# The Role of Physical Controllers in Motion Video Gaming

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## ABSTRACT

Systems that detect the unaugmented human body allow players to interact without using a physical controller. But how is interaction altered by the absence of a physical input device? What is the impact on game performance, on a player's expectation of their ability to control the game, and on their game experience? In this study, we investigate these issues in the context of a table tennis video game. The results show that the impact of holding a physical controller, or indeed of the fidelity of that controller, does not appear in simple measures of performance. Rather, the difference between controllers is a function of the responsiveness of the game being controlled, as well as other factors to do with expectations, real world game experience and social context.

### Author Keywords

Touchless, affordance, 3D graphics, gestural interaction, input devices, video game design

### ACM Classification

H5.2 [Information interfaces and presentation]: User Interfaces. Graphical user interfaces.

## INTRODUCTION AND MOTIVATION

Xbox Kinect [23] is the first widespread commercial gaming system that supports user interaction without requiring a physical controller, instead capturing full body motion and gestures as input via a camera. This can be thought of as a kind of "touchless" interaction with technological systems, which we increasingly encounter in our daily lives. Of course, some kinds of touchless systems have been around for years: automatic doors in public places are an obvious example, and the taps and toilets in public restrooms are others. Whereas such systems depend on simple proximity sensors, Kinect is the first commercial system to use computer vision to take advantage of full motion body tracking in a way that engages our full attention. In doing so, it has introduced the possibility of "systems that see" into people's homes and lives.



It is perhaps unsurprising, then, that Kinect and other systems like it have fired the imagination of researchers and developers, and indeed even casual hackers. We are not only seeing a new gaming paradigm, but also new applications in domains beyond gaming such as medical, health and shopping. Systems that use computer vision as a powerful form of input have undoubtedly unleashed and fuelled a kind of worldwide creativity.

This coming paradigm raises interesting new research questions for HCI. For example, computer games have historically evolved with physical controllers. Early games used generic controllers such as keyboards and joysticks. Later on, gaming manufacturers made more specialized devices, such as steering wheel controllers for racing games. We began to see the first use of computer vision as input with the Sony EyeToy. More recently, systems such as the Wii [26] used accelerometers to take advantage of body motion. The history of gaming controllers may be seen as the evolution of increasingly sophisticated physical devices as developers and designers strive to create a more immersive gaming experience, eventually leading to their being abandoned altogether.

A key question this raises is: how is the gaming experience altered when a physical device or tool is replaced by gestural or body-based interaction? After all, humans throughout history have been characterized both as tool makers and users, tools usually being understood to mean physical implements or artifacts often specialized for the task at hand. If we now remove those physical artifacts and require that users (in this case, gamers) simulate interaction with those physical devices instead, how does this affect performance in the game, expectations of the game, and the overall enjoyment of that gaming experience?

These issues are important to understand not just from the point of view of games system design, but as a more general question that impacts any kind of application in which physical interaction (meaning direct contact with a physical device) is simulated by touchless interaction. For example, think of remotely controlling a space vehicle through hand gestures alone, or the touch-free manipulation of medical data by a surgeon in an operating theatre. Such scenarios are examples of how touchless interaction offers new possibilities, such as the need to interact with something at a distance, or where materials should not be touched (such as in a sterile operating theatre). In these situations, if there are aspects of performance likely to be affected by the absence of a physical artifact, or if there are other ways in which interaction is impacted, these are important to understand. While we focus on gaming in this study, we hope to pose questions and begin to provide answers that can be explored in other settings.

### Gaming as a target domain

Computer gaming is a good domain to choose as a starting point for investigation, as many computer games are designed to simulate real world games involving physical artifacts. We do recognize that new genres of games are being designed specifically for vision-based systems, and also that some games seem more naturally suited to systems which no longer require a physical controller. Dance and fitness games are obvious examples where the capture of full body motion enhances the experience. However, given that many real world games make use of physical tools or implements, and many others have co-evolved with the development of specialized game controllers (such as first person shooters), it is clear that it should be examined how touchless versions of these games might be different. Further, such games provide an excellent platform within which we can explore the issues we have outlined above.

Having said that, when we turn to games designed to in some way simulate aspects of "real life" games (such as tennis, baseball and golf), it is clear that, despite the best efforts of games designers, there are many ways in which the games are different, and ought to be different. Indeed, the balance between realism and fantasy is surely part of the great skill of good games design—there are aspects of war games in which we want more realistic aspects of the experience, but somewhere a line must be drawn. Likewise, the controller for Guitar Hero [7] is easier to master than a real guitar—something which most people appreciate, but which expert guitarists might not. And finally, an element of fantasy, and breaking "the rules" of realism is surely what makes some games so compelling. What makes a good game is beyond the scope of this paper. For our purposes it is enough to say that there are many ways in which the representation of game dynamics, players' actions, environment, physical artifacts and interaction with other players make computer game play different from the "real" or represented experience.

