Bendtroller: An Exploration of In-Game Action Mappings with a Deformable Game Controller

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ABSTRACT
We explore controller input mappings for games using a deformable prototype that combines deformation gestures with standard button input. In study one, we tested discrete gestures using three simple games. We categorized the control schemes as binary (button only), action, and navigation, the latter two named based on the game mechanics mapped to the gestures. We found that the binary scheme performed the best, but gesture-based control schemes are stimulating and appealing. Results also suggest that the deformation gestures are best mapped to simple and natural tasks. In study two, we tested continuous gestures in a 3D racing game using the same control scheme categorization. Results were mostly consistent with study one but showed an improvement in performance and preference for the action control scheme.

Author Keywords
Deformable User Interactions; Games; Controller; Novel Input; Bend; Twist

ACM Classification Keywords
H.5.2. User Interfaces – *Interaction Styles*

INTRODUCTION
While new methods of input in games are constantly developed, only a few researchers have looked at deformation gestures in games [5,15,44], focusing solely on bending and twisting without any other form of input. They designed prototypes to allow users to play games on the device themselves [15,44]. As many standard game controllers are separated from the display, we imagine that users might appreciate performing deformation gestures on such stand-alone controllers instead.

We further propose that combining bending and twisting with the standard forms of input, such as buttons and directional pads, could make the experience engaging and more stimulating to players who are used to playing games with standard controllers. Implementing gestures parallel to button input provides users with more input options that are easily accessible without lifting their fingers from buttons. We look into some common game mechanics and evaluate which types of actions will map best to buttons and gestures.

CHI 2017, May 06–11, 2017, Denver, CO, USA

DOI: http://dx.doi.org/10.1145/3025453.3025463

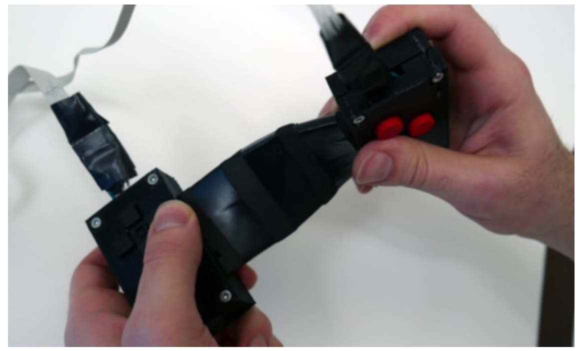

Figure 1. Twist input using our bendable game controller.

To explore these possible mappings, we designed a new controller using six buttons and four deformation gestures (Figure 1). We developed three control schemes, the first using only button input, the other two combining button and deformation gestures, each based on generic in-game mechanics: action and navigation. We first tested three unique, but simple, arcade games with these three schemes. Our second study used continuous gestures in a 3D racing game, as opposed to discrete gestures as used in the first study. Finally, we suggest ways of mapping gestures to in-game mechanics. The main contributions of this paper are (1) proposing the combination of deformation input with standard button input; (2) developing and implementing a stand-alone controller that uses of deformation gestures and button input; and (3) providing empirical evidence that deformation gestures have a place in games, through two studies, with four games and three control schemes.

RELATED WORK
We leveraged prior work exploring deformation interactions from being generic inputs to specific inputs for games, and discuss novel and natural game interactions to create innovative video game controllers.

Deformation Interactions
Deformation is a broad category of interaction that includes bends, twists, wave-forms, and scrunches in the device [1,9]. Researchers have used deformation interaction to perform tasks such as to navigate a smartphone [9,11,32], to create music [39], secure passwords [16], and control a TV as a

remote [14]. Herkenrath et al. [5], with TWEND, were the firsts to look at both bend and twists as interaction techniques for deformable devices, but only implemented bends. With the Kinetic Device, Kildal et al. [9] implemented and evaluated both in a mobile context, noting their worth, but that deformable gestures were not going to replace other methods of input such as touch or buttons, and instead focused on determining the best use for bend and twist gestures. They determined that (1) bend and twist are performed better with two hands, (2) up and down when referring to twist is intuitively different depending on the user's handedness, (3) continuous gestures are better for tasks handling the magnitude of a parameter, and (4) discrete gestures are better used to trigger discrete actions.

