# Giving your self to the game: transferring a player's own movements to avatars using tangible interfaces

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## ABSTRACT

We investigate the cognitive connection players create between their own bodies and the virtual bodies of their game avatars through tangible interfaces. The work is driven by experimental results showing that execution, perception and imagination of movements share a common coding in the brain, which allows people to recognize their own movements better. Based on these results, we hypothesize that players would identify and coordinate better with characters that encode their own movements. We tested this hypothesis in a series of four studies (n=20) that tracked different levels of movement perception abstraction, from own body to that of an avatar's body controlled by the participant, to see in which situations people recognize their own movements. Results show that participants can recognize their movements even in abstracted and distorted presentations. This recognition of 'own' movements occurs even when people do not see themselves, but just see a puppet they controlled. We conclude that players – if equipped with the appropriate interfaces – can indeed project and decipher their own body movements in a game character.

### Author Keywords

Common coding, body memory, video game, virtual character, tangible user interface, game avatar, puppet.

### ACM Classification Keywords

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## INTRODUCTION

Players engage and identify often very intensely with the virtual game characters under their control. Virtual avatars can become important projection planes for a player's agency in the game world and are often seen as dramatic connections to a game world. In this work, we combine approaches from cognitive science, tangible interfaces, and virtual worlds to investigate this connection on the level of the body, movement, and comprehension of movement.

A rapidly expanding research stream in cognitive science and neuroscience suggests that execution, perception and imagination of action share a common representation in the brain. Known as common coding theory, this work suggests that when humans perceive and imagine actions, our motor system is activated implicitly. A common instance of this 'simulation' process is familiar to cinema goers: while watching an actor or car moving along a precipice, viewers move their arms and legs or displace body weight to one side or another, based on what they would like to see happening in the scene [Prinz 2005]. Anecdotal reports suggest similar effects are seen in sports fans and novice video game players. Such 'simulation' of others' actions underlie our ability to project ourselves into different character roles. Whether the actions are performed by an animated character in a virtual world or a human being in a film, we understand the actions of others through our own body memory reservoir, which is 'leveraged' to predict actions and movements in the world.

A central result of work in common coding is that the neural system underlying the simulation (the mirror neuron system) may be better activated when watching one's own actions. [Knoblich and Sebanz 2006] report that people can recognize their own clapping from a set of recordings of clapping, and pianists can pick out their own rendition of a piece from a set of recordings of the same piece. Applying this 'own-movement effect', we are seeking to build a video game that uses tangible interfaces to transfer a player's own movements to a virtual character. The motivation for this work is two-fold. One, the 'own-movement effect' suggests that if characters encode a player's own movements, the player would both identify and coordinate better with the character. In a game setting this could trigger higher levels of engagement and better control. Second, it is possible, based on common coding theory, that novel movements executed by such a 'personalized' character may be transferred back to the player via the perception-action link, thus improving a player's ability to execute such movements in imagination, and, perhaps, also in the real world (see also [Jeannerod 1997]). This might indicate that virtual characters can be valuable tools for teaching certain movements in fields such as physiotherapy.

To encourage a relatively direct mapping of movements from the real to the virtual world, we are designing a tangible game interface in two phases. In the first phase, we record a person's body movements and test whether users can identify their own movements under two conditions, a perception-only condition (no feedback), and a control-and-perception condition (with feedback). In the first condition, players will see different simplified digital representations of their own movement, such as movements in silhouette, in a figure, in an animated character, in different proportions etc. In the second condition, players will control these representations using a tangible user interface such as a puppet. Instead of seeing their own body movements mapped into the game world, the puppet's moves will drive the game animations. In both conditions, we test the extent to which players can identify their own movements in the game character. Testing these two conditions would allow us to build up a base matrix of situations where players can identify their own movements in the character – the space of different representations, movements and perspectives under which self-identity is maintained. Once this matrix is developed and we show the connection between player and game character, the second phase will test *one* possible effect of such self-identification with a character: we will map a person's movement to a virtual character, and then examine whether interacting with such a 'personalized' game character executing novel body movements improves a player's imagination of such movements.

