

# I'm in the Game: Embodied Puppet Interface Improves Avatar Control

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## ABSTRACT

We have developed an embodied puppet interface that translates a player's body movements to a virtual character, thus enabling the player to have a fine grained and personalized control of the avatar. To test the efficacy and short-term effects of this control interface, we developed a two-part experiment, where the performance of users controlling an avatar using the puppet interface was compared with users controlling the avatar using two other interfaces (Xbox controller, keyboard). Part 1 examined aiming movement accuracy in a virtual contact game. Part 2 examined changes of mental rotation abilities in users after playing the virtual contact game. Results from Part 1 revealed that the puppet interface group performed significantly better in aiming accuracy and response time, compared to the Xbox and keyboard groups. Data from Part 2 revealed that the puppet group tended to have greater improvement in mental rotation accuracy as well. Overall, these results suggest that the embodied mapping between a player and avatar, provided by the puppet interface, leads to important performance advantages.

## Author Keywords

Puppet, tangible user interface, embodied interface, virtual character, video game, common coding, body memory, creativity.

## ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces---*input devices and strategies, interaction styles*; J.4 [Social and Behavioral Sciences]: *Psychology*; J.5 [Arts and Humanities]: *Performing arts*. K.8 [Personal Computing]: *Games*.

## General Terms

Design, experimentation.

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## INTRODUCTION

When players move through a virtual environment, they need a means to project their intentions and expressions into the virtual space, such as a control device or interface. Most current game systems make use of a number of generic controllers for this purpose, such as keyboards, mice, joysticks and gamepads. These input devices are generally 2D positioning devices, or arrays of buttons that provide low-bandwidth single-channel streams of information. Complex characters, however, have many degrees of freedom to control, which is not easily done with input devices that provide two degrees of freedom at most. As a result, there is significant abstraction between the movement of the control device and the movement of the virtual object that is being controlled. Jacob and Sibert describe this problem as a mismatch between the perceptual structures of the manipulator and the perceptual structures of the manipulation task [11]. They have shown that for tasks that require manipulating several integrally related quantities (e.g. a 3D position), a device that naturally generates the same number of integrally related values as required by the task (e.g. a Polhemus tracker) is better than a 2D positioning device (e.g. a mouse). A high level of abstraction limits the player's ability to precisely control their character across all its degrees of freedom, and also restricts their freedom to generate a variety of different movements and expressions in the virtual space. For example, in many video games 'walking forward' in virtual space is accessed by pressing the 'w' key on a standard keyboard. This single response coding for a complex movement pattern restricts the degrees of control to the extreme, as the player is not able to easily access a range of different walking expressions for their virtual character.

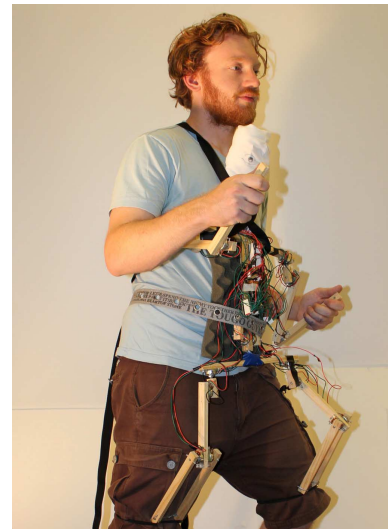
Given the limited form factor of existing control interfaces, application designers and researchers have been exploring new ways to better integrate the physical and digital spaces in which we exist. These efforts have resulted in emerging areas of human-computer interaction research, such as tangible, gestural and embodied interaction. These

approaches leverage the capabilities of the human hands and body, enabling users to control virtual characters and objects in ways that build on or even simulate real-world interactions. These new forms of interaction are gaining popularity in the gaming world, such as the Nintendo Wii Remote, the Sony Playstation Move, and Microsoft's Kinect for the Xbox 360. These interfaces offer a much more direct sensori-motor mapping to the virtual space than conventional mouse or keyboard-based interfaces. With the growing relevance of consumer level control devices of this kind, it has become increasingly important for HCI designers to consider fundamental aspects of the interaction between perceptual, cognitive and motor processes [22]. One model that has great potential in this context is common coding theory.