Our concern here is to focus more narrowly on the impact of changing the nature of the game controller for games that typically rely on a physical device. Specifically, there are two aspects of game design which we investigate: the fidelity of the artifact, tool or piece of equipment used to play the game, and the fidelity of recognition of the players' expressive actions by the system. Holding all else constant in the design of the game, whether or not a player uses a physical object to control the game (and the nature of that controller), as well as the mapping of that controller to the dynamics of the game, are the issues we wish to explore.

## BACKGROUND

There has been a great deal of research on controlling user interfaces with handheld motion input devices [2, 15, 40] tangibles [4, 22], touch [34], in-air gestures [1, 8, 14], and the whole body [5, 10, 13, 20, 21, 24, 25, 33, 36, 41]. Many technical challenges exist, which have led to considerable research on sensing the six degrees-of-freedom pose of handheld devices [27], the human body [29, 30, 31], or physical objects or actions on surfaces, using computer vision or embedded sensing techniques [39].

To explore the question of the differences between gestural (touchless) control and the use of physical controllers, we can draw on the extensive body of literature on tangible interaction, gestural interaction and spatial input. This has been assimilated in various theoretical frameworks and discussions that lay out much of the conceptual groundwork to inform our understanding [e.g. 3, 9, 10, 11, 12, 16, 17, 18, 37, 38]. A number of key themes emerge.

One such theme is the notion of the *body-thing dialogue* [18]. While both touchless and physical interaction exploit the spatial nature of action, the manipulation of objects and things (as opposed to free movement in space) alter this dialogue. It is not just that objects provide tactile and kinaesthetic feedback [9, 18]. The physical properties of a controller give it weight and inertia that impact the way it is moved – for example, the mass of an object can dampen unwanted or random movements of the hand. Haptic feedback enhances our bodily awareness and the understanding of the object's position in space and relative to our bodies, i.e. proprioception. In addition to this, the physical properties of a particular object constrain and structure action in task appropriate ways – what Hornecker refers to as *embodied facilitation* [11, 12]. In part this comes from the inherent physical qualities of the device, but can also arise through building on associations with past skills suggested by the artefacts, establishing expectations about movement possibilities. Physical objects can provide an important *external representation of state* [e.g. 4] providing a frame of reference for action but also overcoming some of the inherent constraints on hand/body movement (e.g. through ratcheting type interactions [9]).

Of course the way that physical objects constrain and enable certain types of movement and performance is well known to designers and manufacturers of tools and equipment. But there is not always a simple relationship with performance. For example, more sophisticated sports equipment is designed to be more responsive and nuanced in the range of controllable actions. But such responsive equipment can also be extremely unforgiving in non-expert hands. In these circumstances, it is possible to limit the performance and control possibilities to be less flexible and responsive but in a way that allows control by a novice. In this respect we can see an example where a more sophisticated physical artefact might not always lead to improved performance in all circumstances.

To understand interaction using tangible controllers, we cannot simply look to the physical object itself or the dialogue that we have with objects. Of concern in the various tangible computing frameworks is the relationship between the physical manipulation of an object and the corresponding digital representations that they control. Hornecker, for example, articulates this in the concept *expressive representation.* Fishkin [3] describes it in terms of different levels of metaphorical relationships linking the digital to physical, while Koleva et al [17] discuss the degree of coherence between the manipulations of physical objects and the system effects of these actions. In particular they discuss the extent to which these mappings are *literal* or transformation mappings between the physical and digital. Significant in this discussion is that the relationship between a physical controller and digital information that is controlled is treated as a spectrum of interaction.

Another issue that moves beyond performance and control issues. Studies of physical gaming paradigms such as the Wii or Playstation Move have highlighted the phenomenon of *gestural excess* [32], a term that refers to movements and actions beyond what is strictly necessary for successful control. Gestural excess is an important part of engagement in that often this is something that a player does to make the game more interesting for themselves and for others watching--part of the fantasy and performance of play as opposed to control of the system. The extent to which players engage in gestural excess is argued to be dependent upon the sophistication and realism of the controller. For example, Simon et al [32] argue that the more forgiving but less sophisticated control offered in Wii Tennis allows greater room for gestural excess. With more advanced control options, such as in Wii Table Tennis where a nunchuck is used to control more features, increased complexity leaves less room for gestural excess.

Within these arguments, then, we can begin to see a number of factors at play in influencing the role of physical controllers during interaction. Some of these factors work together while others are traded off against each other. What we can subsequently infer from this is that different factors will be more or less apparent using different kinds of physical objects, with different kinds of digital representations, and depending on their coupling. Curiously, though, while there have been a huge number of studies relevant to our concerns here, there appears to be almost no empirical research that specifically compares physical interaction with touchless gestural interfaces. Studies on graspables and tangibles [22, 37] have compared the use of tangible objects to traditional input devices, and more recently to multi-touch surfaces [16]. Results indicate the benefits of tangibles for acquisition and manipulation tasks. However, most of these experiments have been based on 2D tasks, and furthermore have compared tangibles with 2D input devices such as pucks, mice or touch surfaces.

