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Towards a Neuropsychological Basis of Presence

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Abstract: *Presence research studies the experience of being in a place or being with someone as it is mediated through technology. The experience of presence appears to be a complex perception, formed through an interplay of raw multisensory data, spatial perception, attention, cognition, and motor action, all coupled through a constant dynamic loop of sensorimotor correspondence. The fact that technology can start working as a transparent extension of our own bodies is critically dependent on (i) intuitive interaction devices which are 'invisible-in-use', seamlessly matched to our sensorimotor abilities, and (ii) the highly plastic nature of our brain, which is continuously able and prone to adapt to altered sensorimotor contingencies. The perception of ourselves as part of an environment, virtual or real, critically depends on the ability to actively explore the environment, allowing the perceptual systems to construct a spatial map based on sensorimotor dependencies. Provided the real-time, reliable correlations between motor actions and multisensory inputs remain intact, the integration of telepresence technologies into our ongoing perceptual-motor loop can be usefully understood as a change in body image perception – a phenomenal extension of the self.*

INTRODUCTION

Interactive systems that allow users to control and manipulate real-world objects within a remote real environment are known as *teleoperator* systems. Remote-controlled manipulators (e.g., robot arms) and vehicles (e.g., NASA's Mars Exploration Rovers) are being employed to enable human work in hazardous or challenging environments such as space exploration, under-sea operations, or hazardous waste clean-up. They also allow for transforming the temporal and spatial scale of operation, as is the case with for instance minimally invasive surgery. In teleoperation, the human operator directly and continuously guides and causes each change in the remote manipulator. Sensors at the remote site (e.g., a stereoscopic camera, force sensors) provide continuous feedback about the slave's position in relation to the remote object, thereby closing the continuous perception-action loop that involves the operator, the master system with which she interacts locally, and the remote slave system. In the context of telerobotics, telepresence is closely associated to the sense of *distal attribution*,¹ the externalisation of the self to include remote tools that phenomenologically become extensions of one's own body, even if they are not physically part of it.

Whereas teleoperation systems enable the manipulation of remote real-world environments and

objects within it, virtual environments (VEs) allow users to interact with synthetic or computer-generated environments. In its most well-known incarnation, VEs are presented to the user via a head-mounted display (HMD) where visual information is presented to the eyes via small CRTs or LCDs, and auditory information can be presented using headphones. Importantly, the HMD is fitted with a position tracking device which provides the necessary information for the computer to calculate and render the appropriate visual and auditory perspective, congruent with the user's head and body movements. Haptic information, although not yet usually included in present-day VEs, can be added through the use of for instance an exoskeletal glove or arm, acting both as sensor and actuator.

Telepresence (in relation to teleoperation) and virtual presence (in relation to VEs) both address the psychological phenomenon of *presence* – the sense of 'being there' in a mediated environment, or a "perceptual illusion of non-mediation" as Lombard and Ditton² defined it. Perceived transparency of the medium is crucial, i.e. a sense of direct perceptual stimulation and potential for action, without an awareness of the remoteness in time or space of the simulated or reproduced realities.

MEDIA CHARACTERISTICS INFLUENCING PRESENCE

Since the early 1990s onwards, presence has been empirically studied in relation to various media, most notably VEs. A large number of factors that may potentially influence the sense of presence have already been suggested in the literature. Depending on the levels of appropriate, rich, and consistent sensory stimulation, varying levels of presence can be produced. Sheridan³ proposed three categories of determinants of presence:

The extent of sensory information presented to the participant, i.e. the amount of salient sensory information presented in a consistent manner to the appropriate senses of the user.

The level of control the participant has over the various sensor and interface mechanisms (tracked HMD, dataglove, etc.). This refers to the various sensorimotor contingencies, i.e. the mapping or correlation between the user's actions and the perceptible spatio-temporal effects of those actions.

The participant's ability to modify the environment, i.e., the ability to interact with the virtual or remote environment and to affect a change within that environment.

The extent of sensory information is similar to Steuer's⁴ notion of *vividness*. Level of control over sensors and effectors, and the ability to modify the environment correspond to Steuer's⁴ notion of *interactivity*. These three factors all refer to the media *form*, that is, to the physical, objective properties of the media technology. Importantly, presence research is about relating those media form variables to the human response. In principle, Slater's⁵ contention that one should try to keep content variables out of the presence equation as much as possible is adopted here. According to Slater,⁵ "presence is about form, the extent to which the unification of simulated sensory data and perceptual processing produces a coherent 'place' that you are 'in' and in which there may be the potential for you to act."