Other researchers have looked into combining bend with touch in the front of the device [2,8,28–30,37], in the back [8], or deformation and 3D location tracking [10,36]. For the former, researchers found that these hybrid techniques feel more intuitive than touch on its own, and they demonstrate potential once users are familiar with how the interaction works [8]. Yet, we found no prior work combining gestures with button input for any application, including games.

Deformation Interactions with Games

Most research regarding deformation gestures tends to focus on performance-driven applications such as map navigation [32] or document navigation [42]. Researchers have not thoroughly explored entertainment-driven applications with deformation interaction.

Cobra [44] is an all-in-one deformable handheld gaming system that consists of a flexible board, and a portable shoulder bag supporting a pico-projector. The authors claimed that gestures were dependent on the game being tested as different actions in-game required different methods of input, but did not formally test Cobra. In contrast, Lo and Girouard [15] evaluated deformation input with existing games with their bendable prototype, Bendy. They broke down games into basic tasks and asked users to map bend gestures to them. Users, for the most part, agreed on the gesture mappings. They found that participants had positive reactions to playing games using gesture input, but the inconsistencies in how users held the device led to some issues where participants needed to reposition their hands.

Nguyen et al. created two deformable prototypes, BendID [20] and SOFTii [19] using conductive foam and an array of pressure sensors. However, the authors only informally tested them with 3D games, and did not present any study data. Similarly, Rendl et al. [29] created a transparent flexible film for applications requiring precision with multiple degrees of freedom. They suggest a variety of game mechanics to map to both discrete and continuous gestures already built into FlexSense. They did not, however, test FlexSense with games.

Other researchers integrate games in their studies without making it their focus: one of the tasks in Daliri and Girouard [3] was a simple grid navigation game, while Ahmaniemi et al. [1] asked participants what applications bends would work best with, and reported games where the player controls speed, follows a track, or drops bombs, such as Angry Birds [31] and Tetris [25]. We tested our prototype with simple games based on this body of research. To our knowledge, no prior work has combined buttons with gesture input and performed any formal studies using games.

Novel and Natural Game Interaction

Many researchers such as Villar et al. [41], Ionescu et al. [6], and Smith [35] have tackled novel game interaction, creating adaptable controllers, developing games for controller hybrids, and creating controllers that resemble the main character of the game. This close resemblance to the real world is often said to make interactions more natural. Wigdor and Wixon [43] defined natural as a descriptor "we use to describe a property that is external to the product itself". Skalski et al. [34] separated natural mapping into four distinct categories: directional, kinetic, incomplete tangible, and realistic tangible natural mapping. They determined that natural mapping of a video game controller led to higher spatial awareness and enjoyment when playing games. Naturalness is commonly associated to a positive user experience [20]. Naturally mapped devices offer greater potential for intuitive use, linked to increased experiences for users with less gaming experience or who are familiar with the real-world activity mapped [17]. However, due to their high familiarity with traditional interfaces, expert gamers do not typically experience such an increase in performance with naturally mapped controls.

Some novel controllers attempt to combine traditional input in new ways or with sensors that are new and unique. Ionescu et al. [6] created a system that uses a physical game controller alongside gestures captured by a 3D camera. Users found the interactions natural and immersive as the two types of input provided them with the familiarity of the standard controller combined with the freedom of the hand-movement gestures. Other unique uses for sensors and technology with games include the use of a Rubik's snake to control a samurai sword's shape [7], and a cylindrical motion detecting wand made with two flexible OLED screens [26].

Namco's neGcon controller [45] is the only controller with similar functionality to our intended prototype. Built for a game called Ridge Racer [18], it consists of two rigid halves connected by a dowel that could be twisted relative to each other to turn the car. This 1995 controller only worked with this game, and did not allow for bends.

Our prototype is novel as it combines traditional video game input methods with bend sensors and deformation gestures. We wanted to study the physical gestures alongside buttons, another physical method of input. We attempted to map our control schemes as naturally as possible to maximize fun and easy to use based on this body of work.

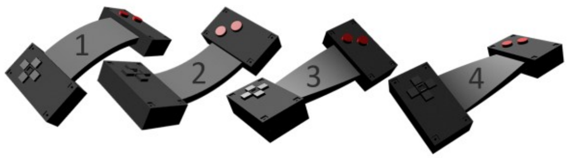

Figure 2. Controller Gestures: (1) Bend Up (2) Bend Down (3) Twist Left (4) Twist Right.

