Evolutionary and Adaptive Systems MSc.

Visual Perception and Cognition Term Paper

The Unfulfilled Potential of Sensory Substitution

Mike Blow
Candidate Number 80761

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1.0 SUMMARY

Sensory substitution (henceforward abbreviated to ‘SS’), a process whereby visually-impaired people can acquire distal information using touch or audio cues, has been known of for more than 30 years. It enables fully blind people to discern spatial information and has raised very fundamental questions regarding the process and nature of perception. Nevertheless it has not achieved widespread acceptance in the blind community and despite its promise remains a field of unfulfilled potential. This paper examines some of the reasons for this disparity, and presents some ideas to overcome the problems. In addition the potential uses of SS systems as ‘sensory enhancers’ are discussed, including applications to the wider population.

2.0 GENERAL BACKGROUND

2.1 History

In the 1960s Dr Paul Bach-Y-Rita and colleagues developed a device which enabled the blind to see. This near-miraculous discovery was possible due to the phenomenon of sensory substitution – that is, the information that normally reaches the brain via the eyes was instead transmitted using touch. The device was called the Tactile Visual Sensory Substitution (TVSS) [2]. The subject sat in a modified dentists’ chair with their back resting on a 20x20 grid of 1mm electro-tactile stimulators. The stimulators were activated by the signal from a camera, which was held on a boom and could be moved and zoomed by the subject. It was found that fairly rapidly subjects could discern lines and edges, and after some practise recognise depth, shadows, shapes and even individual faces, a remarkable result given the relatively poor camera resolution. Moreover the initial feeling of tactile sensation on the skin was quickly forgotten and the perceived objects appeared to exist in three-dimensional space. Indeed, once a subject was familiar with the device the site of stimulation could be moved or the camera could be exchanged for a different type with virtually instantaneous adaptation.

2.2 Fundamental Issues

The fact that the brain could see using information transmitted in this way was astounding enough, but some very fundamental insights arose from the research. It was found that the system only worked if the subjects moved the camera themselves. This challenged the view that perception was a passive reception of external information, as it showed that movement was essential to perception. Indeed TVSS experiments with a fixed camera produced no perception in the subjects whatsoever, even after many hours of use. The implication was that the foundation of perception was in sensory-motor loops, in other words the subject had to know how the muscle control he or she was using related to the sensory information received. Further experiments using other methods also point strongly in this direction [4].

The other issue raised by the TVSS results was that of brain plasticity. The touch sensor is nothing like an eye, and the muscles used to move the camera are of course totally different to those used to move the eye, and yet the brain adapts to be able to process the information to give spatial awareness. A large degree of plasticity must be present in the brain to allow these adaptations to take place. It would also seem that the brain must be ‘pre-wired’ in such a way as to facilitate sight when given any appropriate inputs, even in those blind from birth. Despite never having experienced sight, they can learn visual phenomena such as parallax, zooming and shadows in a few hours.

2.3 Sensory Substitution and Balance

An interesting study was performed, again by Bach-Y-Rita, on subjects who had lost their sense of balance. When connected to an accelerometer via the SS system they were able to maintain balance with minimal practise.

2.4 Minimal Stimulation

Although it is tempting to think that SS need a high resolution to be effective, a successful experiment has been performed by Lenay [6] using just one photocell and one tactile stimulator. After some practise subjects were able to tell the direction and approximate distance of a light.

2.5 The State of the Art

Many SS systems have been produced, some commercial and some for research purposes, using a variety of senses to replace visual information. The Sonic Pathfinder [5] uses 2 ultrasonic transmitters and three receivers to measure object proximity, which is relayed to the user in the form of a musical scale. The closer the object is the lower and nearer the tonic the note becomes. The vOICe system [10] uses a video camera mounted on sunglasses and converts the result picture into stereophonic sound information. Brightness is indicated by volume and height by pitch. The full system costs about $2500 but there are freely-downloadable software versions available for use with webcams and camera-equipped mobiles.

In terms of tactile devices the TVSS system is still sold under the name VideoTact, and can power a 768 point array of electrical stimulators. There is also a tactile reading aid called the Optacon, which aims to allow a blind person to read printed text.

