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Sensory Substitution and Walking Toward Targets: An Experiment With Blind Participants

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The most widely-used mobility aid for the blind is the long cane. A main challenge for improving the mobility of visually impaired and blind people is the development of electronic travel aids (ETAs) that improve mobility beyond the mobility allowed by the long cane (Hersch & Johnson, 2008). In this chapter, we argue that the design of ETAs crucially depends on our conception of what mobility is, or, formulated in an ecological way, on our understanding of the informational guidance of movement. An experiment is presented to illustrate this claim.

ETAs consist of three components (Visell, 2009). First, a sensory component that detects certain information from the environment that is not available to the user of the ETA because of the loss of sight. Second, a component that transforms the detected information into the information to be delivered to the perceiver. And third, a display component through which the novel information is actually delivered. With regard to the display component, the device tested in the present experiment applied vibrotactile stimulation to the abdomen by means of 72 actuators. In the sensory component, the device relied on the distance to the nearest surface in the environment, having a total horizontal field of view of 60º. Finally, the device used a linear function to transform distance into vibration: the closer the object in the direction associated to a particular actuator, the more intense the vibration of that actuator.

The same device has previously been used in a series of experiments by Lobo, Travieso, Jacobs, Rodger, and Craig (2017). The device was designed to allow for active information detection. This aspect of the design was motivated by the ecological view that locomotion trajectories, rather than being planned, emerge dynamically from the online coupling of information to action. The ecological focus on information and emergence differs from the focus on spatial representations (Schinazi, Thrash, & Chebat, 2016) and on brain plasticity (Maidenbaum, Abboud, & Amedi, 2014) of other studies concerning sensory substitution.

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In the reported experiment, blind users of the device walked toward targets. An outstanding non-representational model for the visual control of walking to targets is the one by Fajen and Warren (2003). Their model illustrates how the trajectories followed by participants may emerge from a direct coupling of action parameters to simple optical variables. Our sensory substitution device provided haptic analogues of the optical variables that were important in Fajen and Warren's model: the body-referenced angle of the target and the distance to the target. We hypothesized that our device permits successful performance because it allows the detection of the relevant informational variables.

Method

Six blind individuals participated. Their mean age was 54.3 years (*SD* = 10.9). None of them had previous experience with the sensory substitution device.

The 72 vibrotactile actuators that were attached to the abdomen were distributed in three horizontal rows of 24 actuators each. The total field of view of 60º was divided in 24 segments of 2.5º associated to the individual actuators. Each actuator vibrated if the target was located in its 2.5º segment of the field of view. The equation used to transform distance in vibration was: $V = V_{\max} - 0.12 \times D$, where V is the voltage level, expressed as a percentage of the maximal voltage level $V_{\max}$, and D is the participant-target distance (in cm). The vibrotactile information was contingent upon the participant's exploration. To achieve this, the participant's position was recorded (at 100 Hz) with a motion capture system (Qualisys AB, Sweden). The detected position and orientation of the participant relative to the target was used to compute the voltage levels. Note that the current device did not include actual distance sensors. A related device, described by Cancar, Díaz, Barrientos, Travieso, and Jacobs (2013), did actually detect the relevant distances.

Participants were asked to walk to a target. Six target locations were used, which differed with regard to their initial distances and heading directions (3 m and ±15º, 4 m and ±10º, and 5 m and ±5º, respectively). The target was virtual: although the target location determined the vibration, the target was not physically present. Participants verbally indicated when they believed that they had arrived at the target location. Participants completed two repetitions of each of the six experimental trials as well as three familiarization trials (2 m and ±30º and 6 m and 0º).

As mentioned, the intensity of vibration increased when the distance to the target was reduced. In addition, different actuators were active depending on the relative angular location and the angular size of the target. For example, when participants rotated in a clockwise direction, the vibration on the abdomen moved in a counterclockwise (leftward) direction. The vibratory information hence specified target direction and distance.

Results and Discussion

On 70 of the 72 trials (97.2%), performance was successful in the sense that participants arrived at the location of the target. The two unsuccessful trials (2.8%) and one trial with recording errors (1.4%) were not used in the analysis. An example of a successful trial is shown in Figure 1. Note the oscillatory pattern in the right panel of the figure. This left-to-right oscillation in the vibratory flow occurred because, while participants moved forward, they performed exploratory yaw rotations of the upper body.

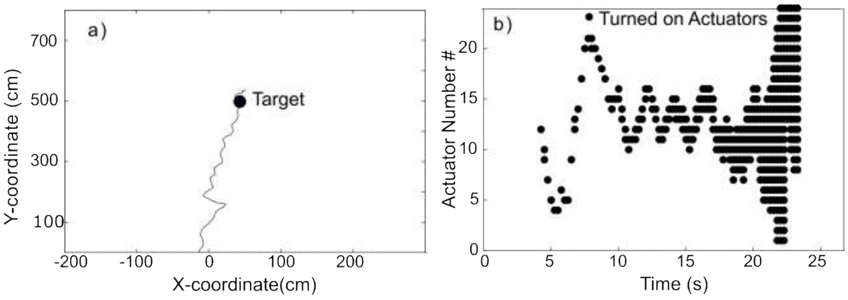

Figure 1. One-trial example of the (a) two-dimensional participant position and (b) changing pattern of vibration during the trial. Not shown is the rotation of the upper body.

The average spatial error (the Euclidean participant-target distance at the end of the trial) was 67.89 cm (*SD* = 19.87). The mean trial duration was 33.97 s (*SD* =15.20). Participants performed an average of 18.4 (*SD* = 7.4) oscillatory movements per trial. The mean amplitude of the oscillations was 28.3° (*SD* = 13.4). The amplitude of the last oscillation before the decision was 7.1° (*SD* = 3.7). We did not observe a significant effect of the initial target distance on the number of oscillations and neither on the mean amplitude of the oscillations: $F(2,66) = 0.03$, $p = .97$, and $F(2,66) = 0.08$, $p = .92$, respectively. The trial duration was inversely related to the spatial error: the longer a trial, the larger the error ($r = .40$, $p < .001$). On average, participants walked 18.31 cm/s. This walking speed is substantially lower than the typical walking speed of visually impaired individuals with a long cane (Johnson, Johnson, Blasch, & de I'Aune, 1998).

We compared the performance of the blind participants in the present experiment to the blindfolded sighted participants in a corresponding experiment by Lobo et al. (2017). The blind participants had larger spatial errors (67.89 vs. 39.62 cm; $t[6.5] = 3.2$, $p = .02$). However, this difference is difficult to interpret because the blind participants were older (54.3 vs. 27.6 years, $t[5.9] = 5.6$, $p = .001$) and had a clear disadvantage in terms of general motor abilities. We did not observe differences between the blind and blindfolded participants in other performance-related variables: angular error, trial duration, total distance covered, walking speed, and amount and amplitude of exploratory rotations. Lobo et al. (2017) observed similar exploratory rotations in an orientation task with a fixed participant-target distance.

To summarize, the blind participants in the present experiment successfully reached the target in almost all of the trials. This high level of performance indicates that the tactile sensory substitution device allowed the detection of relevant informational variables—analogues of which are usually detected by the visual system. By coupling these variables to action parameters, the locomotion trajectories may have emerged in an online fashion (Fajen & Warren, 2003), without need for trajectory planning on the basis of spatial representations (Schinazi et al., 2016). If this suggestion is correct, then the design of future ETAs should focus on the possibility to actively detect the variables implied in the relevant information-action couplings.

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