PROTOTYPE

We sought to create a game controller to test flexible input combined with binary input for simple video games. We based our prototype on the Nintendo Entertainment System (NES) game pad, the original pad used to play some of the games testing with our prototype. We added a flexible bridge in the middle of the game pad, between the directional buttons and the action buttons, and used the prototype to test PC ports of NES games as well as a PC-based racing game.

Interaction Language

Our controller has ten inputs: 4 deformation gestures and 6 buttons. While prior work discussed over thirty deformation gestures [13], we selected a smaller number so as to not overwhelm our participants. The four gestures are as follows: (1) bend up (2) bend down (3) twist left, and (4) twist right (Figure 2). We define bend up as the bridge arching upwards, and the back of the panels being bent towards each other, similar to Kildal et al. [9]. We define twist left as bringing the top of the left panel away from the user and the top of the right panel towards the user, and twist right as the opposite. Twists were defined that way to simulate how people activate automobile turn signals: rotating your left hand away from your body (flick down) is used to signal left whereas rotating your left hand towards your body (flick up) is used to signal right. Our controller has six buttons, four on the left panel (up, down, left, and right) and two on the right panel (action 1, on the left; action 2, on the right).

Hardware

We built a handheld game controller with rigid side panels connected by a flexible bridge that can bend and twist (Figure 3). We designed the controller to be held with both hands (162 * 75 * 21 mm). We modified the original NES game pad design and dimensions slightly to implement the flexible bridge, and modified the button positions after testing it with multiple hand sizes. We 3D printed the side panels (40 * 75 * 21 mm each) using polylactic acid (PLA) filament which produces a rigid plastic end-product. The flexible bridge (82 * 43 * 6 mm), was made of two 2-inch FlexPoint bend sensors [4] fastened on the rear side of a foam board cutout.

After testing many materials such as plastic, foam and rubber, we selected foam as it was malleable enough to bend and twist in all directions and could retain its shape fairly well, even after excessive use. The internal bend sensors overlap diagonally in the centre of the flexible bridge to accurately distinguish between our four gesture-based input methods. We placed the sensors so they were able to slide.

Figure 3. Front and back view of the prototype.

Wires emerge from the top of either panel, connecting to an external Arduino Leonardo, which in turn connected a MacBook Pro laptop computer via USB. The Arduino has one additional button used to calibrate the controller which we will refer to as the calibration button.

Software

Using Arduino 1.6.7, we analyzed the raw bend sensor data to determine the gesture performed. We implemented a calibration system that set the rest (flat) positions of the bend sensors based on their average input values over a period of ten frames at 66.67 Hz. To minimize accidental input, we used a sensitivity threshold of the value of 80 (sensor values ranging from 0–1024), only above which, from the rest position, a bent gesture will be triggered.

Bend up (or down) was triggered when both sensors read higher (or lower). Twist left (or right) was triggered when the left (or right) sensor read higher (or lower) and the right (or left) sensors read below its rest position. In study one, gestures, like buttons, were triggered discretely, i.e. a gesture cannot be triggered again until the user restored the controller to its rest position. In the second study, gestures were triggered continuously, without the need to go back to their rest position.

In study 1, we used the Arduino virtual keyboard library to simulate key presses with button presses and gesture input to play the game using our prototype. In study 2, participants played a game developed in Unity3D, which read the serial port and parsed the sensor data for use within its scripts. In both studies, the buttons and gestures could be triggered simultaneously.

STUDY 1: BEND INPUT METHODS FOR SIMPLE GAMES

Our primary research goal was to determine if flexible input, combined with binary input, is a satisfying method of input when playing simple video games using our custom-built controller. Our secondary research goal was to determine the differences between various bend control mappings in specific games, which we will assess by looking performance and subjective ratings.

We created two types of mapping between bend gestures and game actions: one that focuses solely on common in-game actions (such as jumping or causing an explosion), and the other on in-game navigation (moving objects in space). This allowed us to generalize the control schemes to give the participants a better immediate idea of what the gestures would be mapped to in each situation.