Common coding (ideomotor) theory [9, 18, 19] posits a common neural representation connecting perception, execution and imagination of movements. This creates a tight coupling between action plans and their associated effects, and allows for fluid, automatic and bidirectional connections between the planning, perception, imagination and execution of action. This model provides an interesting design framework to derive new interaction formats [3, 16], and has the potential to help us better understand the role played by the motor system in our interactions with computational media. One of the most interesting experimental results from common coding research is the consistent ability of people to recognize their own movements shown in the abstract (such as a person's writing movement displayed by the movement of a point-light). People also tend to coordinate better with their own actions [13]. In an effort to exploit this 'own-movement' effect for the development of new media, we designed a full-body control interface (puppet) for video games that maps a player's own body movements onto a virtual avatar using a puppet (see Figure 1). The puppet provides a fine-grained connection between self movements (action planning and execution) and virtual avatar movements (perception/imagination of action effects). The common neural coding between perception of movements and imagination/execution of movements suggests that this connection, provided by the embodied interface, could eventually be used to transfer novel movements executed by the on-screen character back to the player.

Unlike the Wii, which tracks the position and movement of a single point/joint using heavily simplified mappings with its Wii Remote, the puppet can transfer a player's whole body movements to their virtual avatar with many degrees of freedom. And unlike the Kinect, which exploits camera-based motion capture, the puppet does not constrain the player's interaction to a fixed area defined by the visual field and the tracking abilities of the camera. In comparison to professional motion capture systems, the puppeteering approach is low-cost and portable. It can also open up a space for expressive exaggeration, since puppets can be made to perform actions unachievable with the human body

alone. The abstraction of a puppeteering device can thus allow players to execute actions in virtual space that are impossible in real space, while their body movements still map directly onto the virtual avatar. Such an exaggeration is often part of video games, where players might control non-human avatars or perform specialized actions. In addition, the puppets have been used to raise engagement of new audiences in digital media. For example, primitive puppets have been used as digital storytelling devices for young audiences that are not computer-literate [14].



**Figure 1. Full-body puppet interface.**

Our earlier experiments have shown that the puppet interface supports players' recognition of their own movements in a 3D virtual character. The puppet approach is thus effective in personalizing an avatar by transferring a player's own movements to the virtual character [17]. Building on this work, the present paper reports the results of a study that examined the use of the puppet interface in comparison to standard video game control interfaces (keyboard and Xbox game controller). We looked at: (1) whether the puppet interface facilitated player performance by providing more accurate responses when controlling their avatar, and (2) whether perceiving a 'personalized' avatar executing novel body movements lead to improved cognitive performance of the user. The study made use of a custom-designed game in which the player had to make their avatar complete a series of aiming movements to touch virtual objects in 3D space, while at the same time having to constantly recalibrate their own body space in relation to the orientation of the avatar in the virtual world.

The following section summarizes the background for our project. We then provide a brief overview of the design of our puppet interface and the 3D virtual environment it manipulates. Next we describe the design of the experiments, and present the results. We conclude with future directions and implications of this work.

## RELATED WORK

A number of efforts have centered on new physical interfaces for character control and animation. For example, the Monkey input device was an 18" tall monkey skeleton equipped with sensors at its joints in order to provide 32 degrees of freedom from head to toe for real-time character manipulation [5]. While its many degrees of freedom allowed a range of expressions to be translated into the virtual space, smooth whole-body real-time manipulation was in fact difficult to achieve and the device was thus better suited for capturing static poses (e.g. as in stop-motion animation). Johnson et al.'s work on "sympathetic interfaces" used a plush toy (a stuffed chicken) to manipulate and control an interactive story character in a 3D virtual world [12]. The device captured a limited range of movements (wing movements, neck rotation, and pitch/roll) and did not map the user's own full-body movements to the virtual space. Similarly, equipped with a variety of sensors in its hands, feet and eye, the ActiMates Barney plush doll acted as a play partner for children, either in a freestanding mode or wirelessly linked to a PC or TV [1]. Additionally, our own past and ongoing research has used paper hand puppets tracked by computer vision [10] and tangible marionettes equipped with accelerometers to control characters in the Unreal game engine [15].

