The Importance of Temperature Information in Virtual Training Environments

Dr. George Van Doorn; Dr. Mark Symmons; Dr. Barry Richardson
Monash University
george.vandoorn@arts.monash.edu.au

Abstract. Temperature is an important source of information in our interactions with the environment but it is rarely built into virtual reality and simulation. In this paper, the findings from several of our experiments are brought together to discuss the efficacy of adding temperature information in simulation applications. In the first, Peltier tiles were added to an exoskeleton device designed to provide kinaesthetic feedback when interacting in a virtual environment. The effects were explored in terms of the potential to increase presence when interacting with virtual objects. We also describe an experiment in which movement was either active or passive-guided. In the active condition the degree of “coldness” felt at the fingertip was reported as less intense than when movement was passive. It appears that intentionality of movement plays a role in the attenuation of the stimulus. Other work suggests that the perception of temperature is not influenced by a simultaneously presented colour. For example, the perception of coldness is not enhanced when it is processed in conjunction with a blue colour. It is proposed that thermal feedback may be a useful adjunct for virtual reality interface devices.

1. INTRODUCTION

While extremes of temperature are an important warning of danger, other temperatures also convey useful information. We are likely to grasp a cup in order to decide whether the contents are at a suitable temperature to drink. Indeed, if there is no ice or steam then it is only through tactile temperature perception that we can make such a judgment. The precision with which touch can discriminate temperature has value in medical diagnoses. An over-heated body core can be accompanied by either a pale or flushed skin appearance, so touch is required for greater certainty. Hypoperfusion (shock) is best diagnosed with a combination of indicators which include subjectively felt temperature (Kaplan, McPartland, Santora, & Trooskin, 2001).

Given the demand for more realistic virtual environments (VEs) and more immersive interactions within those environments, ignoring temperature feedback may be at the expense of the quality of the experience. For example, learning to perform surgery via a simulator may be enhanced if the training combines the texture of skin and organs with their temperatures. Although not specifically arguing for the inclusion of temperature, Shams and Seitz (2008) suggest that training protocols that replicate natural settings “produce greater and more efficient learning” (p. 41). In relation to virtual reality (VR) interface gloves and other haptic interactive devices, Woods (1998) argues that “any comprehensive system will have to measure thermal conductivity” (p. 125) while others suggest that thermal conductivity should augment the user’s ability to identify objects and improve the authenticity of VEs (Bergamasco, Alessi, & Calcara., 1997; Kron & Schmidt, 2003). Jones and Berris (2002) suggest that thermal information could serve to complement visual or tactile stimuli. To progress this work an understanding of human thermal processing is needed, both on its own and when in conjunction with other modalities (e.g., vision). It is also not yet known whether temperature information actually contributes to, or is important for, the perceived realism of VEs.

In the series of experiments briefly described here we examine the importance of temperature feedback in the realism of VEs. We also investigate whether that temperature information should be veridical – matching what would be experienced in the real world.

2. ADDING TEMPERATURE TO VIRTUAL ENVIRONMENTS

2.1 The Exograsp

Devices used to haptically explore virtual objects usually rely on kinaesthesia to indicate contact with a surface. Besides our own, we know of only one other device that provides temperature information along with kinaesthetic cues (see Kammermeier, Kron, Hoogen, & Schmidt, 2004). Our device – the Exograsp (see Figure 1) – uses tension-controlled pulley cables to simulate the collision forces that take place when the thumb and forefinger grasp a “virtual” object (see Richardson, Wuillemin, Symmons, & Accardi, 2005 for details of the design and construction of the Exograsp).

We developed an additional set of attachments for the Exograsp – 2cm square trays on which Peltier (thermal) tiles could be mounted. The Peltier tiles contact the pads of the thumb and forefinger. When a current is applied these tiles become hot on one side and cold on the other. When the fingerpad is about to contact a virtual object (e.g., a soft-drink can – see Figure 2), a collision algorithm is triggered and the Peltier tile is activated. The hand is thus restricted from closing any further and the fingertips feel cold at the moment the user sees a graphic of their hand grasp the virtual soft-drink can.
In our first study we aimed to determine the extent to which the addition of temperature to graphic cues and force feedback creates a suitable level of “realism” when interacting with a virtual object.

2.2 Contribution of Temperature to VR Realism

To test “realism” in a VE we modified an approach developed by Slater and colleagues (see Slater & Steed, 2000 and Slater, Usoh, & Steed, 1994). The Slater-Usoh-Steed (SUS) consists of six questions that identify three presence indicators (i.e., sense of being there, extent to which the VE becomes more “real” than reality, and the extent to which the VE is considered a place visited). Although all participants completed all questions from the SUS, two of the three presence indicators were discarded to focus on the “sense of being there”. We hypothesised that the introduction of temperature feedback would improve perceived realism when grasping a virtual soft-drink can.