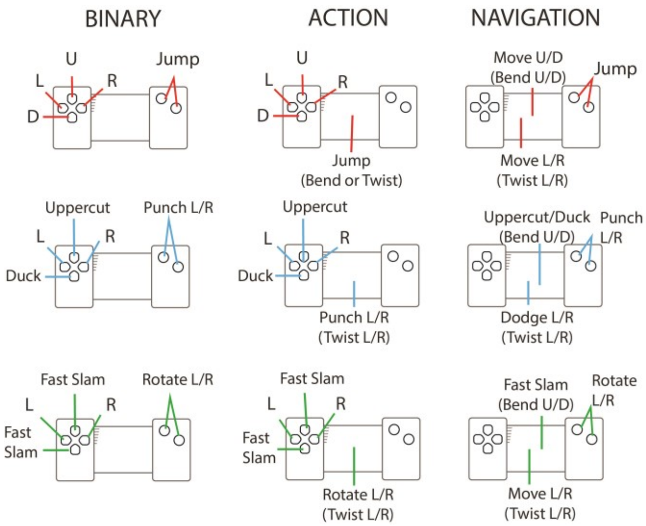

Figure 4. Control Schemes for study one for Donkey Kong (top row), Punch Out (middle), and Tetris (bottom). L=Left, R=Right, U=Up and D=Down.

Games

We selected three games for our study. Donkey Kong [23] is an arcade platformer in which the player avoids obstacles falling down towards him/her (barrels) while climbing up. The player can jump, move left and right, and climb ladders. Punch-Out [27] is an arcade boxing game. The player must punch left, punch right and perform uppercuts. They can also protect their face, duck, dodge left, and dodge right as defensive maneuvers. Tetris [25] is a tile-matching puzzle game. The pieces can be moved and rotated as they fall towards the bottom of the screen. We used OpenEmu [24] to run original NES versions of our games, and users played the games from the first level.

The games were selected on three criteria: our ability to isolate the action and the navigation within the games (for our second goal), the ability to measure performance objectively, and a diversity within gameplay. The latter ensured that the experience with each game was mutually exclusive (learnability did not transfer from one game to another during the study).

Control Schemes

We tested three classifications of control schemes (Figure 4). The first control scheme is only button input, and is representative of the game's original control scheme. We call this scheme **binary** as it only makes use of button input. We include it to provide baseline scores to which we can compare the scores that the gesture schemes receive.

The other two schemes combine binary and gesture input methods. We differentiated these control schemes by the type of in-game mechanic controlled by the gesture input: to control **action** input or to control **navigation** input. We mapped all other necessary inputs to binary controls, and disabled inputs with no direct action in-game.

Methods

We tested the three control schemes with the three games for a total of nine conditions per participant. Each condition consisted of two trials that lasted two minutes each. Each session took about 80 minutes. We presented the games in a counterbalanced order. Within each game, participants played the three control schemes also in a counterbalanced order. We explained each game to participants, and offered them the opportunity to play the game using the keyboard before the trials began, minimizing the measurement of the learnability of the game itself.

We measured performance through raw score for each game. The scores are taken from the games themselves, based on barrels skipped (DK), completed lines at once (Tetris) and type of punch (PO). We measured the user experience using the User Experience Questionnaire (UEQ) [12], an assessment tool used to evaluate an overall user experience with a product or system. It produces results in six categories: attractiveness, perspicuity, efficiency, dependability, stimulation, novelty, further grouped into three categories: attractiveness, pragmatic quality, and hedonic quality. Due to an error creating our survey, we measured the UEQ using a 5-point Likert scale instead of a 7-point. We presented the questionnaire after each game/scheme combination, for a total of 9 times.

After completing all schemes for one game, we asked participants to rank control schemes based on three criteria for each game: most fun and most natural. They had to rank (1–3) all schemes in each category. Finally, we collected demographic data and asked general questions about our flexible controller. This protocol was approved by the Carleton University Research Ethics Board.

Hypotheses

The binary scheme should outperform both the action and navigation schemes (H1). We also predicted that the binary scheme would score higher in pragmatic quality on the UEQ (H2). We believed this would be the case because binary control schemes are already familiar to most players.

However, our third hypothesis was that gesture-based schemes would be more fun and receive higher attractiveness and hedonic scores in the UEQ (H3). Deformation input, being relatively new, would be seen as novel to most participants and using novel input to do something inherently fun, such as playing video games, would likely augment their stimulation levels and sense of enjoyment.

Finally, we predicted that the action scheme would perform better than the navigation scheme across all three games (H4), as the action scheme required less deformation input across all three games compared to the navigation scheme. We also predicted that action would perform better over navigation due to its relative simplicity.

Participants

Our 16 participants (3 female) had a mean age of 22.6 years old (SD=2.7). All were all right-handed. Eleven reported to

Table 1. Statistical results for study one.