2.6 Why bother?

An important question remains. Why bother with this 'roundabout' method of getting visual information to the brain when it is possible to implant electrodes and stimulate the visual cortex directly? The answer is threefold: SS is a proven science; it is non-invasive; and it is easy to maintain and upgrade. These points could not currently be made with such force for surgical brain-machine interfaces. Implants also raise important social issues, given society's distrust of artificial implants and 'cyborg' fears. Hopefully once the benefits of SS implants were realised these misgivings would diminish and the system be viewed in a similar way to a pacemaker or artificial limb.

2.7 Unforeseen Problems

Despite the incredible promise of SS systems, they have not achieved widespread use and indeed once the initial novelty has worn off blind users find the results somewhat depressing. The problem is that the quality of the visual experience is lacking. SS has lower resolution, smaller field of view and no colours. Most importantly for a blind person there are no emotional feelings attached to any of the perceived images. Reaction to visual images is a learnt and reinforced phenomenon and so it is not surprising that a blind person feels nothing; nevertheless it is still a disappointment when the face of a loved one causes no emotion whatsoever. Bach-Y-Rita called these elements that create the content or even joy in the visual experience 'qualia'. Lack of qualia is not a phenomenon restricted to SS – people born blind who somehow regain sight report the same feelings.

Technology has also played a part in restricting the acceptance of SS devices. Until recently tactile stimulators were large, heavy, itchy and inefficient, requiring powerful batteries. The skin that the stimulators connected too had to be covered in a conducting gel, and cameras were heavy and bulky. Thankfully most of these issues are improving very rapidly. Nowadays cameras are tiny, batteries are more powerful, and successful tactile stimulators have been developed for use in the mouth, obviating the need for gel. Both the vOICe and Sonic Pathfinder systems mentioned earlier are based around modified sunglasses, and miniaturisation of technology can only bring benefits to these kinds of devices.

2.8 Sensory Substitution is not Sight

Given the lack of qualia it seems inappropriate to define the experience offered by SS as sight. It seems that sight involves the attachment of psychological responses to received images, and is not merely the discernment or categorisation of shapes. It is more accurate to say that SS is a separate phenomenon, new and different to any previous sensory experience. It follows that a sighted researcher and a SS subject viewing the same object are not sharing the same experience, and that a prior knowledge of sight is not necessarily a good reference by which to judge experimental success.

3.0 ANALYSIS AND DISCUSSION

3.1 Sense Replacement Potential

The key to increasing the use and effectiveness of SS systems would seem to be increasing qualia. So how is this to be achieved? The fundamental problem - that the experience disappoints because there is no emotional content to the images – is exceptionally difficult to remedy. These emotions do not appear overnight nor can they be engineered. If the subject has been able to see in the past it might be possible for them to transfer the emotions generated by a familiar face from sighted memory to the SS image. Alternatively for people born blind the obvious answer is to wear the device from birth. In this way the experiences and emotions should in theory be able to build qualia in the sensory experience in an analogue of the development of normal sight. Of course getting a baby or toddler to constantly wear a SS device is another problem altogether!

The other shortcomings of the SS experience might be easier to remedy. It might be possible to encode colour, for example by having a different frequency or direction of vibration in a tactile interface. Image size could be improved with the new breed of digital cameras. Their resolution is now so large that it would be hard to find enough skin to replicate the image, given that there is a minimum distance between two points that can be differentiated by touch. However use of the 'saltation effect', whereby touch stimuli at two points and separated by time can be perceived as originating between those points [9] might increase the perceived resolution of the system. The other issue to overcome in this case is sensory overload. A larger image would convey a far more 'sight-like' experience but without the selective attention that allows a sighted person to filter out the enormous amount of unwanted data. Perhaps a device that emphasised the centre of the image but kept some peripheral information at a lower intensity might emulate this technique. However given the earlier point about the difference of the sighted and SS experience ideas like these must only be seen as a starting point, with feedback from the users driving the developmental process.