Related approaches are already in use in professional production companies, which have increasingly turned to various forms of puppetry and body or motion tracking in order to inject life into 3D character animation. Putting a performer in direct control of a character like in puppetry, or capturing body motion for real-time or post-processed application to an animated character, can translate the nuances of natural motion to computer characters, which can greatly increase their expressive potential. For example, The Character Shop's trademark Waldo devices are telemetric input devices for controlling puppets (such as Jim Henson's Muppets) and animatronics that are designed to fit a puppeteer or performer's body. Waldos allow puppeteers or performers to control multiple axes of movement on a virtual character at once, and are a great improvement over older lever-based systems that required a team of operators to control all the different parts of a single puppet. The Character Shop's control interfaces evolved into real-time digital controllers of varying granularity: the characters in the PBS series *Sid the Science Kid* are controlled in real-time, each by two puppeteers with different systems [8].

A comparable approach is also used by Animazoo in their Gypsy 7 exo-skeletal motion capture technology. A big limitation of motion capture puppetry is that it typically requires significant cleanup of sensor data during the post processing stage. Further, the high price-point of both camera and exo-skeleton-based systems targets professional motion capture applications and precludes their use in the consumer space. As a result, it is not feasible to make use of these systems as control devices for everyday game players.

In the home entertainment domain, standard game controllers remain the dominant paradigm, with the exception of the newer interfaces (Nintendo Wii Remote, Sony Move, and Microsoft Kinect).

To our knowledge, none of the work on tangible interfaces for virtual character control is based on ideomotor theory. The rich experimental techniques from this literature (such as self-recognition, and better coordination with self-movements) have thus not been used to examine how such interfaces improve the user experience, or change the user's cognitive abilities. Most of these systems focus on fidelity of motion capture, and not on control of a character by a user. They therefore do not examine how the user's experience of control can be pushed further, and in what situations the feeling of control breaks down. As such, we believe our interface provides a valuable interdisciplinary approach towards the design of control systems that can help enhance the user's expression and problem-solving.

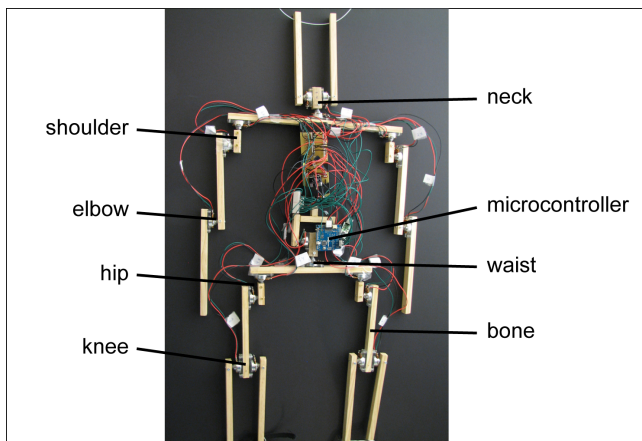
## SYSTEM OVERVIEW

As described in [17], our puppet interface is designed to support the player's self-identification with the virtual avatar through faithful transfer of own body movements to the avatar, while still providing the abstraction of a control device between one's own movement and that of the virtual avatar. The system consists of two main components: the puppet control interface and the 3D engine, described in the following sections. The 3D engine enables us to implement and deploy small "games" that provide the player with tasks to solve in the virtual world. We describe the virtual contact game developed for our experiments.

### Puppet Interface

The puppet is a hybrid full-body puppet that is strapped to the player's body, and controlled by the player's arms, legs and body. This approach provides a high level of articulation and expressiveness in movement without requiring the skill of a professional puppeteer. And in contrast to motion capture systems, the puppet interface is both low-cost and portable.