In a repeated-measures design, five participants (4 females, 1 male; $M_{age} = 38.8$ years, SD = 11 years) were asked to explore a virtual soft-drink can with and without temperature cues (order was counterbalanced across participants). The median “presence” value when subjects explored the soft-drink can made to feel cold using the Peltier tile was 3, on a 5-point scale, while the median value when subjects explored the can without a temperature change was 1. A Wilcoxon signed rank test of presence, with five matched observations [$z = -2.12$, $p < 0.05$ (one-tailed)], indicated that a colder temperature added significantly to the “believability” of grasping the soft-drink can in a VE. By extension, it is suggested that adding temperature to virtual training environments will, if nothing else, increase the believability of those environments and may facilitate the learning experience.

2.3 Temperature Judgments Change With Self-Generated Actions

Temperature’s contribution to VEs may depend on factors other than simply whether or not thermal information is present. Gibson (1962) argued that there is a difference between touching and being touched. As such, perceptual awareness may be modified by cues from active movement. Some authors (e.g., Bolanowski, Verrillo, & McGlone, 2004) contend that an awareness of the object is generated by active exploration. Being passively guided over an object evokes a “distinctly different subjective percept, that of an internal sensation confined not to the environment but to oneself” (Bolanowski et al., 2004, p. 41). If an active mode of input promotes the perception of objects as distal, and a passive mode gives rise to more proximally located experience, we may expect thermal judgments to differ, depending on the mode of input.

Van Doorn, Richardson, Wuillemin, and Symmons (2005) provided the first direct test of whether active and passive movements result in differences in how temperatures are perceived. Participants judged the temperature of a Peltier tile as an experimenter moved it across their stationary index finger. In a second condition, participants moved the Peltier across their own stationary index finger at a speed consistent with that of the experimenter. Temperature was judged as being colder when movement of the tile was made by the experimenter.

A second study was carried out to investigate the effect of passive-guided movement – a condition not included in the first experiment (Van Doorn, Richardson, Wuillemin, & Symmons, 2006). In one condition participants did not actively move but were guided across the stationary Peltier tile by the Tactile Display System (see Richardson, Symmons, & Accardi, 2000 for more detail). In the second condition, subjects made regular, self-generated movements across the stationary Peltier tile that matched the Tactile Display System’s speed. Again, temperature was judged as being colder when movement of the tile was made by an external source.
The findings of the two studies were consistent, leading Van Doorn et al. (2006) to conclude that when a finger is passive-guided or stationary, perceived temperature is colder than when movement is active (i.e., self-generated). Although corollary discharge was considered as a possible explanation in the first experiment, this seems unlikely when considering that attenuation occurred regardless of whether the motor signals were distal (first experiment) or proximal (second experiment) to the stimulated skin. Taken together, the data suggest that intentionality of movement plays some role in the differential perception of temperature. The analogy of pupil dilation springs to mind, where increased light results in relaxation of the iris muscles, and thus a decrease in pupillary size (Sherwood, 1995). Iris muscles are controlled by the autonomic nervous system which regulates activity outside consciousness and voluntary control (Sherwood, 1995). In the same way, the afferent information associated with passive movements may not reach the conscious level, with no way of controlling the resultant motor output. Consequently, the differing experiences of temperature may be inherent. The findings of these two experiments could be applicable to remote surgical training. Gunn, Hutchins, Stevenson, Adcock, and Youngblood (2005) demonstrated the viability of a master-slave training system for haptics. If it can be shown that surgical skills can be learnt through passive movements (e.g., learning the movement patterns of an experienced surgeon), the presentation of temperature may not be straightforward.

Humans can detect temperature changes at the skin of 0.06°C per second after two seconds (Herget, Granath, & Hardy, 1941). If such small variations in temperature can be identified, the results of our experiments indicate that temperature during passive-guided training may need to be adjusted to be consistent with the temperature experienced during similar active exploration rather than simply providing a faithful match.

### 2.4 Congruence Effects in Temperature Perception

Although some disagreement is present, there is a propensity for adults to speak of blue as being a “cool” colour and red as being “warm” (von Allesch, 1925 cited in Berry, 1961). This assumed correspondence has permeated our everyday lives. For example, hot taps have red labels while cold taps are tagged with blue. Melara and O’Brien (1987) suggest that correspondences between stimuli reveal a metaphorical, rather than a literal, connection between features of separate senses. Further, correspondences seem to be non-arbitrary and are accumulated through experience (Williams & Bargh, 2008). In the case of colour and temperature, associations may stem from experience of, for example, fire (i.e., warm and red) and large bodies of water (i.e., blue and cool). An argument similar to William and Bargh’s would suggest that the feeling of warmth you get when holding a hot cup of coffee might activate memories of warm colours (e.g., red) because associations between these stimuli occur throughout life. This could indicate that an asymmetry is present in the processing of congruent and incongruent stimulus pairings (Melara & O’Brien, 1987). Congruent attributes, such as red and warmth, should be easier to identify than incongruent pairings, such as blue and warmth.