Grandhi et. al. [6] explored pantomimic gestures describing tool-based tasks when participants either pretended to hold or represented an object with a body part.

Terrenghi et al. [35] showed how the lack of 3D input on interactive tabletops provides a barrier when compared with physical manipulation tasks. This limitation of interactive multi-touch surfaces has led researchers to explore how such displays can support 3D gestural input [34]. However, studies that directly compare 3D tabletop interactions with physical manipulation tasks have yet to emerge.

Hinckley et al. [9] explored the use of a prop – a doll's head – for manipulation and navigation tasks in a 3D medical visualisation application. The prop was held in the non-dominant hand and formed a point of reference for the user to define a cutting plane or point within 3D space using a specialised input device held in the dominant hand. Users showed preferences for the physical prop, and the combination of bimanual input and frame of reference outperformed traditional WIMP-based GUI input.

The VR literature has also demonstrated the benefits of physical controllers including 6 degree of freedom styluses, gloves and other body worn sensors [2, 28, 33] for pointing and manipulation tasks. More recently, researchers have also studied the benefits of interacting with onscreen content using indirect pointing devices including mobile phones [34] or other motion-based input devices [2]. The closest work to ours is Lok et. al.'s, comparing interaction with real or virtual objects and avatar fidelity in a VR environment [19]. To our knowledge however, none of these systems has directly compared physical control with touchless gestural interactions.

## APPROACH

In this study, we aimed to examine how the presence or absence of a physical controller influences video game play in terms of performance outcomes, physical movement characteristics and overall game experience. Further, we wanted to understand whether the influence of a controller was different when using a realistic and dedicated physical controller versus a more generic controller. This was partly motivated by the fact that some games platforms, like the Nintendo Wii, make use of fairly generic physical controllers for a range of games, yet one can buy attachments (like an extension shaped like a tennis racket) that give them some of the affordances of the real world object it is meant to mimic. Further, as we discussed in the related work section, there are various factors at play that potentially favour more generic low fidelity controllers (e.g. more forgiving and less complicated), while other factors may favour more specific "high fidelity" controllers (e.g. more potential for nuanced control, or customization for a particular game). Comparing different types of controller in this way will help us more deeply understand the role of physicality and its affordances in this gaming scenario.

With these issues in mind, we wanted to use a game that: (a) was based on a real world physical game; (b) used an obvious physical tool that has co-evolved with the game; (c) could be sensibly played with a generic controller; and (d) could be sensibly played using only gestures that mimic their real world counterparts. We chose Table Tennis for these reasons, and it also has well-established equivalents on the major gaming consoles.

### Dimensions: Prop Fidelity and Interaction Fidelity

In this study, we compare across two key dimensions. The first, which we will call *Prop Fidelity* refers to the means of controlling input, and varies, as the name suggests, in its fidelity to the real game. We compare: the use of a real table tennis paddle (Paddle condition), a generic stick as controller (Stick condition) and a tracked hand as controller (ie. no "prop" or controller—Hand condition).

The second dimension we explore addresses the question of the coupling between input mechanism and effects in the digital world: that is, how sensed movements of the controlling input are translated into the digital behaviours of the game. We will call this aspect *Interaction Fidelit*y. Different commercial gaming systems already vary in the degree to which they capture and then use the actions of the prop or controller. In this study, we vary Interaction Fidelity according to whether velocity, position and angle of input are sensed and used as game control parameters. The condition with the lowest fidelity captures only the velocity of the input (Velocity condition). A second condition captures both velocity and position of the input (Position condition), and the third condition captures velocity, position and angle of input (Full condition).

### Research Questions and Hypotheses

Within the context of these dimensions and simulated table tennis game, we sought to answer four main research questions. The first two questions concern *Prop Fidelity*:

Q1. Does presence versus absence of a physical prop affect game play in terms of performance outcomes, how it is played or enjoyment of the game?
Q2. Is a more realistic prop (Paddle) different from a generic prop (Stick) in terms of performance, game strategy or enjoyment?

The third question concerns the relationship between *Prop Fidelity* and *Interaction Fidelity:*

Q3. Do the effects of Prop Fidelity depend on the different levels of Interaction Fidelity? In other words, does the effect of input control vary depending on how sensitive the game is to the input?

And finally, we are interested in the extent to which these variables change over time:

Q4. Does game play change with practice? Here we are specifically interested in performance in the game.