It is of clear theoretical and practical value to establish what the optimal mix of cues might be for different application contexts, or, if the opti-

um is unattainable, which elements are most critical to the experience of presence. It appears, for instance, that pictorial realism contributes less to the experience of presence in VEs than, for instance, interactivity of viewpoint.⁶ As Heeter⁷ noted, "the alchemy of presence in VR is in part a science of tradeoffs." It is not clear at present how much each feature or perceptual cue contributes to eliciting a sense of presence for the participant (i.e., the relative weighting), nor is it clear how these cues interact with each other. A model of multisensory information integration and interaction for presence - a *presence equation*, if you like - will be a valuable theoretical and practical contribution. Ellis⁸ has argued that an equation relating presence to its contributing factors should allow for iso-presence equivalence classes to be established, that is, maintaining the same level of measured presence, whilst trading off contributing factors against each other. However, testing such a model's empirical validity will critically depend on sufficiently reliable, valid, and sensitive measures of presence which are currently being researched (for an overview see van Baren & IJsselsteijn, 2004;⁹), but can not yet be said to exist at this point in time.

ESTABLISHING SENSORIMOTOR DEPENDENCIES THROUGH ACTIVE EXPLORATION

Perception serves the individual's need to control relevant moment-to-moment behaviour or action within a changing environment. The development of visual perception of object shape and environmental layout is strongly dependent on consistent correlations between vision and input from other sensory systems (mainly touch and kinesthetics) through active exploratory behaviour of the environment, establishing a stable yet flexible multisensory representation of space.

In a classic study, Held¹⁰ convincingly demonstrated the relation between locomotor experience and the understanding of spatial relations. He designed an experiment using a 'kitten carousel' in which kittens, who were raised from birth in total darkness, were placed in pairs. One kitten pulled the carousel, thus using its movement to determine what it saw. The other kitten was placed in a basket at the other end of the carousel, which was controlled by the first

kitten. In this way, the second kitten received identical visual stimulation to the first kitten, yet without the ability to control the visual input. Between these sessions of visual exposure, the kittens were returned to the dark. After 42 days of 3 hour sessions, the effects of active versus passive movement became strikingly apparent when the kittens were tested on a visual cliff surface. The kittens who had been active in the carousel shied away from the cliff and appropriately stretched out their legs to land on the lower surface. The passive kittens showed none of that behaviour, thereby providing support for the view that the development of perception is action-dependent. Observations in humans have led to similar conclusions. For instance, Verkuyl¹¹ indicated that so-called Soften on children, who do not possess upper extremities due to the use of a sleeping drug in the early stages of the mother's pregnancy, had severe problems in 3D-perception.

Studies of adaptation to prismatic displacements provide further support for the importance of establishing reliable sensorimotor correlation maps through actively negotiating the physical environment. Held & Hein¹² studied prismatic displacements in humans under three conditions: active arm movement, passive arm movement, and no arm movement. In the active arm movement condition the subject swung her arm back and forth in the frontal plane, in the passive condition it was transported in the same manner by means of a moving cradle to which it was strapped. Results, as measured in terms of visual-motor negative after-effects, showed that adaptation was only produced in the active movement condition and not in the passive or no-movement conditions. Another classic experiment on visual displacement¹³ used lenses that turn the world upside-down. The study showed that full adaptation to this situation (i.e., seeing the world right side up again) occurred after a few days only when subjects were allowed to actively explore a complex world. When a subject was simply pushed around in a wheelchair, he did not show this perceptual adaptation to the lenses.

Similarly, telemanipulation experiments using the Delft Virtual Window System¹⁴ demonstrated a significant perceptual advantage of active observers, whose head movements con-

trolled the movements of a remote camera (generating movement parallax), over passive observers, who received identical visual input (i.e. motion parallax), yet without the ability to actively change the viewpoint. This is in line with results found in relation to virtual environments, where Welch et al.¹⁵ showed that participants who had active control over a simulated environment indicated higher levels of presence than participants who were passively exposed to the same environment.

BRAIN PLASTICITY AND OUR NEGOTIABLE BODY-IMAGE

The fact that technology can start working as a transparent extension of our own bodies is critically dependent on the highly plastic nature of our brain, which is continuously able and prone to adapt to altered sensorimotor contingencies, as the studies on adaptation to prismatic displacement and tele-systems already illustrated. This fact finds its basis in the significant evolutionary benefit of having a negotiable body image to accommodate lifetime development and change, which requires a continuous remapping of bodily boundaries. Although body-image adaptations across the lifespan can afford to take their time, it is the relative speed of these sensorimotor adaptations that enables us to experience man-made technology as, quite literally, part of ourselves - be they a blind person's cane or an advanced telerobotic arm.

Further evidence of the high-speed plasticity of the body image is provided by the amazing adaptation processes that may occur in the body-image of people with an amputated limb. Ramachandran, Rogers-Ramachandran and Cobb¹⁶ had (amputated) phantom limb patients view their intact arm in a mirror, such that their amputated arm appeared to be resurrected. Several subjects reported feeling their phantom limb touched when they viewed the mirror image of their intact arm being touched – see also Ramachandran & Blakeslee.¹⁷