In the present paper, we report the results of a set of experiments conducted during the first phase of the project (building the matrix). The experiments demonstrate that users can recognize their own movements in simplified and abstracted representations. We first present an overview of results from common coding, virtual environments and tangible interfaces that drive our research. Then we describe the experimental design from the first phase of the project, and present the results. We conclude with future directions and implications of this work.

## BACKGROUND

The research proposed here builds on three separate fields: cognitive science, virtual environments, and tangible user interfaces. Common coding theory from cognitive sciences provides the theoretical and experimental basis for developing technological tools for enhancing human imagination and action. This cognitive model links perception, action and imagination, and can help us to better understand how to employ our body memories in developing novel computational media. To this end, tangible interfaces combined with virtual environments can provide a link between physical actions and the digital space. Video game spaces and real-time game engines provide the digital space into which a user can project their expressions and solutions, and tangible interfaces provide a physical form factor that naturally maps control onto a high level of granularity in action within the virtual world. In this section, we provide an overview of the state of the art in these three related areas of research and discuss the ways in which they drive and support the project.

### The Common Coding Approach

The common coding view argues for a shared representation in the brain that connects an organism's movement (motor activation), its observation of movements (perceptual activation), and imagination of movements (simulation). This common coding allows any one of these movements (perception, action, imagination) to generate the other two movements ([Prinz 2005]; also see [Decety 2002, Hommel et al. 2001]). The central insight emerging from the common coding approach is a body-based 'resonance' – the body acts similar to a tuning fork, replicating all movements it detects. To illustrate, going round and round can make you dizzy, but equally, watching something go round and round can also make you dizzy. This is because observing a movement leads to an implicit replication of the (spinning) movement by the body. The replication and simulation of the spinning movement in the observer then activates the perceptual effects of the action (dizziness) in the mind of the observer. However, all the replicated movements are not overtly executed. Most stay covert because the overt movement is inhibited. But such replication generates a representation of the movement in body coordinates, which plays a role in cognition and imagination. In this way, the common coding hypothesis can also explain the ability of two people to coordinate task performance (say in a multi-player game) because perceiving the other's actions activates one's own action system, leading to an intermingling of perception and action across players [Knoblich and Sebanz 2006].

#### *Perception-Action common coding*

When participants execute an action A (say tapping fingers on a flat surface), while watching a non-congruent action on a screen (say another person moving in a direction perpendicular to the tapping), the speed of the performed action A slows down, compared to the condition when the participant is watching a congruent action on screen [Brass et al. 2002]. This is because the perceived opposite movement generates a motor response that interferes with the desired tapping pattern. A similar interference effect has been shown for competing movements within an individual – movement trajectories of participants veer away or towards the location of a competing non-target object

[Welsh and Elliott 2004]. Supporting many such behavioral results, neuro-imaging experiments show action areas are activated when participants passively watch actions on screen ([5] provides a review). Expert performers of a dance form (such as ballet and capoeira) when watching video clips of the dances in which they are experts, show strong activation in premotor, parietal and posterior STS regions, compared to when watching other dance forms. Non-dancer control participants do not show this effect [Calvo-Merino et al., 2005]. Similar motor activation has been shown for expert piano players watching piano playing [Repp and Knoblich, 2004]. When we observe goal-related behaviors executed by others (with mouth, hand, foot) the same cortical sectors are activated as when we perform the same actions [Gallese et al. 2002]. We do not overtly reproduce the observed action, but our motor system acts as if we are executing the observed action. The neuronal populations that support such action co-representation are termed "mirror neurons" (see [Hurley and Chater 2005] for a review). In contrast, motor areas are not activated when humans watch actions not part of our repertoire (such as barking). Perceiving an action also primes the neurons coding for the muscles that perform the same action [Fadiga et al. 1995, Fadiga et al. 2002].

### *Imagination-Action common coding*

Effects of this common coding have been found in multiple disciplines. When sharpshooters imagine shooting a gun, their entire body behaves as if they are actually shooting a gun [Barsalou 1999]. Similarly, imagining performing a movement helps athletes perform the actual movement better [Jaennerod 1997]. The time to mentally execute actions closely corresponds to the time it takes to actually perform them [Decety 2002, Jeannerod 2006], and responses beyond voluntary control (such as heart and respiration rate) are activated by imagining actions, to an extent proportional to the actual performance of the action.