The puppet consists of 10 joints at the knees, hips, waist, shoulders, elbows and neck, allowing us to capture a range of movement data (see Figure 2). Its feet attach to the player's knees, its head attaches to their neck, and its midsection attaches to their waist. The player uses their hands to control the hands of the puppet. This configuration allows the puppet to be easily controlled by both the hand and full-body movements of the player, and allows the puppet to faithfully transfer the player's own movements to their virtual avatar. While not implemented in the current version, the full-body puppet form factor could also enable us to incorporate vibrotactile feedback into the puppet device. This would allow the virtual avatar's movements to feed back into the physical device and stimulate player movements.



**Figure 2. Puppet interface with 10 joints across the knees, hips, waist, shoulders, elbows and neck.**

The puppet is built out of wooden “bone” pieces connected across the 10 joints using potentiometers, allowing the movement of the joints to be measured. Joints such as the shoulders and hips, which rotate in two directions, contain two potentiometers oriented at 90 degrees in order to sense the rotation in each direction independently. The potentiometers are connected via a multiplexer to an Arduino Pro microcontroller attached to the chest of the puppet. The microcontroller sends the movement data to a host computer via a Bluetooth connection, where a software application written in Processing normalizes the values and sends them to the rendering engine via the OSC (OpenSound Control) protocol.

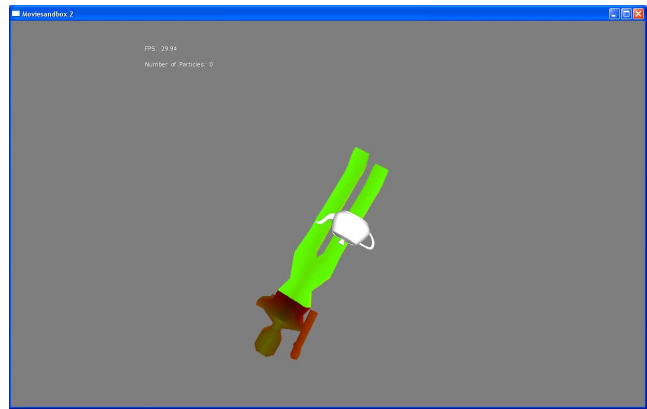
### 3D Engine

The 3D renderer allows the physical puppet interface to steer a virtual puppet in real-time (see Figure 3). It is based on the Moviesandbox (MSB) application, an open-source, OpenGL-based, machinima tool written in C++ ([www.moviesandbox.net](http://www.moviesandbox.net)). The renderer uses XML files to store the scenes and settings for the characters allowing for very flexible usage.

The 3D renderer receives the OSC messages sent by the Processing application, and maps them onto the virtual avatar. Based on the settings for the joint rotations in the currently loaded XML character file, positions of the bones are set relative to one another using forward kinematics. In addition to character control, the application currently supports camera placement, panning and tilting. The 3D renderer also includes advanced import functions for standard 3D modeling files and has basic animation recording options. Both are valuable for experimenting with different virtual puppets and comparing the animations our puppeteers create with them.

The system provides us with a basic but highly flexible virtual puppetry engine that mimics the functionality of video game systems – in fact, its first installment used Epic's *Unreal* game engine as renderer, but to provide better flexibility and access to the animations we moved to an

Open GL approach. This allowed us to better adjust the necessary control mechanisms to the interfaces we were designing.



**Figure 3. 3D renderer with avatar in the teapot game.**

### Virtual Contact Game

The first game developed in our 3D engine was designed to investigate two research questions. First, we wanted to examine how the puppet performed as a control interface, in relation to standard interfaces such as joysticks and keyboards. Secondly, we wanted to examine how novel movements executed by a virtual avatar might contribute to the player's cognition, specifically mental rotation. To examine the first question, we needed a 'neutral' task, different from standard tasks seen in games, because if game-related tasks are used, expert game players would perform at high levels, and possibly skew the data towards standard interfaces. Further, the puppet interface affords novel forms of interactions within video games, and we therefore wanted to develop a task not commonly seen in standard video game interactions. To examine the second question, we needed a task where the user perceived movements not commonly executed in the real world, so that we could examine the effects these movements had on the player's ability to imagine related movements, in isolation from any previous motor training.