As we have seen in our discussion of the literature on tangible computing, there are a number of factors that may influence expected outcomes with a physical prop versus control without a prop. We would argue that both the Paddle and Stick conditions provide some form of embodied constraints that facilitate a body-thing dialogue, providing the player with feedback as to orientation and position of the striking surface. We might expect this feedback to be better when using the more specialized prop (Paddle) since it provides more constraints in interaction, such as greater visibility of orientation of the striking surface. All of this suggests that using a physical object—and in particular a high fidelity one—might lead to better game performance, the need for less practice, or perhaps better enjoyment of the game, compared to no controller.

But this is likely too simplistic. As well as impacting the control characteristics of the device, the literature would suggest that the nature of input control might impact the perceived coupling between control and game behaviour. For example, when using the higher fidelity prop, namely the Paddle, this might create player expectations that their actions will be closely reflected in the onscreen representation of the table tennis paddle and in the way actions are interpreted by the game. Following on from this, we might expect there to be frustrations and dissatisfaction when these do not match. This would predict that different prop conditions are evaluated differently, depending on interaction fidelity.

In a further argument here, we might expect issues of gestural excess to come into play in relation to people's prop preferences. The higher fidelity prop may facilitate people's imagination and engagement to an extent, but the potential for more nuanced control might also inhibit the ability to engage in gestural excess. The lower fidelity prop and interaction conditions may allow greater opportunity for gestural excess in ways that could influence preference under particular conditions.

It is clear that there are a number of conflicting factors at play that might impact the outcome of the study. Thus, it is difficult to make predictions, and we must instead treat the research questions Q1 through Q3 as exploratory.

With Q4, however, we expected performance in all game fidelities to improve over time as players adapt to the game. Having said that, we expected a higher degree of improvement as the game became more difficult (the Position and Full games) as there is more to learn, and thus better adaptive strategies can evolve with experience.

## METHOD

### Game Design

We created a Table Tennis simulation game specifically for the experiment. The goal in the design of this game was to have a game-like experience that would be repeatable and predictable enough to generate useful results. We also designed it so we could vary the Interaction Fidelity.

**Figure 1. A screenshot of the game. Note the table tennis table, the paddle and the incoming ball. Distortion is due to camera angle. No avatar is used to represent the player.**

*Table Tennis Game*

The player is presented a view of one side of a Table Tennis table (see Figure 1). We render a representation of the players' paddle that responds to their control, but not an avatar or any other kind of representation of the player or opponent. While we felt it important to give visual feedback on the action of the hand or physical prop, we felt an avatar would only potentially confound the player's interpretation of the visual feedback. The game consisted of the repeated launching of a table tennis ball from the *opponent's* side of the table with random variation in the left-to-right start point, left-to-right end point, and "smash factor". Smash factor refers to whether the arriving shot was more smash-like or lob-like. Smash-like shots start higher, and have a greater downwards velocity, while lob-like shots start lower, and have a greater upwards velocity. The parameters of the ball launching were tuned so that all shots would hit the player's side of the table at least once. Not all shots were of equal difficulty, e.g. a cross-court smash was very hard to return successfully. A successful return meant hitting the ball and returning it to hit the opponent's side of the table (a more complete description of scoring is described later).

*Input control (Prop Fidelity)*

Three different types of input controllers were devised. For each of these we tracked the movement of the arm by combining arm and wrist position data from a Kinect sensor. We also tracked more precise hand position and orientation with a separate UM6 IMU sensor attached to the hand or prop and connected to a computer via USB cable to a USB wireless connection and battery pack in the participant's pocket. Figure 2 shows the Hand, Stick and Paddle conditions with the position of the attached IMU.

*System Behaviour (Interaction Fidelity)*

We created three different versions of the game, with increasing levels of Interaction Fidelity, which we call the *Velocity*, *Position* and *Full* conditions.

**Figure 2. IMU placement in each of the Prop Fidelity conditions: on the back of the palm for the hand, and on the tip of the prop for both the stick and the paddle.**

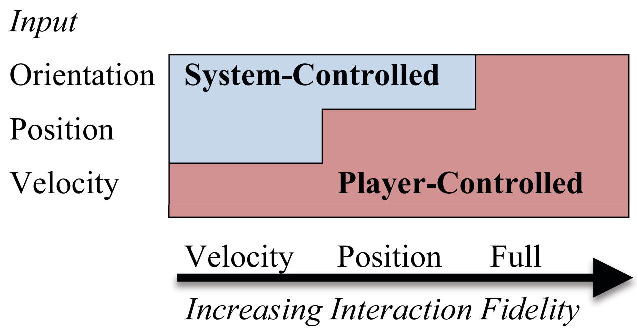


**Figure 3. The balance of System versus Player control in each condition.**

As Figure 3 shows, as game fidelity increases, the player must take control of more aspects of the interaction (i.e., the system relinquishes more control to the player). A detailed description of each level of Interaction Fidelity follows:

*1. Velocity* - In this condition, the player must simply swing the control input in the correct direction for the return at the correct time; both position and angle of the input are controlled by the system to be optimal. The return velocity of the ball is calculated based on the velocity of the paddle and the ball at the moment of impact. It is critical for the player to not just hit the ball back, but also to impart suitable sideways force to ensure it hits the opponent's side of the table. For example, when the ball comes as a cross-court shot left-to-right, the player must hit the ball back and towards the left. This fidelity is similar to the degree of fidelity found in Wii Sports Table Tennis [26].