While imagining a mental rotation, if participants move their hands or feet in a direction that is not compatible to the mental rotation, their performance suffers [Wohlschlager 2001]. Also, planning another action can interfere with mental rotation [Wohlschlager 2001]. [Wexler et al. 2004] shows that unseen motor rotation during mental rotation leads to faster reaction times and fewer errors when the motor rotation is compatible with the mental rotation than when they are incompatible. In some cases motor rotation made complex mental rotations easier, and speeding/slowing the motor rotation speeded/slowed the mental rotation. Some complex mental rotations automatically generate involuntary hand movements [Chandrasekharan et al. 2006]. Links between imagination and action have also been found in mechanical reasoning, such as how people imagine the behavior of pulleys or gears. [Hegarty 2004]. Imaging experiments support these results, showing that premotor areas are activated while participants do mental rotation [Vingerhoets et al. 2002].

## 3D Game Worlds

3D spaces have become widely accessible and familiar to their player through countless video games. Players can navigate these worlds and perform specialized interactions in them, usually via an avatar as a projection plane and access point to the virtual world. In that way, virtual characters are focus points for the player's agency in the game world and expressive channels for their interactions.

### *Player-Character relations*

Often highly individualized in appearance, specialized in their virtual abilities, and equipped with items gathered during long playing hours or extensive avatar customization before the game, virtual characters "belong to" their players. They can become manifestations of the player's individual play achievements and unique preferences. It is no wonder that players identify with their game avatars and create a personal connection to their characters [Turkle 1996; Isbister 2006]. A widespread paradigm is that of the player as actor with the avatar as a representation of the performance in the virtual world. Through customization and gradual mastering of the controls, players closely connect to their virtual alter egos to the point where players can feel situated in the virtual. The close mental connections between physical player body and virtual world have been utilized in numerous virtual training applications in the area of Serious Games. These range from treatment of the fear of flying [Rothbaum et al. 2006] to treatment of post-traumatic stress disorder in the wake of the 9/11 attacks [Difede and Hoffman 2002] to military combat simulations. However, the detailed mechanisms of how the projection from the player onto the avatar operates are not entirely clear. There are various suggestions to explain and measure player's presence (e.g. [Slater 1999] vs. [Witmer and Singer 1998]) and models to define and track immersion (e.g. [Lombard and Ditton 1997]) but the cognitive connection between player and virtual character remain obscure. While we know that this connection exists and is highly effective at times, we cannot precisely tell why or how it works. Our focus is specifically on the cognitive connection between the player and the avatar *body*. Within this area we are not interested in questions of appearance or customization of game characters, but concentrate on their movements.

### *Movement expression*

The mapping of a player's ergodic participation onto the virtual character's in-world actions is often highly abstracted. A player might trigger a highly complex animation sequence through a single button press as animations and usually pre-recorded elements and defined by the game designer who maps them on the interaction design for the specific game title. These pre-defined sets of animations are by and large inaccessible to the average player. An avatar's movements, thus, are not unique but mostly pre-defined and largely repetitive. Engines can blend between different animations and create hierarchies between them, but even most advanced titles such as the

*Unreal 3* engine still base animations on pre-captured motion data. At the same time, the flexibility and complexity increases: the number of bones and the animation details grow exponentially, procedural animation can be added [Hecker et al. 2008], and physics can be applied to the skeleton. The expressive quality of animation systems improves dramatically, but the conceptual underpinnings of the limited control mechanisms combined with largely pre-canned and inaccessible animations still dominate video games, blocking out more direct mirroring of players onto their virtual bodies. Thus, even as games become platforms for self-expression and socialization, featuring highly advanced animation and control technologies, they mostly follow outdated paradigms that prevent direct and creative control of the animation system.