Botvinick and Cohen¹⁸ provided a first description of the 'rubber hand illusion'. This crossmodal perceptual illusion occurred when participants' left hand was placed out of view and a life-size rubber model was placed in front of them. Subsequently, both the rubber hand and

participants' left hand were gently stroked by two small paintbrushes, synchronizing timing as closely as possible. In line with the Ramachandran et al.¹⁶ results, subjects reported feeling a sense of ownership of the rubber hand, as if it was actually their own. Ramachandran, Hirstein and Rogers-Ramachandran¹⁹ further extended this work, showing that this illusion also works when physical similarity is absent. Instead of using a rubber hand, they simply stroked and tapped the tabletop for about a minute. In this case, subjects also reported sensations arising from the tabletop. They argue that the illusion mainly arises "from the 'Bayesian logic' of all perception; the brain's remarkable ability to detect statistical correlations in sensory inputs in constructing useful perceptual representations of the world – including one's body." (p. 1500). In a further study, Armel and Ramachandran²⁰ showed that when the physical integrity of the rubber hand was threatened (bending a finger backwards to seem painful), a clear skin conductance response was generated, and that the illusion could even be projected to anatomically impossible locations. Using the rubber hand illusion, Ehrsson, Spence, and Passingham²¹ have recently studied the neuronal counterparts of the feeling of body ownership. On fMRI measures of brain activity, they found that areas in the premotor cortex reflected the feeling of ownership of the rubber hand, indicating that the multisensory integration in this region provides a mechanism for bodily self-attribution.

The results on perceptual adaptation described in the previous paragraph, as well as the rubber hand illusion, both seem to suggest that what matters most is a closely and continuously correlated loop of sensory input, neural commands, and motor action. Thus, modality-specific feature maps appear to project onto one another through re-entrant connections, which allows disjunctive feature characteristics (e.g., visual and haptic properties of a stimulus) to be connected in the responses of higher-order networks. Sensorimotor correlations will initially be driven by the temporally ongoing parallel signalling between primary cortical areas receiving the sense data associated with stimulus objects at a given time and place. Next, stable feature correlations establish reciprocal connections between previously disjunct feature

maps, thus allowing for higher order perception and categorisation of objects and environments.²² The ensuing body image is most usefully conceptualised as a temporary construct which is remarkably flexible, and may include non-biological artefacts as an integral part of it.

FROM FAR TO NEAR: REMAPPING SPACE IN TELEPRESENCE

In general, the space that surrounds the user can be meaningfully segmented into a number of ranges, usually three or four, based on principles of human perception and action. Several models have been proposed,^{23,24} all of which distinguish between a *peripersonal space* (the immediate behavioural space surrounding the person) and a far or *extrapersonal space*. Referring to haptic space, the peripersonal space corresponds to what Lederman, Klatzky, Collins & Wardell refer to as the manipulatory space, i.e., within hand's reach, whereas the extrapersonal realm would be regarded as ambulatory space, requiring exploration by movements of the body, or through the use of a tool which extends the bodily reach. Animal and human brain studies have confirmed this distinction between peripersonal and extrapersonal space, showing that space is not homogeneously represented in the brain.^{25,26}

Telepresence technologies can be viewed as attempts to overcome the boundaries of spatial segmentation. Their success in doing so is evidenced by a clinical case, described by Berti and Frassinetti,²⁷ where a patient (P.P.), after a right hemisphere stroke, showed a dissociation between near and far spaces in the manifestation of severe visuo-spatial neglect. Using a line bisection task, the neglect was apparent in near space, but not in far space when bisection in the far space was performed with a projection light pen. However, neglect appeared in the far space as well when the line bisection task was performed with a stick (used by the patient to reach the line) and it was as severe as neglect in the near space. Thus, this study provides evidence that an artificial extension of a person's body (the stick) causes a remapping of far space as near space – *essentially telepresence*.

CONCLUSION

The same sensorimotor and brain systems responsible for our sense of bodily boundaries and

our sense of spatial location are also remarkably adaptable to include non-biological elements within the perceptual-motor loop, provided reliable, real-time sensorimotor correlations can be established. When we interact with virtual or remote environments using intuitive interaction devices, isomorphic to our sensorimotor abilities, the real-time, reliable and persistent chain of user action and system feedback will effectively integrate the technology as a phenomenal extension of the self. This fluid integration of technology into the perceptual-motor loop eventually may blur the boundary between our 'unmediated' self and the 'mediating' technology.

Naive definitions of 'self' as everything contained within our bodily boundaries, and 'non-self' as the world outside our own bodies become much less obvious when we regard the intimate dependencies and co-adaptation we can experience when technology starts working as a transparent extension of our own bodies and minds. As cognitive scientist Andy Clark convincingly argues in his wonderful book '*Natural Born Cyborgs*', what 'I' am is not defined by the outer limits of the 'biological skin-bag'. He states: "For our sense of self, of what we know and of who and what we are, is surprisingly plastic and reflects not some rigid preset biological boundary so much as our ongoing experience of thinking, reasoning, and acting within whatever potent web of technology and cognitive scaffolding we happen currently to inhabit" (p.45).²⁸ Thus we learn that our relationship with technology is a two-way adaptive process - we adapt the technologies to fit our needs and abilities (a process also known as *user-centred design*), but at the same time, our brain adapts itself to the technology, so that the technology becomes part of our extended self – the biological self and all non-biological tools and toys we employ to enhance our performance and pleasure.

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