3.2 Sense Enhancement Potential

An area that has barely been looked at is the application of SS to enhancing, or adding to, existing senses. In the past with the difficulty of wearing an SS device this is understandable; but now that the technology allows for small, light and powerful systems the stage is set for some revolutionary ideas. A SS device could allow the user to monitor some important aspect of his environment while keeping other senses and hands free. A fireman might have some form of detector to allow him to pinpoint a person in a smoke-filled room. A soldier could use SS to spot a camouflaged enemy using infra-red or heat detection, or have a camera to provide rear-facing vision. SS could provide compass bearing information to someone out on the hills, or a radioactivity measurement to a worker in a nuclear plant.

Furthermore it is not much of a leap to imagine a scenario whereby an existing sense is heightened. Perhaps the output of a camera with a high zoom factor could be integrated using SS to give a person enhanced long distance vision. Whether processing this new signal and normal vision simultaneously would be possible for the brain remains to be seen, but it is an intriguing concept.

3.3 A New Sense

One of the areas in which SS may well come to play a greater role in the future is that of wearable computing and virtual reality interfaces. Already there exist systems that apply a force to a stylus proportional to the degree of penetration into a virtual object, and virtual sculpting systems giving the user tactile feedback of their interaction with the ‘clay’. Virtual reality is a new and, by definition, immersive construct and it is possible that the best way to transfer the information required might be through a new sensory medium provided by SS. William Gibson’s description of cyberspace in his seminal science fiction novel ‘Neuromancer’ [3] was the first indication in popular culture of how a new sensory experience could be used to provide a fully-immersive human-computer interface. Games could also benefit from SS systems and may well be the first of mainstream computing to embrace the technology. Gamers are by nature competitive, open to new ideas, and willing to put in time and practise to gain an advantage. The scenario mentioned in section 3.2 of the soldier with ‘eyes in the back of his head’ could be easily adapted to a 3D shooter such as ‘Quake’. One can imagine a room full of LAN gamers, mouse in one hand, keyboard in the other, tactile patch on each forehead…

3.4 Experimental and Philosophical Potential

SS offers deep insights into the process and meaning of perception. As such it may be able to provide hard empirical evidence to prove psychological or philosophical theories that otherwise were at best speculation. If one accepts that the SS experience is not sight but something different there is also the chance for investigating the individual’s exploration, reaction and adaptation to a new sense. This is a unique opportunity and is doubly exciting as it involves pushing the boundaries of the human experience beyond anything previously considered.

3.5 Potential for Application in Other Research

It is hoped that this report has shown that the findings of this work have greater scope than merely helping disabled people integrate in the world (great though this accomplishment is). Any area which involves perception might benefit from concepts created during SS study. Robotics is a prime example, with its emphasis on active perception of the environment. The acquisition of perception by sensory-motor loops discovered by Bach-Y-Rita may well have application in learning machines in the future. It already casts doubt on the idea, implemented in ‘sense-plan-act’ robots like ‘Shakey’ [8], that interaction with the world is possible through passive sensing and subsequent movement without any feedback or link between the two.

3.6 Experimental and Technological Improvement

As mentioned previously improvements in technology have meant that SS systems are becoming easier to live with. Sensors and actuators are smaller and batteries more effective. In the future improvements in commercial technology should trickle down (or up!) to the more important task of restoring or enhancing the human sensory experience. Improvements in areas such as solar power, performance and longevity of implanted electrodes, neuroscience and low-power actuators may all play a part in making SS more accessible.

The ongoing research and deeper understanding of the SS experience should also help researchers in their study of the phenomenon. Much research remains to be done, including the use of SS from an early age and the impact of SS on multiple users in a group context.

4.0 CONCLUSIONS

Sensory Substitution is a fascinating discovery which has failed to live up to its initial promise. It is hoped that this report has shed some light on the reasons for this situation and shown that the potential applications for the technology stretch far beyond the boundaries of psychological experimentation. If ways of increasing qualia can be found it should become more acceptable to disabled users, and perhaps live up to its promise as a real substitute for sight. Technological advances and deeper insights into the phenomenon should help its integration into other diverse areas of life, in the real world and in virtual reality. Perhaps its time is yet to come.

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