2. *Position* - In this condition, the player must swing the control input or hand in the right direction, as outlined above, but the control input must also be in the right 3-dimensional position to hit the ball at the right time. This is similar to Kinect Table Tennis. The return velocity of the ball is calculated the same as in the Velocity condition.

3. *Full* - In this condition, the velocity, position and orientation (from the IMU) of the control input are used. The control input must be in the right position and have the right velocity as before, but the angle of the device must also be correct when it strikes the ball. If the control input is angled so that the paddle is edge-on (as indicated by the representation of the virtual paddle on screen), it is unlikely the ball will be hit at all, much less so that it returns to the other side of the table successfully.

The Velocity condition is obviously the easiest of the game conditions; all the player has to do is respond by swinging at the correct time and in the correct direction, as the paddle is moved to the correct position to intercept the ball. For the Position condition, the orientation of the paddle for the sake of visual feedback is inferred from the player's shoulder and elbow position. In both the Velocity and Position conditions, the orientation of the paddle is only simulated for the sake of visual feedback; in the physics simulation, the paddle is represented as a sphere. In the Full condition, however, the paddle is represented as a rectangular prism.

### Subjects

We recruited eighteen subjects by word-of-mouth, email and posters. All were right-handed and had not played Kinect before. Subjects were chosen to be non-technical as we wanted them to intuit, rather than deduce, how the game worked. Since we sought only non-technical subjects, we went beyond the typical "undergraduate computer science students" group. Our subjects' ages ranged from 16 to 77, with a mean of 36 and a standard deviation of 17.

### Design

The design was a 3x3 mixed design. Prop Fidelity was a within-subjects independent variable: all 18 subjects used the Hand, Stick and Paddle to control the game. However, Interaction Fidelity was a between-subject variable, meaning that 3 different groups of 6 subjects played the Velocity, Position and Full games. We did not want subjects to experience more than one type of game (as defined by its Interaction Fidelity), as we wanted subjects to determine the best way to play the game they were given without interference from prior understanding of game play.

Each subject was randomly assigned to one of the 3 Interaction Fidelity conditions. Within this game, the ordering of Hand, Stick or Paddle was determined using a fully counterbalanced design.

### Procedure

Each subject was introduced to the game and told to stand from 1.5 to 3 metres away from the screen. He or she was then given 3 minutes to practice with each of the 3 different prop conditions (Hand, Stick and Paddle). During this phase, the researcher would press a button to launch a new ball whenever a subject felt ready. In this phase subjects were told not to worry about doing well in the game, but rather to experiment with the best way to play.

Once the familiarization and practice session was completed, subjects then entered the "competitive" phase, where they were instructed to do as well as they could in the game. In this phase there were two blocks of 40 trials for each Prop condition. A trial consisted of the virtual ball being launched and the subject's response. A new ball would be launched every 4 seconds. In total, each subject played 240 trials (80 per prop).

At the end of the whole session, subjects were asked for their preference of prop and to justify their choices.

### Measures

We measured a number of dependent variables that related to game performance outcomes, physical characteristics of player action and player enjoyment.

For game performance, players' returns were categorized as either a:

1. *Win* - where the player returns the ball successfully back onto the opponent's side of the table;
2. *Missed Return* - where the player hits the ball but it misses the opponent's side of the table;
3. *Miss* – where the player misses the ball completely.

To gauge player enjoyment, we collected *preference rankings* for each of the Prop Fidelities. Accompanying comments were audio-recorded and transcribed.

## RESULTS

### Game performance

The mean percentage scores for *Wins*, *Missed Returns* and *Misses* are shown in Figures 4, 5, and 6 respectively. For each of these scores we conducted a 3x3 mixed ANOVA.

*Wins*

The type of prop used (Hand, Stick or Paddle) was found to make little difference in terms of percentage of Wins in the game. While the ANOVA revealed a significant main effect of *Prop Fidelity* ($F(2, 14)=3.88$, $p=0.046$), further investigation with pairwise t-tests revealed no significant differences between Hand, Stick and Paddle at any level of Interaction Fidelity.

As expected, the different kinds of games, as determined by increasing interaction fidelity, did mean that it was harder to win returns as the game became more complex. This was confirmed by a significant main effect of *Interaction Fidelity* ($F(2, 15)= 26.98$, $p<0.001$). Here, post hoc Tukey tests revealed the percentage of Wins in the Full condition was significantly lower than both the Position condition ($p<0.05$) and the Velocity condition ($p<0.001$). The Position condition was also significantly lower than the Velocity condition ($p<0.01$).