Measure	Game	Main effect	Comparison *Binary/Action* *Binary/Navigation* *Action/Navigation*
Score	Donkey Kong	F [1.726, 25.890] = 10.096), $p = 0.001$	$p = 0.032$ $p = 0.001$ not significant
	Punch-Out	F [1.799, 26.969] = 5.397), $p = 0.013$	not significant $p = 0.017$ not significant
	Tetris	F [1.529, 21.410] = 3.930), $p = 0.045$	not significant $p = 0.049$ not significant
Fun	Donkey Kong	not significant	
	Punch-Out	not significant	
	Tetris	not significant	
Naturalness	Donkey Kong	χ^2 (2) = 18.375, $p < 0.001$	$Z = -3.198$, $p = 0.001$ $Z = -3.666$, $p < 0.001$ not significant
	Punch-Out	not significant	
	Tetris	χ^2 (2) = 20.933, $p < 0.001$	$Z = -2.399$, $p = 0.016$ $Z = -3.542$, $p < 0.001$ $Z = -2.841$, $p = 0.005$
Attractiveness	Donkey Kong	not significant	
	Punch-Out	not significant	
	Tetris	F [1.954, 27.357] = 7.901), $p = 0.002$	not significant $p = 0.007$ $p = 0.021$
Pragmatic Quality	Donkey Kong	F [1.830, 27.452] = 16.111), $p < 0.001$	$p = 0.002$ $p < 0.001$ not significant
	Punch-Out	F [1.922, 28.824] = 6.487), $p = 0.005$	not significant $p = 0.009$ not significant
	Tetris	F [1.999, 27.980] = 6.619), $p < 0.001$	$p = 0.001$ $p < 0.001$ not significant
Hedonic Quality	Donkey Kong	F [1.975, 29.628] = 22.247), $p < 0.001$	$p = 0.001$ $p < 0.001$ not significant
	Punch-Out	F [1.561, 23.410] = 29.654), $p < 0.001$	$p < 0.001$ $p < 0.001$ not significant
	Tetris	F [1.988, 27.827] = 30.639), $p < 0.001$	$p < 0.001$ $p < 0.001$ not significant

play video games for more than three hours weekly. Two had experience using flexible input in a prior study. We presented each participant with a $10 CAN gift card as compensation.

Results & Analysis

We analyzed games individually, as game play, scores and user experiences were not equivalent, and cannot be compared. An overview of the performance statistics can be found in Table 1.

Performance. Every participant played every game with every control scheme apart from one participant who did not play Tetris. We only analyze the values for the second trial,

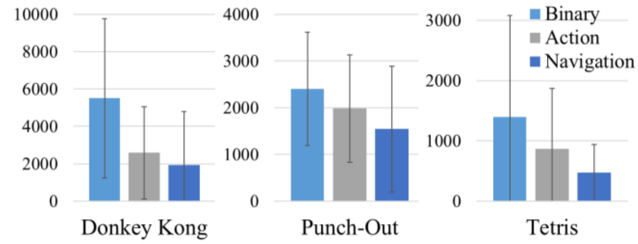

Figure 5. Mean game scores with standard deviation (SD).

to avoid the initial learnability of the game/scheme combination. We performed a repeated measures ANOVA with a Greenhouse-Geisser correction on the score. For significant main effects, we used post-hoc tests using the Bonferroni correction to investigate pairwise comparisons. Figure 5 presents the mean score for each combination.

Game Experience. We ran a Friedman test to evaluate the main effect of the control scheme for each game on naturalness and fun. For significant main effects, we conducted post-hoc analysis using a Wilcoxon signed-rank test with Bonferroni correction applied ($p < 0.017$). In Donkey Kong, binary was more natural than the other two schemes, while in Tetris, binary was more natural, followed by action, then navigation.

User Experience Questionnaire. We followed the UEQ analysis method and transformed the scores of the 26 ranking questions into values for the three high-level categories (scores between -2 and 2 given our Likert scale error). We evaluated each of the schemes based on these three categories. We performed the same ANOVA as for the performance results. Donkey Kong's mean UEQ scores are displayed in Figure 6.

