Distance perception in visual-to-tactile sensory substitution

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EXPERIMENTAL QUESTIONS

There have been many accounts of blind and blindfolded subjects using sensory substitution devices to behave successfully with respect to visual stimuli (Bach-y-Rita, 1972; Auvray, *et al.*, 2007). Yet there remain unanswered questions about why sensory substitution works:

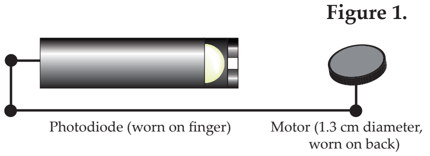
1) Does sensory substitution enable subjects to *perceive* distal objects, or do they become aware of them as a result of cognitive inferences on the proximal stimulation?
2) How does self-movement facilitate distal attribution during sensory substitution?

METHODS

Subjects. 31 sighted participants.

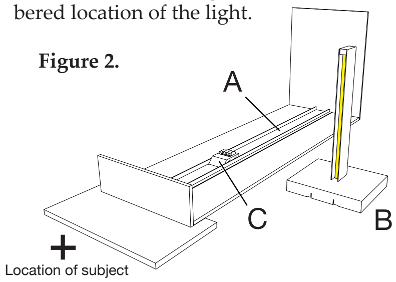
Apparatus. A simplified sensory substitution device was used, similar to that of Lenay, *et al.* (2001). The device consisted of a single finger-mounted photodiode that activated a small vibrating motor whenever subjects directed it toward a light source.

Figure 1.



Experimental protocol. Blinfolded, seated subjects used the device to determine the distance of a fluorescent light (**B**) placed randomly along a 1.93-m track (**A**). After 2 minutes, the light was removed, and the subject visually guided a remote-controlled target (**C**) to the remembered location of the light.

Figure 2.

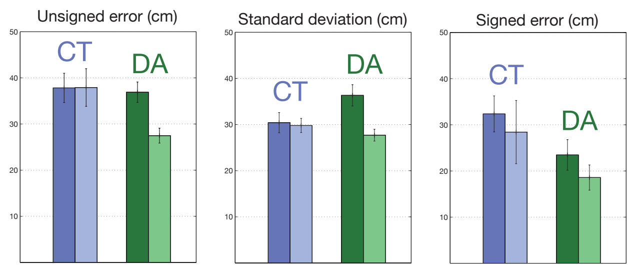


Experimental phases.
(1) Learning phase: 60 trials over two sessions; no feedback about performance or the nature of the light source.
(2) Transfer phase: 30 trials over one session; the device was altered prior to the start of this phase to determine whether learned abilities transfer to new conditions.

Instructional conditions.
Group CT: "Conscious triangulation"; instructed to *attend to* proximal variables (e.g., arm angle) [N = 11]
Group DA: "Distal attribution"; instructed to *ignore* proximal variables [N = 20]

RESULTS

Figure 3. *Effect of instructional condition on performance*



Dark bars: first 20 trials
Light bars: last 20 trials before transfer

Significant interaction effect for unsigned error ($p = 0.033$) and standard deviation ($p = 0.023$) [2x2 mixed ANOVA].

The distance judgments of DA subjects became more consistent, less biased, and generally more accurate over time (Fig. 3). Some DA subjects achieved vision-like accuracy (Fig. 4). Similar improvement was not observed in CT subjects.

Figure 4.

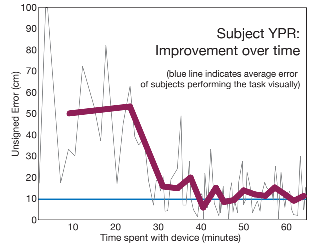
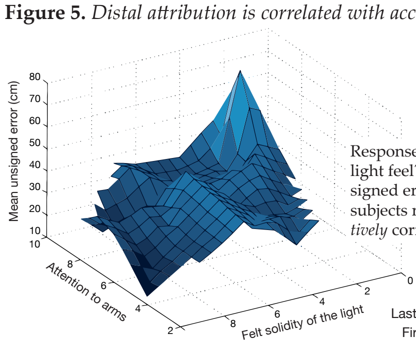


Figure 5. *Distal attribution is correlated with accuracy*



Responses to the question, "how solid does the light feel?" are *negatively* correlated with mean unsigned error ($p = 0.0005$). The amount of attention subjects reported paying to their arms was *positively* correlated with error ($p = 0.0387$).

Figure 6.

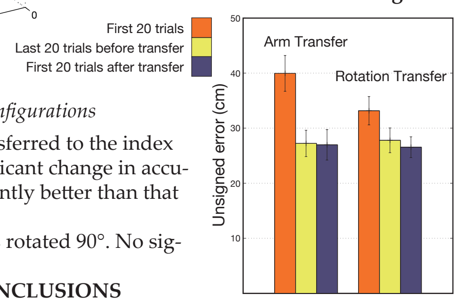


Figure 6. *Learning transfers to new limb configurations*

Arm Transfer. [N = 11] Photodiode is transferred to the index finger of the opposite hand. No significant change in accuracy. Mean unsigned error is significantly better than that of first 20 trials ($p = 0.0065$) [t-test].

Rotation Transfer. [N = 9] Subject's body is rotated 90°. No significant change in accuracy.

CONCLUSIONS

- Biasing subjects toward attending to the light itself (DA), as opposed to proximal variables only (CT), improved distance judgments. Subjects that experience the light as a "solid object" perform the task better. This is evidence that sensory substitution devices enable their users to perceive distal objects, rather than simply learn about the environment through conscious inferences on proximal stimulation.
- Based on the results of the transfer phase, abilities gained during the learning phase are not disrupted by changes in the "sensorimotor contingencies" (O'Regan & Noë, 2001) involved in the task (Fig. 6). The perceptual skills learned by subjects are not limited to a single motor system and are not disrupted by changes in the relationship between arm angle and the distance of the light.

REFERENCES

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