No interaction between the two variables was found ($F(4, 30)=0.45$, $p=0.77$) meaning that the effect of Interaction Fidelity did not vary across different props.

*Missed Returns*

Missed Returns did not show the same performance difference across the different games. For Missed Returns, there was no significant effect of *Interaction Fidelity* ($F(2, 15)=0.15$, $p=0.86$), nor was there a main effect of *Prop Fidelity* ($F(2, 14)=1.48$, $p=0.26$) or significant interaction ($F(4, 30)=0.68$, $p=0.61$).

*Misses*

For Misses, there was a significant main effect of *Interaction Fidelity* ($F(2, 15)=20.32$, $p<0.001$) but no main effect of *Prop Fidelity* ($F(2, 14)=1.34$, $p=0.29$) and no significant interaction ($F(4, 30)=0.56$, $p=0.69$).

For Interaction Fidelity, post hoc Tukey tests showed that the percentage of Misses in the Velocity condition was significantly lower than the Full ($p<0.001$) and Position conditions ($p<0.01$). No significant difference was found between Position and Velocity ($p=0.2$).

*Practice effects: 1st half trials vs 2nd half trials*

To look for practice effects, we compared performance in the first half of the trials with the last half. *Trial Block* was analysed as an additional within-subjects factor.

For *Wins,* there was no main effect of *Trial Block* ($F(1, 15)=3.59$, $p=0.08$). There was no interaction between *trial block* and the two primary factors.

For *Missed Returns* there was no main effect of *Trial Block* ($F(1, 15)=1.65$, $p=0.22$) and no interaction between *Trial Block* and the two primary factors.

For *Misses* there was a main effect of *Trial Block* ($F(1, 15)=8.75$, $p=0.01$). There was also a significant interaction between *Trial Block* and *Interaction Fidelity* ($F(2, 15)=5.62$, $p=0.015$) but no interaction between *Trial Block* and *Prop Fidelity*. Post hoc tests (Bonferroni corrected) revealed that these practice effects were due to a significant reduction in Misses (from 42% to 23%) in the Position condition ($p < 0.053$).

**Preference and Player Expectations**

Using a Borda count method, a score was assigned according to the subjects' ranking, with 3 points for 1st place (or most preferred), 2 points for 2nd place and 1 point for 3rd place (least preferred). These scores were then added together to give an overall preference score for each Prop condition, with a higher score indicating a higher preference. Total preference scores are shown in Figure 7.

We used pairwise t-tests to understand where the real differences lay. For Prop Fidelity, we found there to be a significant preference for the Paddle over both the Stick ($p<0.002$) and Hand ($p<0.03$) but only for subjects in the Full fidelity condition. For Interaction Fidelity we found a preference for Full fidelity over Position when using the Paddle ($p<0.01$). When using the Hand, the Position condition was preferred to the Full condition ($p=0.034$). None of the other comparisons were significantly different.

Such a pattern of data represents an intriguing result for our understanding of prop-based vs propless interaction. What is of note here is that there is not a straightforward pattern of preferences for the different kinds of control but rather that preferences depend in part on the relationship between the type of prop and the responsiveness of the game. That is, there is a strong preference for the more realistic prop (Paddle) but only when this is accompanied by a more nuanced set of on-screen interaction behaviours (Full condition). When using the Hand, a less responsive game (Position) is preferred to one that is more responsive (Full).