Post Questionnaire

We asked our participants three questions at the end to get a general sense of their feelings towards the controller. These answers ranged between 1 and 5, 1 being highly disagree and 5 being highly agree (4 and 5 are considered in agreement). 10 participants (63%) agreed that: "the controller was comfortable to use". All participants agreed that: "the controller was fun to use". Finally, 12 participants (75%) agreed that: "I would use this controller to play other games," and only 1 participant disagreed (selected a 1 or 2).

We also asked participants which game they had the most fun playing. Punch-Out was the most popular with 10 votes

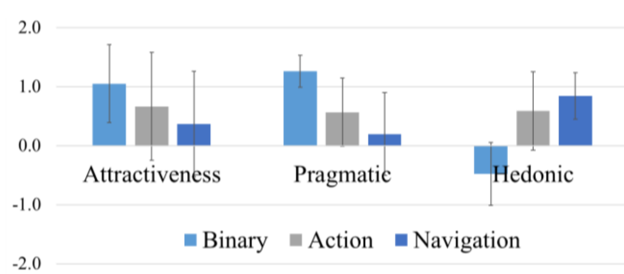

Figure 6. UEQ mean scores for Donkey Kong with SD.

(63%), Donkey Kong was the runner-up with 5 votes (31%) and Tetris only received 1 vote (6%). Participants who chose Punch-Out claimed that the controls felt the most natural and they felt more immersed in the game when using bend/flex controls. Participants who chose Donkey Kong as the most fun game did so because the controls were simple and "didn't impede the gameplay". Finally, the one participant who chose Tetris as their favourite game said it was "less complicated as it involved fewer actions".

We also asked users to describe their overall experience with the controller and which, if any, games they would like to play with bend control schemes. Participants were clear that the controller worked well for some games and not for others and stated that it worked much better with simple actions as opposed to complex input such as navigation in our study. Participant suggestions for potential game genres include: 3D flight games, racing games, 2D platformers, arcade fighting games, rhythm games, and sports games. Five participants commented on the sensitivity and occasional unreliability of the input saying it was too sensitive thus resulting in some unpredictable input.

Discussion

Binary Dominance

Binary consistently outperformed both action and navigation in all games, supporting H1. Binary ranked higher in naturalness than the two gesture-based schemes across all three games. The UEQ displayed higher pragmatic scores for the binary scheme over the gesture-based schemes and consistently outscored those schemes on attractiveness. These subjective results support H2. Our results show that the binary control scheme, across all three games, performed better, ranked better, and required the least amount of work compared to the other two schemes.

We believe that participants' familiarity with standard controllers is the main reason why the binary scheme consistently outperformed and outranked our unique control schemes: all participants were experienced players using standard methods of input, while only two participants had experience, though quite limited, using flexible input methods. Second, the time required to press a button (in place motion) is much lower than that of bending our controller (3D movement). Hence, it took longer for participants to complete their tasks, producing a lower performance overall, which affected their game experience.

Based on this, we conclude that deformable gestures, specifically using our prototype, will not replace binary input for existing games, in part or in whole. However, we introduced the binary scheme in our study mainly to establish a baseline with current game controllers: our real objective with this study is to evaluate two novel control schemes using deformation as input.

Gestures Are Fun

Not only did the gesture schemes outscored the binary scheme in the UEQ for hedonism, participants evaluated action and navigation positively across all three games (the UEQ deems a score of 0.53 or greater as a positive evaluation [12]). The hedonic category averages the stimulation and novelty scores of the UEQ. As this was an introductory study to our prototype, we did not design our tests to negate the novelty effect so this could have an impact on these hedonic scores. However, contrary to the action and navigation schemes, the binary scheme scored negatively in hedonism across all three games. We believe this would be the case regardless of whether or not we tested with the novelty effect in mind. In addition, all three schemes across all three games received similar fun rankings from the game experience survey. This is interesting as the binary scheme significantly outranked gesture-based control schemes in all other categories. While we hypothesized that action or navigation outranked binary in this category (H3), their close values demonstrate that using gestures does not decrease the amount of fun participants had while playing the games.

In addition, we think that the frustration and discomfort the users experienced while using these schemes directly impacted the fun rankings for the gesture schemes. It is possible that by making the controller more comfortable to hold and use, and strengthening the gesture recognition algorithm that the fun rankings will increase.

Participants described their experience using the flexible prototype as "riveting", "innovative", and "immersive". A participant stated that "using the bendable controller made the game more enjoyable compared to the regular button system", and another participant added that the gestures "added another level (to the experience) which I found enjoyable". Every participant agreed that the controller was universally fun to use with three quarters of them claiming that they would like to use bend and twist controls to play other games such as Mario Kart [22], Star Fox [21] and Sonic [38].

