy backpack during Experiment 2. Under this altered condition, it was expected that verbal estimation and tape-pulling would yield divergent patterns of response, if they were subserved by dissociable "what" and "how" processes. Given that these two measures mostly produced statistically indistinguishable data in Experiment 1, any differentiation between them would be indicative of the dissociation between conscious perception and action guidance in whole-body movements.

Method

Participants Twelve participants (6 males and 6 females, 21–53 years of age) from the Cleveland State University community volunteered in return for monetary compensation or extra credit in psychology courses. None of them participated in Experiment 1. A new group of participants were recruited for Experiment 2 to avoid demand characteristics in the backpack manipulation. That is, if the same participants were asked to perform the tasks twice with and without the backpack, it would be relatively obvious to them that the backpack was intended to affect their performance.

Materials, Design, Procedure, and Data Analysis Experiment 2 was conducted in the same manner as in Experiment 1 except that each participant wore a backpack that weighed between $1/5$ and $1/6$ of their body weight. This weight range was adopted from previous studies in which the same backpack manipulation successfully induced measurable effects on distance perception (e.g., Proffitt, Stefanucci, Banton, & Epstein, 2003). To determine the appropriate weight of the backpack, each participant's body weight was measured before beginning the experiment. Participants put on the backpack when they were positioned at the starting position in the hallway for the first trial. They kept wearing it until all trials were completed. The backpack weight varied between 10.20 kg and 19.96 kg among participants (mean = 13.58 kg).

Results

Constant Error Mean constant errors in Experiment 2 are plotted in Figure 2C as a function of response mode and walked distance. Compared to Experiment 1, constant errors observed in the present experiment, especially those yielded from verbal estimation, tended to be larger (i.e., participants showed a tendency to indicate the walked distances to be shorter). This change was more prominent in verbal estimation than in tape-pulling, resulting in comparable responses from them throughout the range of walked distance used in the present study. Consistent with this observation, only the main effect of walked distance was significant, $F(3,30) = 159.90, p < .001, \eta_G{}^2 = .68$.

Variable Error Figure 2D shows mean variable errors in Experiment 2 as a function of response mode and walked distance. Variable errors in tape-pulling kept increasing as participants walked farther, just like variable errors in Experiment 1. On the other hand, variable errors in verbal estimation exhibited a qualitatively different pattern: Participants' responses at 6 m were as consistent as those at 4 m. This observation was supported statistically by the significant interaction between response mode and walked distance, $F(3,30) = 4.98, p = .020, \eta_G{}^2 = .050$, and a post-hoc contrast comparing the difference between tape-pulling and verbal estimation at 6 m with those at other distances, $F(1,11) = 8.13, p = .016, \eta_G{}^2 = .42$. The only other effect that was significant in the ANOVA was the main effect of walked distance, $F(3,30) = 18.15, p < .001, \eta_G{}^2 = .29$.

Discussion

The backpack manipulation exerted two noticeable effects in the present experiment: (1) It caused greater underestimation of walked distance (i.e., larger constant error), especially in verbal estimation at longer distances, which removed the difference between the two measures observed in Experiment 1; and (2) variable errors in verbal estimation did not show further increase beyond the 4-m distance, while those in tape-pulling showed steady increase as a function of walked distance as in Experiment 1. Given that the overall pattern of constant errors exhibited by tape-pulling and verbal estimation was mostly the same as that observed in Experiment 1, much importance may not be attributable to the change in constant errors in Experiment 2. However, the fact that altered sensory input into nonvisual walking only affected response consistency in verbal estimation suggests that processes underlying verbal estimation and tape-pulling are dissociable. Thus, a sign of dissociation between conscious perception and action guidance within whole-body movements was found in the present experiment.

General Discussion

The present study was designed to explore whether dissociable processes for conscious perception and action guidance can be found in whole-body movements, in which the presence of vestibular information creates a unique perceptual condition. To that end, nonvisually perceived walked distance was assessed by two modes of response: One required explicit recognition of the walked distance (verbal estimation) and the other was primarily controlled by a motor action (tape-pulling). When sensory input into nonvisual walking was altered by having participants carry additional weight, variability in verbal estimates was markedly modulated. On the other hand, variability in tape-pulling responses largely remained unchanged. This suggests that information about walked distance is processed with qualitatively different levels of precision for verbal estimation and tape-pulling, showing a sign of dissociation between the process underlying conscious perception and that subserving action guidance in whole-body movements. This result builds upon previous findings that the same dissociation is present in visual, auditory, and somatosensory systems (e.g., Belin & Zatorre, 2000; Dijkerman & de Haan, 2007; Milner & Goodale, 1995), supporting a claim that it is a general principle with which perceptual systems are organized.

Although the present study successfully showed the initial evidence for dissociation between conscious perception and action guidance in whole-body movements, several questions are still unanswered. Most notably, it remains to be seen whether the pattern shown by variable errors in Experiment 2 is extendable to longer walked distances. A follow-up study should be carried out by expanding the range of walked distance. The follow-up study should also include a larger number of participants so that Experiments 1 and 2 can be statistically compared; such an analysis was not possible in the present study due to the lack of statistical power. Furthermore, the fact that underestimation of walked distance was exacerbated by the backpack manipulation in Experiment 2 was somewhat counterintuitive: Considering that those participants had to expend a greater amount of energy for walking a given distance, it may be more reasonable to expect that they would judge the distance to be longer, not shorter (Proffitt et al., 2003). Similarly, it is not readily clear why the additional weight increased, not decreased, precision of verbal estimates at the 6-m distance. Further research should be carried out to fully understand these important details.

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