### Tangible Interfaces

When players move through a virtual environment, they use a control interface to project their intentions or expressions into the virtual space. With the exception of some new physical game interfaces like Nintendo's WiiRemote, most game systems use generic controllers for this purpose, such as keyboards, mice, joysticks and gamepads. These are generally two-axis pointing devices and button arrays that provide low-bandwidth single-channel data streams. Yet complex characters have many degrees of freedom, which cannot be easily controlled with input devices that provide at most two degrees of freedom. This requires a high level of abstraction between the control device and the virtual object. Jacob and Sibert describe this as a mismatch between the perceptual structure of the manipulator and manipulation task [Jacob and Sibert 1992]. They have demonstrated that for tasks that require manipulating several integrally related quantities (e.g. 3D position), a device that generates the same number of integrally related values as required by the task (e.g., Polhemus tracker) is better than a 2D positioning device (e.g., mouse). Since high level abstraction limits the players' ability to precisely control their character across all its degrees of freedom, it also restricts their freedom to generate different movements and expressions in the virtual space. For example, if walking forward is controlled by the 'w' key, the player will not be able to easily access a range of walking expressions.

Given the limited form factors of existing human-computer interfaces, designers and researchers are exploring new ways to integrate the physical and digital spaces. These efforts fall under emerging areas of digital interaction, such as tangible user interfaces (TUIs) or tangible interaction. TUIs aim to extend our means of digital input and output beyond a primarily audiovisual mode, to interactions that make better use of the skills that humans have with their hands and bodies [Ishii and Ulmer 1997, Ulmer and Ishii 2001]. The approach couples digital information with physical artifacts that act as both controls and representations for the underlying systems they embody. TUIs take advantage of our manual dexterity and capitalize on the well-understood affordances and metaphors of everyday physical objects. They can provide approaches for mapping player expressions into the virtual space in two ways. First, TUIs can provide a high level of granularity across many degrees of freedom in the physical world. Second, TUIs can be designed in a physical form that naturally maps the real onto the virtual.

Related approaches are already used in professional production companies, which have increasingly turned to puppetry and body motion tracking to inject life into 3D character animation. Putting a performer in direct control of a character via puppetry, or capturing body motion for real-time or post-processed animated character control, helps translate the nuances of natural motion to virtual characters and increases their expressive potential. For example, The Character Shop's Waldo devices are telemetric input devices for controlling puppets (e.g. Jim Henson's Muppets) that are designed to fit a puppeteer's body. Waldos allow puppeteers to control multiple axes of movement on a virtual character at once, unlike older lever systems that required a team of operators to control different parts of a single puppet. A limitation of motion capture puppetry is that it typically requires significant clean-up of sensor data in post processing. The high price point also precludes its use in the consumer space for enhancing the expressive potential of everyday game players.

In interaction research, a number of efforts have centered on new physical interfaces for character control and animation. For example, the Monkey Input Device is an 18" tall monkey skeleton with sensors at its joints, providing 32 degrees of freedom for real-time character manipulation [Esposito and Paley 1995]. Researchers have also used Measurand's ShapeTape, a fiber optic-based 3D bend and twist sensor, for direct manipulation of 3D curves and surfaces [Balakrishnan et al 1999]. Others have used puppeteering techniques with various input devices (joysticks, MIDI controllers) to manipulate 3D virtual characters in real-time [Virpet project]. Additionally, our own past research used paper hand puppets tracked by computer vision [Hunt et al. 2006] and tangible marionettes with accelerometers [Mazalek and Nitsche 2007] to control characters in the *Unreal* game engine. However, to our knowledge none of the work on tangible interfaces for virtual character control has applied common coding theory to enhance the user's identification with a virtual character. As such, our project provides a unique interdisciplinary approach towards the design of systems that can help to enhance the user's experience and abilities.

## EXPERIMENTAL DESIGN

The first stage of the project outlined here investigates the extent of the connection between the player's own movement and that of an abstracted virtual entity. We are interested in this connection because it creates a channel wherein players make a direct connection between their own physical movements and that of the virtual avatar. Our ultimate objective is to use this channel to transfer novel movements executed by the character on screen back to the player, via the common coding between perception of movements and imagination/execution of movements. This could be useful in training games involving cognitive processes linked to action and also in medical rehabilitation tasks, e.g. for patients with stroke or movement disorders.

We conducted four experiments to assess the hypothesis that a person can identify her own movement even when the movement is visually abstracted. A series of studies of biological movement [Beardsworth and Buckner 1981, Cutting and Kozlowski 1977, Knoblich and Flach 2001, Knoblich and Prinz 2001], have shown that when a person sees a visually abstract representation of her movement, (something as simple as a light-point animation, see figure 2), one can recognize the image's movements as one's own.