Based on these experimental constraints, we developed a game where players saw virtual objects (teapots) appear in proximity to their 3D avatar, and they had to move their body and the puppet interface to make the virtual avatar touch these objects (see Figure 4). The teapots appeared randomly at different points near the avatar, and the player had to move her hands or feet to make the avatar touch the teapot. To investigate the effect of perceived novel movements on mental rotation abilities, we added a special camera behavior to this game task. The camera slowly rotated around the avatar in an unpredictable manner, making the avatar float in space in different orientations (see Figure 3). This apparent movement of the avatar forced the player to constantly reconsider the position and orientation of the virtual avatar in relation to their own body, the interface strapped to their body, and also the

virtual teapots they have to touch. Once touched, each teapot disappeared and a new one appeared in a different location. The player's goal was to touch as many teapots as possible in the time provided (13 minutes). The number of teapots touched and the time at which each teapot was touched were tracked by the system.

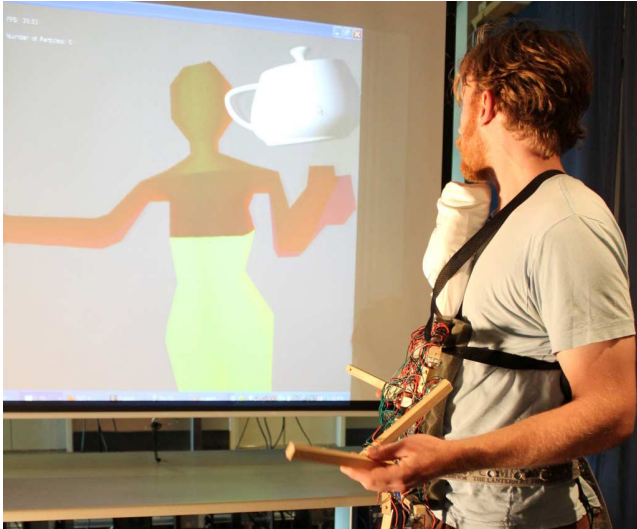


Figure 4. Playing the virtual contact game with the full-body puppet controller.

### EXPERIMENT DESIGN

Previous experiments have shown that our puppet interface is effective in personalizing an avatar by transferring a player's own movements to the virtual character [17]. Building on this work, we presently report a study that examined the performance of the puppet interface in comparison to standard video game control interfaces. Specifically, we looked at: (1) whether the puppet interface facilitates player performance by providing more accurate responses when controlling their virtual avatar, and (2) whether perceiving a 'personalized' video game character executing novel body movements leads to improved cognitive performance in the player. The study involved 30 participants playing the virtual contact game and completing mental rotation tests. The participants were pseudo-randomly assigned (our only constraint was having equal n across the conditions) to one of three interface conditions: puppet, Xbox controller, and keyboard. There were thus 10 participants per interface condition, of which 50% were female (i.e. 5 per condition, or 15 overall).

The two components of the study (teapot touching and mental rotation) were conducted within a single session. The participant was first asked to complete two sessions of a standard mental rotation test. After this, the participant was asked to play the virtual contact game using one of the three control interfaces. After they had played the game for 13 minutes, participants completed another two sessions of the mental rotation task. The mapping between the character's body and the Xbox/keyboard interfaces were as follows.

	Arm/leg toggle	Shoulder/hip movement	Knee/elbow bending
Keyboard	F (left) H (right)	W,A,S,D (left) I,J,K,L (right)	Q,E (left) U,O (right)
Xbox	Click joysticks (left/right)	Move joysticks (left/right)	Triggers (left/right)

### PART 1 RESULTS

To determine if the puppet device has performance advantages over the more conventional devices (Aim 1), we analyzed the mean number of successful teapot contacts using a one-way between-subjects ANOVA (alpha set at 0.05). Post-hoc analysis of the significant effect ( $F=5.87$ ;  $p<.01$ ) using paired one-tailed  $t$ -tests ( $p<.05$ ) revealed significant advantages for the puppet and Xbox controllers over the keyboard. Performance advantages of the puppet over the Xbox controller, although numerically large, only tended toward statistical reliability ( $p<.13$ ; see Figure 6). Despite the absence of a statistically reliable difference, effect size calculations of the differences between puppet and Xbox controllers were in the medium range (Cohen's  $d=.52$ ) suggesting important functional and practical differences in performance.