Action Scheme Better Than Navigation Scheme

The action scheme, across most criteria for all three games, ranks higher than the navigation scheme as a method of gesture input with our prototype. The performance was not significantly different, which does not support H4. Participants mentioned that "the bending controls were very frustrating to use for navigation". The participant who made the last comment also claimed that the controller was fun when the gestures were used specifically for action.

Action schemes were unique between games, but results show that participants consistently preferred this scheme. In Donkey Kong, bending or twisting in any direction caused Mario to jump in game. Allowing users to move Mario around with the buttons allowed for more precision (necessary in Donkey Kong) and we believe that mapping jump to the gesture input simulates the urgency of jumping in the game. Often times, jumping is reactionary and users jump with little to no preparation in Donkey Kong, which is why we believe gesture input fit so well: participants were able to trigger a jump by simply bending or twisting the controller using the quickest and easiest gesture for them.

A participant stated that “the bending controls were very frustrating to use for navigation, especially when dealing with precision”. Another summed up their experience by stating that “bends are better for simple actions” and a third participant chose Donkey Kong as the game they had the most fun with because “jumping with the bend felt quite natural, it was fun to use, and didn’t impede the gameplay”.

Natural Mapping

Taking into account the gesture schemes only, we noticed that game/scheme combinations that ranked higher for naturalness performed relatively better, and were preferred by participants over the other gesture-based scheme.

Tetris was the only game where there was a significant different in attractiveness between gesture control schemes, with action scoring higher. Action for Tetris also received one of the highest naturalness rankings. Twisting the controller in Tetris rotated the piece in the corresponding direction. We believe that this scheme ranked high in naturalness because the act of twisting is technically a rotation along the x-axis, hence naturally similar to rotating an option in the game. Multiple participants were able to predict how the action scheme would map before it was explained to them, which illustrates its instinctive mapping.

Scheme Consistency & Game Preference

Punch-Out behaved differently from the other two games: we did not find the action and navigation scheme’s results to be significantly different in most cases. We also did not find the binary scheme to be significantly different than the other schemes as often. When combined with the fact that 63% of participants chose Punch-Out as the game they had the most fun playing using the flexible prototype, we find this game to be most successful for our novel controller. We believe that Punch-Out’s consistency between control schemes is what led most participants to choose it as their preferred experience.

Participant comments support their preference for action due to its naturalness. Participants who chose Punch-Out as the most fun specifically commented on how natural twisting to punch felt. A participant commented that twisting “gave a unique and tangible way to feel more immersed in the actual fight”. However, both the action and navigation schemes for Punch-Out received similar scores across all of our evaluations. The act of leaning in either direction with our hands out in-front of us (similar to how boxers hold their hands out) is very similar to the input required to move left and right using the navigation scheme.

In summary, our results revealed that the binary scheme did outperform the gesture-based schemes. Results also showed that the gesture-based schemes were more stimulating and novel, but were not necessarily more fun or attractive. The action scheme received better feedback than the navigation scheme overall. The most naturally mapped the gestures were, the more attractive and appealing they were to participants. Participants suggested using bends and twists for different types of games, like racing games.

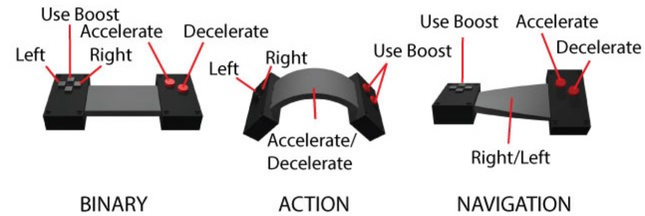

Figure 7. Control schemes for study two

STUDY 2: CONTINUOUS BEND INPUT IN RACING GAME

Where in study one we tested discrete gestures, we here explored how continuous gestures could play a role in video game control mapping using bipolar input to control high resolution parameters, as suggested by Ahmaniemi et al. [1]. We evaluated the same prototype, and used the same control schemes categories to see if results would stay consistent. We selected a 3D racing game based on our earlier participants collectively suggesting that a racing game could work well with gesture-based input, given the natural similarities between steering and twisting our prototype. We believed that a racing game has potential to test continuous gestures and new, more advanced, game mechanics.