There were two types of experiments. The first type analyzed participants' ability to recognize their body movement (study one and two); the second type analyzed participants' ability to recognize the way they move a puppet (study three and four). These studies enable us to establish the spectrum of self-recognition. We were interested in discovering whether participants were able to recognize the movements they make while using a control interface (like a puppet). This can allow us to establish whether a user will perceive the movements of a virtual character controlled by a tangible user interface as their own movement. In turn, this determines whether it is possible to use an external interface (e.g. puppet rather than body motion capture) as the basis for extending a user's body memory. Each study asked a specific question:

***Study One***: Can participants identify their own body movements when they are represented as a proportionately correct but visually abstracted movement?

***Study Two***: Can participants identify their own body movements when they are represented as proportionately standardized (not in their own natural proportions) and visually abstracted movement?

***Study Three***: Participants move a physical puppet; both, their own movements and the puppet's movements are captured. A visually simplified video of the person moving the puppet is played alongside videos of other participant's puppet movement. Can participants recognize their own movements relative to other participants' movement?

***Study Four***: Same as three, except that the participants see only the puppet's visually simplified movement, not their own actions involved in moving the puppet. Can they distinguish between puppets manipulated with their own movements and puppets manipulated by others?

There were a total of twenty participants in this study: ten participants (5 male, 5 female) participated in the body movement experiments; and ten participants (5 male, 5 female) in the puppet movement experiments. None of them was an experienced puppeteer.

### Recording and Recognition Sessions

In each experiment, light-emitting diodes (LEDs) were attached to key points of articulation of the participant's body: head, torso and limbs. The participant's movements were recorded then by camera. This generated abstract images of body movement, where only the moving light points of the LEDs were visible (figure 2).

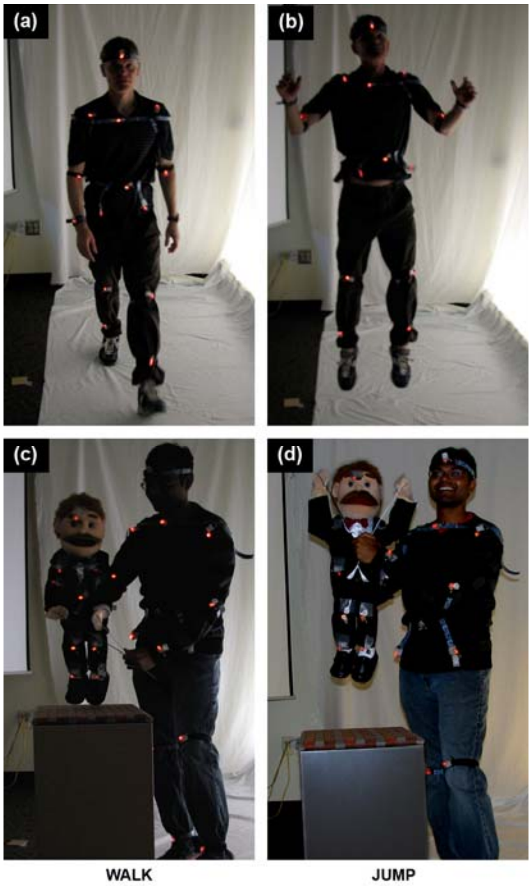

**Figure 1. Walk and jump movement tracking with LED straps attached to: participant body (a & b) and both puppet and participant bodies (c & d).**

In the first two studies (Body, Body Proportion), LEDs were attached to participants and they were asked to execute two actions: walk and jump. The walk was a natural walking style, and the jump was a moderate jump, straight up and down (figure 1a&b). Body proportions of the participant were unaltered in study one. In study two, the video's body proportions were altered—using post-production techniques—to a standard body size. For each participant, 5 walk and 5 jump trials were captured, for Body and Body Proportion studies.

Ten or more days after the recording session, participants returned for two blocks of recognition sessions (Body and Body Proportion). In each session, participants watched a series of trials, each with two clips of visually abstracted movement (figure 2a&b). One clip showed the participant's own action (e.g., jump) and the other showed the same action performed by another participant. The participant was asked to identify which video displayed her own action. There were 70 trials each for Body and Body Proportion sessions. The two sessions were counterbalanced – half the participants were shown the videos from Body first, followed by those from Body Proportion, whereas the other half were shown videos from Body Proportion first, followed by those from Body.