	Puppet	Xbox	Keyboard
Contacts	123.9	90.6	41.1
Std. Dev.	74.1	50.74	28.33

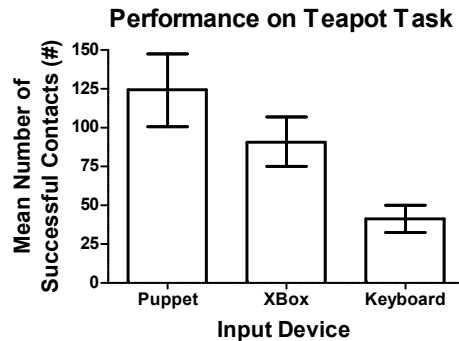
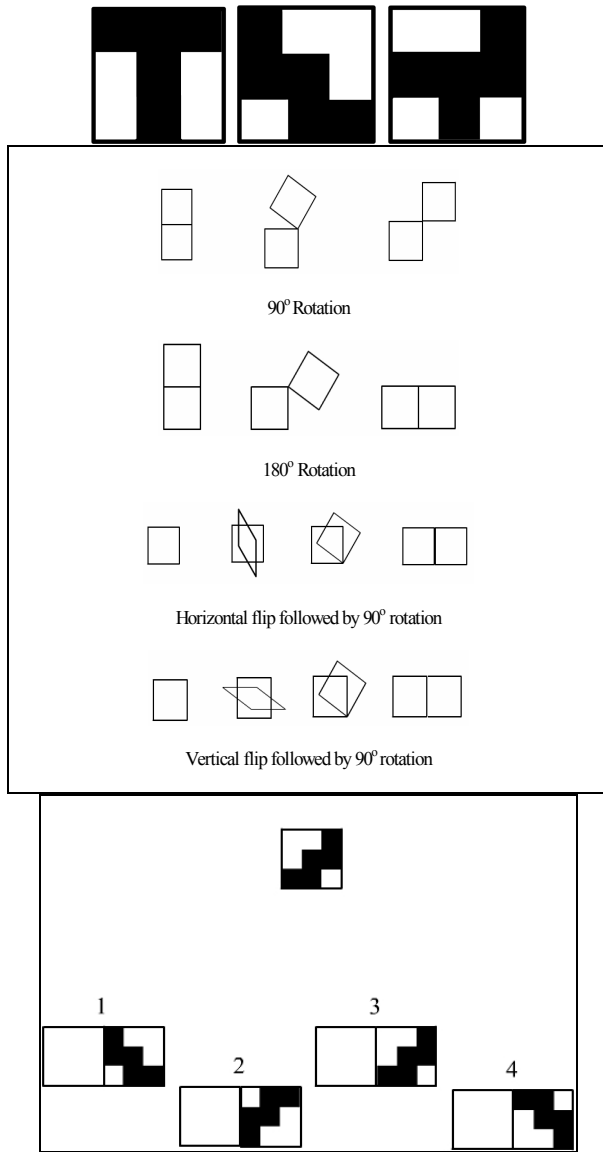


Figure 6. The average number of teapots touched across the three conditions (puppet, Xbox and keyboard).

### MENTAL ROTATION TASK

Playing video games has been shown to have cognitive effects, such as improvement in attention, spatial ability and mental rotation [6, 7]. Manipulating virtual objects has been reported to improve subsequent mental rotation and recognition of such objects [21]. Games have also been shown to help overcome cognitive limitations, such as fear of flying [20] and post-traumatic stress disorder in the wake of the 9/11 attacks [4]. Based on these previous findings, we wanted to examine whether interacting with an avatar that encodes the player's own body movements using an embodied interface leads to improvement in imagined movements, primarily mental rotation, compared to interactions based on standard control interfaces, which do not as faithfully transfer the player's own body movements to the avatar. Such a transfer would be predicted by

common coding theory, as a common neural representation underlies perceived and imagined movements. To examine this prediction, we had players complete a mental rotation task before and after interacting with the avatar, and we then compared the accuracy and the time taken for their responses. This analysis was done for the three interface conditions. The task is described below.