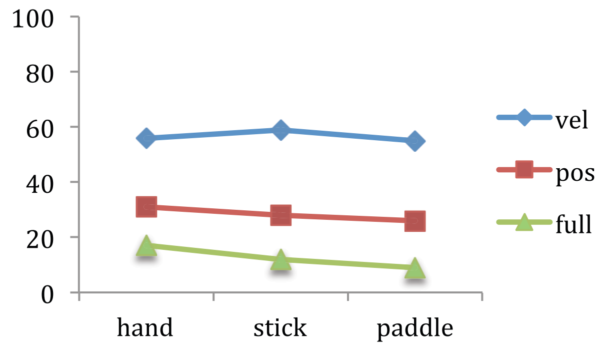


**Figure 4. Percentage of *Wins***

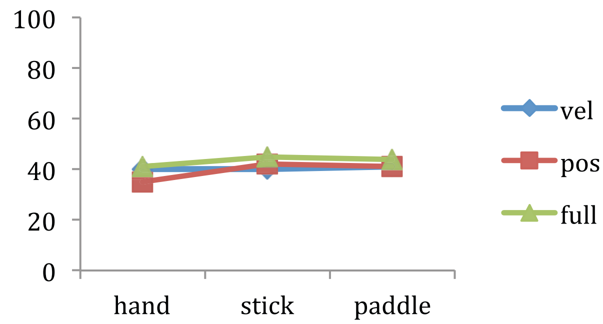


**Figure 5. Percentage of *Missed Returns***

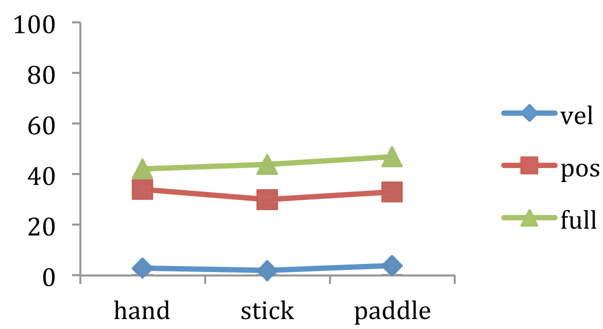


**Figure 6. Percentage of *Misses***

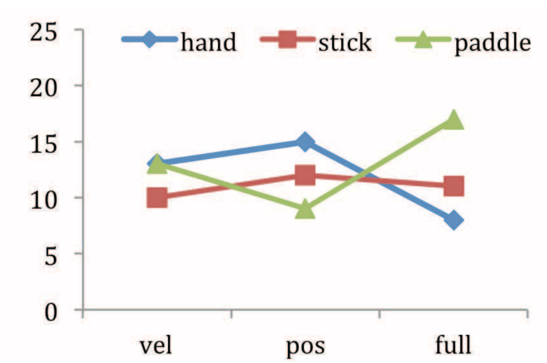


**Figure 7. Borda Count Preference scores for Prop Fidelity under different conditions of Interaction Fidelity.**

To help us understand this further we turn to our subjects' justifications for their preferences. Subjects' explanations oriented to a number of different factors that relate, in part, to issues in our earlier discussions of the tangible computing literature. In particular, subjects justified their preferences in terms of physical sensations, social perceptions, control and, most interestingly, in terms of the expected and actual coupling between type of input control and the degree to which the game was sensitive to that control. Let us consider these further.

From subjects' comments, it was clear that the physical sensation of holding something in the hand was an important factor in their preference. In the Hand condition, people missed the physical sensation of weight and sometimes felt a little silly not having something to hold:

> *"That was okay; I prefer to have something to hold on to. It feels a bit stupid. I feel stupid just moving my hand around."* [P6, Velocity condition]

The Paddle was also described as feeling more natural and realistic, which for some contributed to the perception of it being easier to control and to achieve better performance:

> *"It's definitely easier with the racket. Oh I just think its cause it looks more realistic and how it feels, and what you're used to it feeling like...and you know which space [on the racket] you want to hit it with".* [P3, Position condition]

> *["Can you tell me why you didn't like it with just your hand?"] "I think it's because I'm still thinking about it as an actual game rather than a computer game, so I'm thinking I've got to have the bat in my hand."* [P13, Full condition]

The following Full condition participant was excited to play the game with the Stick after starting with the Hand:

> *"Oh that's much better, that's really much better...more in control. I feel I know more where it's at."* [P12, Full condition]

As we see in the above quotes, these expectations derive from both the inherent characteristics of the prop but also from subjects' prior experience with table tennis, tying in with some of the arguments made in our discussions of the tangible computing literature.

An important characteristic, for example, was the presence of a surface, which, for some subjects, led to their feeling they could better position their movements correctly for a hit. Interestingly, we found seven subjects used a tense, paddle-shaped open palm in the Hand condition, perhaps to compensate for the lack of this affordance. The lack of a clear surface with which to hit the ball may also have contributed to ranking the Stick lower:

> *"You feel like you have a surface you can hit [makes paddle shape with hand]. Of course, its virtual, but you feel like you can hit it. With only the stick you have a small surface...it's much more difficult than playing with something that has a bigger surface.* [P10, Velocity condition]

Such explanations relate primarily to people's relationship to the control mechanisms themselves. This, though, is only part of the story and does not fully account for the pattern of preference data seen in Figure 7. Rather, what appears to be more significant in explaining people's preferences lies in the relationship between the prop and the resulting on-screen behaviours. More specifically, preferences appear to be related to the extent that expectations and opportunities for expression and control are matched with the capabilities of the system.