Soto-Faraco, Spence, and Kingstone (2004) and Marks (2004) found a reduction in errors, and usually response times, when stimulus combinations were congruent rather than incongruent, such as when auditory and visual stimulus pairs moved in the same direction versus moving in opposite directions respectively. Put in general terms, when input from the attended and unattended modalities is ‘analogous’, performance is superior (Martino & Marks, 2000).

In our laboratory, participants were simultaneously presented with a colour (e.g., red) and a temperature (e.g., warm) and performed a timed classification on one of these dimensions. Attributes were either synesthetically congruent (e.g., red/warm) or synesthetically incongruent (e.g., red/cool). Reaction times (RT) did not differ for congruent and incongruent stimuli, and thus our hypothesis was not supported. However, our results may be due to relatively insensitive RT measures. We are seeking to improve them in another experiment.

It is possible, as Morgan, Goodson, and Thomas (1975) argued, that these results reflect the idea that conventional colour/temperature correspondences are based on “loosely held cultural norms” (p. 125). This view is consistent with that of Ernst (2007) who showed that participants could be trained to integrate unrelated stimuli, and thus the integration of sensory signals is not necessarily hardwired.

Shams and Seitz (2008) suggest that training will be enhanced by stimulating each sense with congruent information. This may indeed apply when the parameters are veridical, such as ensuring that blood always appears red in simulations, but perhaps it will not be as critical when the relationship is metaphorical. Further empirical research is needed to determine whether our finding (e.g., that a hot item need not appear red) can be generalised to whether, for instance, blood should be coloured red or whether it can be artificially shown in another colour to, perhaps, make it stand out in the surgical field to better, or more quickly, arrest attention in the event of a bleed during a procedure.

### 3. DISCUSSION

It would seem that a VE is perceived differently when temperature is present, such that participants rate the environment as more “real”. This may have some bearing on how well individuals learn new tasks when trained in VEs or remotely operate equipment via a VR interface — although Richardson, Symmons, and Wuillemin’s (2006) review indicated that there is some
doubt as to whether increased presence results in an improvement in performance. Additionally, if training involves passive or passive-guided movements, temperature may need to be adjusted when using this mode so that it is consistent with the perceived rather than actual level of thermal sensation experienced actively. Further, in our study at least, congruent colour/temperature combinations were not perceived more swiftly than incongruent combinations. It may be that training protocols employing congruent multisensory input may not facilitate learning any more effectively than protocols that provide the user with incongruent stimuli.

Spitzer and Ackerman (2008) discussed “virtual” palpation and the use of haptic devices to display tissue resistance. They and Robb (2008) espoused the benefits of fully immersive, multisensory information in surgical training. However, no mention was made of the availability of thermal information. Neglecting to add temperature limits the information presented to touch, and correspondingly may reduce its functionality. We would argue that this has important implications for many virtual training applications.

All objects have thermal qualities, and while we do not always pay conscious or deliberate attention to these elements, it should not be assumed that they are unimportant. As previously mentioned, Shams and Seitz suggest that training protocols mimicking natural settings have the potential to aid learning. Elhajj et al. (2001) support this view by suggesting that the skilled operation of machinery can be markedly reduced by limiting feedback. If a feature of one modality is neglected (e.g., felt temperature) then an important factor that aids our ability to accurately and efficiently interpret our environment is being overlooked in the design of VEUs and virtual training tools.

Despite the promise of adding thermal information to VR interfaces, a problem for researchers interested in pursuing this outcome is the “rise” time of Peltier tiles. Many objects that are touched are cooler than body temperature to begin with (e.g., a soft-drink can). Peltier tiles placed on the fingertips and switched on need time to become cold. As such, cold may not be “felt”, or registered, at the fingertip until several milliseconds (or even seconds) after contact with an object. We counter-acted this problem by programming an anticipatory triggering of the Peltier tile.

Previous research has noted that multimodal stimuli can promote a sense of realism or presence (Baier, Buss, Freyberger, Hoogen, Kammermeier, & Schmidt, 1999; Miner, Gillespie, & Caudall, 1996; Grane, & Bengtsson, 2005). In addition, performance has been found to correlate positively with presence (see Jiang, Girotra, Cutkosky, & Ullrich, 2005; Sallnas, Rassmus-Grohn, & Sjostrom, 2001; Kazi, 2001). Consistent with Woods (1998), we believe that thermal information has been overlooked by many involved in the design and manufacture of VR interfaces. We have shown that temperature cues enhance presence and there are, therefore, good reasons to include thermal information in haptic VEUs.

REFERENCES


