Intersensory Disambiguation of Shape Perception with Virtual Visuo-Haptic Stimuli

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Extended abstract

Human subjective experience is strikingly multi-modal in nature. For example, we may receive information about a given scene via eyes, ears, and touch, blending the data received to form perceptually rich internal representations of ‘what is out there, in the real world’ which allow us to interact effectively with our environment.

Often information may be received about an individual event through multiple sense modalities. In such situations it is likely that a considerable degree of duplication and, therefore, redundancy will occur within the data obtained. This can prove advantageous for the formation of effective and reliable mental representations, as multiple senses combine forces to reduce informational uncertainty and/or ambiguity.

Evidence regarding multi-modal interactions has been provided by the ‘inter-sensory discrepancy procedure’. This is a paradigm in which information from two modalities is systematically made discrepant, and their relative biases in producing the given type of judgement calculated, by comparing changes in response between single (unimodal) and combined (bimodal) sensory modality methods of stimulus presentation. Using such a procedure it has been shown that, for example, information about shape tends to be biased by vision, texture by touch, and timing data by hearing.

Various hypotheses have been advanced to account for inter-sensory discrepancy effects, including explanations based on sensory precision, directed attention, and modality appropriateness for the type of judgement required. None of the available theoretical accounts, however, preclude the assertion that principles of sensory integration may be occurring in the production of inter-sensory bias effects. These different situations are arguably similar in that multiple sources of information are available which vary in terms of uncertainty and/or ambiguity and that, by combining different sources, it is possible to produce responses which are potentially more reliable and less variable than simply relying on an individual sense modality. Inter-sensory bias represents “...one result of the attempt by the perceptual system to maintain normal perception in the face of inter-sensory discrepancy.”

The current paradigm seeks to test the generalisability of inter-sensory facilitatory/disambiguatory effects to stimuli based on virtual models presented via artificial devices. It is important to do so because the multi-modal psychology experiments conducted to date have used real-world stimuli presented within highly constrained surroundings. It is of both practical and theoretical interest to examine whether the same principles apply to human-computer interactions. If so, then there are strong practical implications for interface design. Inappropriate multi-modal interfaces may produce problems in information flow, resulting in architectural configurational shifts and a breakdown of perceived and potentially actual interactional continuity. By contrast, good design which takes account of multi-modal psychological principles may confer extremely useful computational benefits. For example, multi-modal facilitatory effects may allow designers to produce interfaces which have less than optimal unimodal capabilites. This might allow helpful savings in computational requirements. It may still be possible to achieve acceptable mental representations when multi-modal information sources are integrated by the human perceiver, assessed in terms of usability and/or perceived quality.

It was decided to examine visuo-haptic interactions in the present experiment, as haptic devices are currently an emerging technology in the field of multi-modal interfaces and are gradually beginning to find applications within commercial settings. By using haptic interfaces it becomes possible to feel and interact with virtual objects. There are various potential applications for such technologies, for example, training and rehearsal for tasks such as medical operations or space station repair/maintenance which require visual-motor skills that cannot be obtained 'on the job', and also within tele-operation systems.

Psychologists have studied various aspects of visuo-haptic perception. The main approaches either examine the relative accuracy/reliability of judgements made within the individual senses compared to their bimodal equivalents, or follow inter-sensory discrepancy paradigms. The broad finding is that vision and touch contribute differentially to different types of judgement. For example, vision is particularly good and relatively biasing in terms of spatial location judgements, whereas touch plays a stronger role in constituent material judgements. It has also been found that visuo-haptic sensory interactions are not always a simple matter of one sense biasing another. In the perception of overall texture, for example, it has been suggested that, although both senses contribute about equally to the overall percept, each is playing a quite different role, with vision providing a spatial framework within which touch judgements can be made.

The current experiment examines multi-modal faciliatory/disambiguatory effects in the perception of shape between vision and touch. The perception of shape is particularly appropriate to the design of haptic devices as one of the prime uses of such technology is to allow the user to feel and interact with virtual objects within three dimensions. It is also interesting from a psychological point-of-view. The current literature shows visual shape perception to be more accurate than that for touch, with a correspondingly greater degree of visual bias in inter-sensory discrepancy situations. It may, however, be possible to alter bias relations by producing visual stimuli which are artificially ambiguous. The use of a haptic device therefore has not only relevance to interface design, but also advantages from the point of view of psychological multi-modal theory. The ability to use an artificial situation may allow the elucidation of fundamental human perceptual characteristics which it is not possible to find within the constraints imposed by real-world stimuli.

The paradigm chosen in the current study follows on from previous work, in which subjects were given the task to disambiguate ambiguous visual images, based upon an artificial rendering of the Necker cube using virtual haptic cues presented via a PHANToM device. In this paper we provide an additional in-depth analysis of the experimental data acquired so far.

The PHANToM device was arranged beneath the computer monitor, on which visual stimuli were presented. The computer used to both generate visual and haptic stimuli and record participant responses was an Pentium, with an 21 inch screen operating at 75Hz. Sampling and storing of haptic data occurred at 30Hz following the rate of graphics update.

Visual stimuli
Visual stimuli consisted of Necker-cube images systematically shaded to produce multiple possible interpretations, thereby ensuring ambiguity in the categorisation of shape identity. An essential aspect of the visual stimuli was that, in spite of their predominant interpretations, other interpretations have been found to be reported with significant frequency such that each stimulus had a degree of ambiguity in its shape identity.

Haptic stimuli
Haptic stimuli consisted of solid, hard, smooth-surfaced 3-dimensional shapes, presented via the PHANToM device, one for each of the three equivalent visual stimuli. Implementation was via a transformation from the PHANToM to the haptic display space such that:

- left/right hand movements corresponded to horizontal (x-moves) in the display space;
- up/down hand movements corresponded to vertical (y-moves) in the display-space;
- Hand movements to/from the user corresponded to depth (z-moves) in the display-space.

Due to limitations in both the haptic device and in the accuracy of shape perception by the human perceiver, a much higher level of ambiguity was found during pilot testing for the haptic stimuli compared to visual stimuli, with less reliability in response classifications.

Visuo-Haptic stimuli
Visuo-Haptic stimuli consisted of equivalent visual and haptic stimuli being presented concurrently. Using such a method combined visual and haptic measures could be taken of classification response ambiguity. This allowed comparison to unimodal ambiguity statistics.

An in depth analyis of the data collected is being currently conducted. A number of results will be available to be presented in a full paper and discussed at the workshop.