This is evident especially with respect to subjects' comments about the Paddle. As we noted above, it appears that the connections with real table tennis lead to greater expectations about control and performance possibilities. The specialized shape of the Paddle too is seen to allow greater opportunity for expression and control--something that subjects explored as they played the game. But the fact that the Paddle was only preferred when used in the Full condition suggests that a mismatch between the ability to be expressive and the responsiveness of the game might create problems. Evidence for this is found in frustrations voiced by some of the subjects in the low fidelity games:

> *"I [hold fingers on the back of the paddle blade] to get more control. However, it seems that any control that I get doesn't reflect on the screen.".* [P5, Position condition]

> *"With the racket I kept trying to twist it so it was the right way around, but with the handle [Stick] thing, I just left it, it was fine."* [P2, Position condition]

The onscreen behaviours are made up of both the behaviours of the returned ball and the onscreen representation of the table tennis paddle. When using a real paddle as control, participants expected a stronger mapping between what they were trying to do with the physical paddle and what was seen with the onscreen paddle. The flipside of this was that using just the hand in some sense allowed subjects the freedom to learn new associations between control and system response, and meant they were less tied to notions of the physical world, or to past experience:

> *"I do like the whole arm, working with nothing [Hand condition]. Because when you're holding something, you're basically trying to match the picture with what you're holding and it's splitting your attention".* [P16, Position condition]

> *"I mean it's a little like Guitar Hero, it's not learning to play guitar, it's learning to push different buttons…I feel like I was tapping in to table tennis instincts, instead of trying to do what was working on the screen…using the hand was pretty comfortable and stuff, you feel like*

*you're getting the same thing you would as with a paddle perhaps and maybe you get a sense that you're playing a game rather than just playing table tennis on a screen.*" [P5, Position condition]

All of this suggests that game experience is as difficult to assess as it is to design, but that the relationship between type of control and game response is key to that experience.

## DISCUSSION

Returning to our original research questions, the results of this study were surprising in a number of ways. By objective measures of performance, we found that whether or not a player held a physical controller had no impact on the outcome of the game. The fidelity of the physical prop, too, had no discernable effect on performance as measured by number of trials won or lost. This result is somewhat unexpected given the predicted benefits of using a physical object for control expressed in the tangible computing literature. Perhaps it reflects the fact that players are simply good at adapting their playing strategies to the demands of a given game. Certainly when we look at practice effects (Q4 in our research questions), we found no clear improvements over time (with the exception of fewer Misses over time in the Position condition—a result which is difficult to explain). While we expected the more difficult game (the Full condition) to exhibit more significant practice effects, this was not the case. Therefore it might be that subjects were able to learn effective strategies quite quickly, perhaps during their brief practice sessions, for the kind of game that they had been assigned to.

But it is important that we exercise a certain amount of caution in our interpretation of these null effects. It may be that the performance measures we have chosen were not sensitive enough to demonstrate any potential performance advantages of different types of props as controllers. This might be the case despite the fact that these same measures of performance did highlight differences in the difficulty of the game across the different conditions we created. It may also be that the potential performance benefits of props of increasing fidelity only arise over the much longer term and with expertise, something that would be consistent with current practices for sports equipment design. This would be worthy of some further investigation. Finally while we have manipulated game characteristics in this study, what was sensed and modeled may not have been sufficiently detailed to allow any expression of performance benefits.

The fact that the effects of our manipulations may be difficult to capture with coarse-grained measures is given some credence when we move on to consider other aspects of our experimental data. Indeed, it is when we turn to the preference data, both quantitative and qualitative, that we begin to observe some more complex effects that address our key questions. Notable here was the finding that in the most responsive condition (Full), the highest fidelity prop, namely the Paddle, was preferred to the generic prop which in turn was preferred to using the hand alone. Likewise, when using the hand as controller, subjects tended to prefer a less responsive game to a more responsive one. What this demonstrates is the important relationship that we have alluded to throughout: that understanding the role of physicality in controlling input must take account of the kind of system being controlled.

Further details of this dependency were revealed when we asked subjects about their preferences. These comments illustrated how subjects took into account a number of sometimes competing factors when asked to rank their preference for type of controller (e.g. feedback from holding something, social comfort of holding something, perceptions of naturalness and opportunities for nuanced control). One of the most striking findings was that players were most unhappy when mismatches occurred between the expected behaviour of a controller and the extent to which those expectations are met by system behaviour. With physical controllers, this is a function of the affordances and possibilities offered up by the object itself. A high fidelity object offers up richer control possibilities. These possibilities not only demand more user attention but raise expectations about the parameters of control. Ironically perhaps, simulating the use of a physical controller through gesture alone was found to free up a player's interpretation of how that mechanism might really work, and players were therefore more accepting of touchless control since they had fewer a priori expectations.

## CONCLUSION

These results of course provide no definite answers on the role of physical controllers in such interactive situations but should lead us as researchers and designers to focus on certain important issues when we think about the role of input and its impact on user experience. For example, it suggests that while gesture-based control is often said to be "natural", in fact, it may be quite the opposite, resulting in users being more open to interact in ways that are not tied to the well understood physical realm. As another example, when we choose or design an input technique, we need to consider the important relationship between the input and the system it is controlling not just in terms of interface design, but also in terms of the expectations that different forms of input create for users. These issues will be as important in other domains as they are in gaming.

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