For each video trial, the program picked a random video clip of the participant from a list, and another random video clip from a list of others making the same movement. The location on the screen where the video was presented (left, right) was also random. Participants were asked to press "P" if they thought their video clip was on the right, and "Q" if they thought it was on the left. The videos looped until the participant made a choice. The video presentation program kept track of the randomizations of files and locations, the key press responses of participants, and the time it took for a participant to respond.

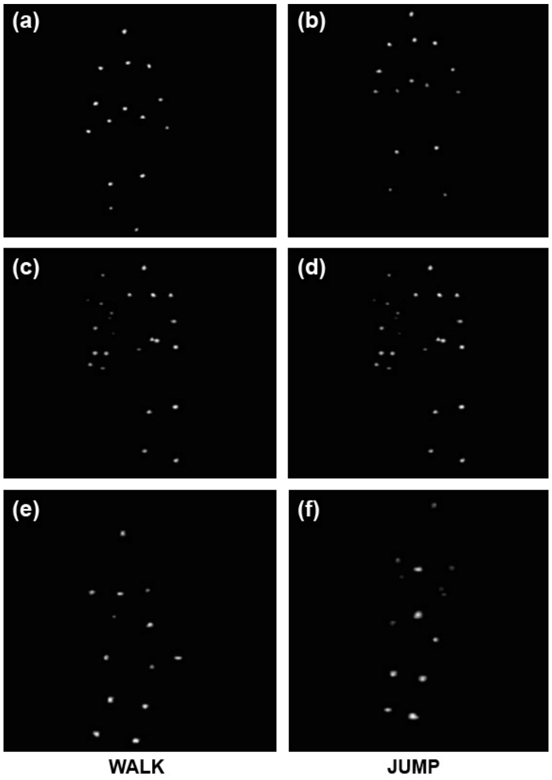

**Figure 2. Video stills of visually abstracted walk and jump movements for: participant body (a & b), participant body with puppet (c & d), and puppet only (e & f).**

Studies Three and Four (Puppet & Puppeteer, Puppet Only) followed the same design, except that the participant made movements with a puppet. Participants again had LEDs attached to their bodies at key points of articulation. They were given a puppet, also with LEDs attached (figure 1c&d) and asked to manipulate the puppet so that it appeared to be walking or jumping. Cameras captured the movement of both the participant and the puppet. The participants then returned for a recognition session, where they tried to recognize their own movement, in two blocks (Puppet & Puppeteer condition, Puppet Only condition). In the Puppet & Puppeteer condition, the participants viewed side-by-side videos of self and others manipulating the puppet. They was asked to determine which clip represented their own puppet manipulations (figure 2c&d). In the Puppet Only condition, the participants viewed video clips of just the puppet. They was asked to determine which clip represented their manipulation of the puppet (figure 2e&f). These two experiments had 60 trials each, and the conditions were counterbalanced, with half the participants viewing the Puppet & Puppeteer condition first and the other half viewing the Puppet Only condition first.

## RESULTS

For each participant, we computed the proportion of correct self-identifications (figure 3). Since the guessing probability is .5, values significantly greater than .5 indicate that participants recognized their own movement.

**Accuracy**: Participants showed high levels of identification in all studies. All accuracy measures were significantly above chance level. The mean proportions of correct identifications are as follows: Body condition: 95.71 (SD=3.49, $\chi^2$ = 296.51, p<.00001); Body Proportion condition: 94.71 (SD=5.42, $\chi^2$ = 283.22, p<.00001); Puppet & Puppeteer condition: 84.33 (SD=18.36, $\chi^2$ = 177.86, p<.00001); Puppet Only condition: 82 (SD=23.5, $\chi^2$ = 182.73, p<.00001). The high standard deviations in the last two conditions are due to one participant performing very poorly, averaging 40 and 31.6 percent correct scores, and another participant scoring 100%.