**Figure 5.** The top panel shows the patterns used, the middle panel shows the rotation operations used, and the last panel shows a screenshot of the decision task. For each trial, a video of one of the operations was displayed first, and then the decision screen. One of the bottom figures shows the top pattern rotated in the sequence displayed in the video. The task is to pick this option.

*Stimuli:* A set of three small 2D patterns within a white square (frame) were prepared on a 3x3 matrix with only five cells being filled, as illustrated in panel 1 (top) of Figure 5. The visual angle was 1.5° x 1.5°. With each of

these patterns, three more patterns were generated by rotating the original three patterns by 90°, 180° or 270°. Any one of the possible four orientations of a particular stimulus pattern was randomly used as a stimulus in a particular trial.

There were eight rotational operations (4 x left/right directions; see Figure 5, panel 2). There were two levels of complexity (low or high). Low complexity operations were rotations of 90° (right and left) and 180° (right and left). High complexity operations were vertical and horizontal flips followed by a rotation of 90° (left or right). The rotational task was given a reference by providing an empty-blank white square (frame). To demonstrate the operations, video clips were created using Flash. Each rotation in the low complexity condition took twenty seconds of display time. In the high complexity condition, each flip operation took twenty seconds in addition to each rotation operation, which also took twenty seconds to complete. There was a two second gap between flip and rotation. The end position (frame) after the rotational operation, stayed for five seconds.

*Procedure:* The experiment consisted of twenty-four trials (8 operations x 3 patterns), presented randomly. Each trial had two phases. In the first phase, a rotation was demonstrated using a video clip. Participants were asked to remember the rotation they saw, apply the same operation on the pattern coming up in the second phase and select the answer that best fitted the mentally rotated pattern.

The second phase started after 2 seconds, during which the screen was blank. This phase presented a pattern to be mentally rotated, along with four possible answers (as shown in Figure 5, panel 3), which remained on screen until participants produced a response, by typing 1, 2, 3 or 4 using the keyboard. This response initiated the next trial, which started after two seconds. Participants responded to 48 trials (two 24-trial blocks) before and after the virtual contact game. The program that controlled stimuli presentation and data collection was designed using ExperimentBuilder software.

## PART 2 RESULTS

The low complexity trials were not included in the analysis, as previous work [2] showed that participants typically reach a ceiling of perfect performance on this simpler task. The influence of the different task conditions on the mental rotation task was assessed by submitting accuracy and response time on the mental rotation tasks to a 3 (Group: puppet, Xbox, keyboard) by 2 (Test: pre, post) mixed ANOVA. The main effect for Test ( $F=11.27, p<.01$ ) revealed that, as a whole, participants improved in accuracy in the mental rotation task following the experience with the teapot game. Specific planned comparisons of the accuracy of the different groups in the pre- and post-tests using paired *t*-tests revealed that this increase in accuracy was driven by the performance of the puppet group. That is, of all three groups, the puppet group demonstrated the

largest improvement and was the only group to demonstrate a statistically reliable improvement in performance ( $p < .05$ ). Improvements in the Xbox ( $p > .07$ ) and keyboard ( $p > .20$ ) were not significant. Further, effect size for the improvement following the puppet controller was in the medium range ( $d = .61$ ), but were in the small range following the Xbox ( $d = .28$ ) and keyboard ( $d = .46$ ).

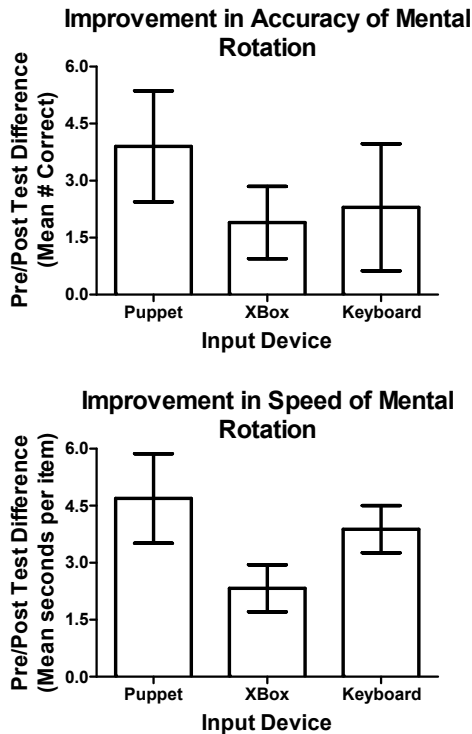


Figure 7. Mean accuracy and speed improvement in the mental rotation task across the three conditions (puppet, Xbox and keyboard).

The absence of similar between-group differences in response time suggests that these improvements were not the results of a speed-accuracy trade-off in which the puppet group performed more accurately because they took more time to complete the task in the post test. Thus, consistent with our hypothesis, it seems that the more consistent perceptual-motor mapping provided by the puppet interface had some facilitatory influence on the users' cognitive capabilities.

	Puppet Pre/Post		Xbox Pre/Post		Keyboard Pre/Post	
<b>Accuracy</b>	15.1	19.0	15.5	17.4	16.5	18.8
<b>Std. Dev.</b>	6.2	6.6	7.1	6.5	4.8	5.2
<b>Time</b>	11.9	7.2	9.43	7.1	14.38	10.5
<b>Std. Dev.</b>	3.7	2.7	3.7	3.5	7.3	7.8

## DISCUSSION

Overall, the execution component of the study revealed that the embodied puppet interface improved performance in the

virtual contact game, compared to Xbox and keyboard interfaces. This finding indicates the value of embodied interfaces for the development of more personalized and less restricted interaction with virtual worlds (such as video games). Additionally, almost all participants who used the puppet interface commented on its ease of use, and many found it to be a fun and novel way of interacting with the avatar. If interaction design seeks to move away from the currently dominant model of abstraction, then the puppet interface offers the necessary opportunities for participation and involvement.

Consistent with previous research [6, 7], the embodied interface, and the transfer of the player's own movements to the virtual character, showed improved accuracy in mental rotation. Further experiments are required to examine this effect more clearly, but the results demonstrate a positive effect of the puppet interface. One element that might influence the results here is the fact that the puppet interface, even though generally perceived as unobtrusive and engaging, presents a completely new interaction format to the test participants. None of the test participants was a trained puppeteer. In comparison, it can be assumed that the Xbox controller and the keyboard are much more familiar. It could, thus, be projected that the puppet interface would perform even better once users get used to it.

## CONCLUSION AND FUTURE WORK

In our past work [16] we have shown the level of self-recognition supported by our embodied interface. The research presented in this paper shows the positive cognitive effects of this interface usage. We conclude that development of similar embodied interfaces could help unlock potential opportunities for game interface design. It is worth noting that while these interfaces use game-based technology, they are not limited to the entertainment sector. Instead, these designs might have applications in other fields, such as movement education and rehabilitation. The success of novel interfaces like the Wii in new areas, such as retirement homes, indicates that such systems can be developed as assistive technologies as well.

Some questions raised by our research remain unanswered and left to future work. One is the question of interface familiarity and different effects along different learning curves of novel interfaces. In order to explore the puppet interface's long-term impact on user performances, a comparative training study would be insightful. Findings of such a study could become relevant for the discussion of other novel interfaces (Xbox Kinect, Playstation Move). Will the level of virtual body control be consistently higher in these kinds of embodied interfaces? How will it develop as users adapt to the new device?

A more pressing question, however, is how we can utilize the connection between one's own movements and the virtual character movements that we have traced in our work. Our ultimate challenge is to see whether an embodied interface can help users learn new movements from a

virtual character. We suggest using the self-recognition in a virtual avatar, and the cognitive effects discussed in this paper, to assist a user in this learning process. In our future work, we hope to explore the application of such a system to the medical domain. To this end, we are currently examining how the full-body puppet form factor can incorporate feedback (e.g. using vibrating motors at the joints). This would allow the movements of the avatar to feed back into the physical device and stimulate player movements. We believe this sort of enhancement would be useful for training or movement rehabilitation applications.

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