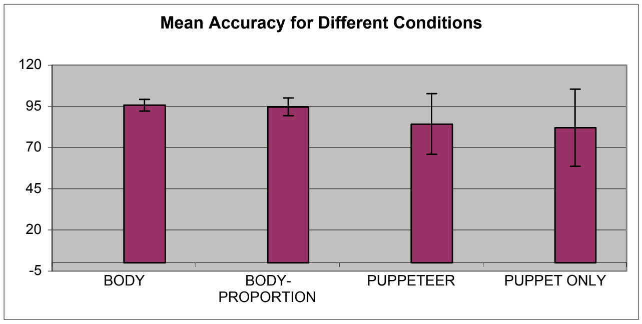

**Figure 3. The average percentage of correct results for all tests across all four study trials. The recognition of body movements is higher than the recognition of puppet movements.**

**Reaction Times:** We allowed participants to take their own time in responding, so there is wide variability within this data. However, a rough trend can be identified, where participants took more time in the Body Proportion condition than the Body one. In the Puppet experiment, the Puppet & Puppeteer condition took more time than the Puppet Only condition.

**Gender**: Previous experiments have shown that people can accurately recognize the gender of a pointwalker [Cutting and Kozlowski 1977]. So it is possible that in trials where the two videos showed participants with different gender, people made the recognition decision by recognizing the other person's gender, and then eliminating that video. To check whether this occurred, we analyzed the data based on the same/different gender in the video. The proportion of correct identifications for same gender trials and different gender trials were extracted for each condition, and compared using T-tests. No significant differences were found between the two cases, though there was a trend (P<.08) towards more accuracy for "different" gender judgments in the Body condition (see figure 4). The lack of significant difference between the two gender combinations, indicates that the self-identification was based on a simulation of the movements seen on video, rather than a logic-based elimination process.

## DISCUSSION

Overall, the results show a higher recognition rate of own body movements than of puppet movements (~95% vs. ~80%). However, we could not identify a dramatic decline in the level of recognition. There was no significant difference between the Body condition vs. the Body Proportion condition. Participants seemed to recognize their own movements, regardless of body proportion.

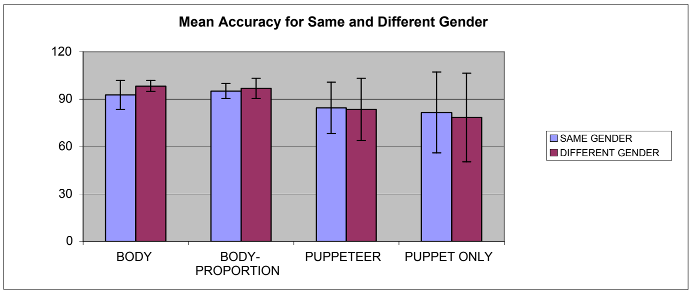

**Figure 4. The average percentage of correct results for same and different gender tests across all four study trials. The recognition of (non-standardized) body movements is higher when the genders are different.**

There is a larger gap between the body movement and the puppeteering studies, but since the self-recognition rates are still far higher than chance, we interpret this as part of an expected decline mainly due to unfamiliarity with the puppet and not as a principle loss of self-recognition. There is also no significant difference between the Puppet & Puppeteer condition (study three) and the Puppet Only condition (study four). Participants were still able to identify their own movements in the Puppet Only (study four) condition. This was surprising, as none of the participants in the study had any puppeteering experience. It would be interesting to compare these results with professional puppet players as participants or do a long-term study of players using the interface.

Overall, the results show an effective translation of self to the character, suggesting that we indeed project ourselves to the movements of characters whose movements derive in second order from our own body memory; probably through a common coding system. We believe these results could be exploited to develop new media and new interfaces. It opens up questions regarding our identification with virtual actors and the feedback loop that avatars can generate with our own body memory.

## CONCLUSION

The research illustrates our ongoing work at the interface between game worlds, new interfaces and common coding theory. Such a connection suggests new paradigms of character control and interface design. These can inform new game design approaches as well as invite a rethinking of the player-avatar relationship. For example, it might be highly relevant for Serious Games in the health sector. However, while the current experiments show that the underlying connection between own body memory and virtual character stay intact, they do not yet offer the necessary interfaces to control the character, nor do they clarify what kind of avatar representations work best. Our ongoing work maps a person's movement to a virtual character through a tangible interface that works like a digital puppetry controller. In our future work, we will examine whether perceiving a 'personalized' video game character executing novel body movements can augment a player's body memory and "teach" a player in that way.

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