Game

Participants played a 3D racing game called O.R.B.S. [33]. In O.R.B.S., players race spherical robots from point A to point B. We designed two custom tracks to test two unique mechanics found in racing games: speed, and precision. The speed track has few sharp turns, with 27 power-up platforms scattered, containing a boost that participants can activate at any time. The boost causes the racer to accelerate forward at a faster rate than normal for a pre-determined amount of time. The precision track’s sharp turns and obstacles are intentionally placed to force participants to be more precise with the controller. There are no power-up platforms on this track.

We also created a practice arena for users to race around before each trial to get used to each control scheme. This arena is a large square, with no finish line, and is full of obstacles and power-up platforms to practice all required in-game mechanics. They were allowed to practice until they felt comfortable with how the scheme worked.

Control Schemes

Similar to our first study, we used three unique control schemes: binary, action, and navigation (Figure 7). We tested binary again to provide a basis from which to compare performance and different qualities from the UEQ. The action control scheme used the up bend gestures to control the racer’s acceleration, and the down bend gesture for deceleration. The greater the magnitude of the bend, the faster the racer will accelerate or decelerate. The navigation scheme uses twisting to turn the racer left and right. The more the user twists the controller, the more extreme the turn.

Table 2. Statistical results for study two.

Track	Measurement	Main Effect	Comparisons *Binary/Action* *Binary/Navigation* *Action/Navigation*
Speed	Time	F [1.127, 19.157] = 13.767, $p = 0.001$	not significant $p = 0.005$ $p = 0.004$
	Collisions	F [1.319, 22.430] = 90.344, $p < 0.001$	not significant $p < 0.001$ $p < 0.001$
	Boosts Used	F [1.605, 27.286] = 21.856, $p < 0.001$	not significant $p < 0.001$ $p < 0.001$
Precision	Time	F [1.232, 20.939] = 29.849, $p < 0.001$	$p = 0.012$ $p < 0.001$ $p < 0.001$
	Collisions	F [1.050, 17.852] = 71.151, $p < 0.001$	not significant $p < 0.001$ $p < 0.001$
Combined	Fun	$\chi^2(2) = 7.741$, $p = 0.024$	$Z = -2.722$, $p = 0.006$ not significant not significant
	Naturalness	$\chi^2(2) = 24.216$, $p < 0.001$	not significant $Z = -4.354$, $p < 0.001$ $Z = -3.029$, $p = 0.002$
	Attractiveness	F [1.933, 67.658] = 4.306, $p = 0.018$	not significant not significant $p = 0.027$
	Pragmatic Quality	F [1.620, 56.685] = 23.143, $p < 0.001$	not significant $p < 0.001$ $p = 0.002$
	Hedonic Quality	F [1.832, 64.112] = 41.447, $p < 0.001$	$p < 0.001$ $p < 0.001$ not significant

Hypotheses
As in study one, we believed that the binary scheme would perform the best across both tracks (H1). We hypothesized that gesture-based control schemes (action and navigation) would score higher for hedonic quality, as well as fun, over the binary scheme (H2). Our third hypothesis was that the navigation scheme would perform better and participants would prefer it over the action scheme (H3) based on the comments participants made in the previous study. Many stated that racing games would make good use of the twisting mechanic as twisting feels very similar to steering.

Methods
Participants answered demographic questions. We tested each control schemes with both the speed and precision tracks for a total of six trials. We counterbalanced by scheme, then counterbalanced the two tracks. Participants first drove in a practice arena before beginning the trials for that scheme. They completed two trials on the track using the current scheme, then answered questionnaires relating to this combination. They then completed the next track with the same scheme, followed by the same questionnaires. This was repeated for all three schemes. After each scheme/track trials, we asked four Likert-style questions regarding

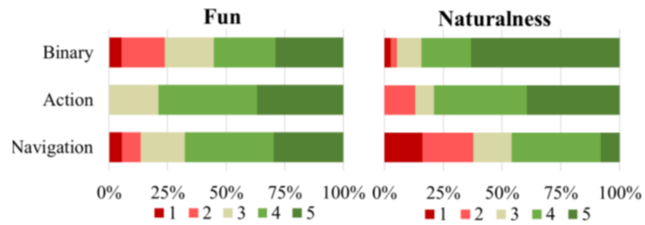

Figure 8. Naturalness and Fun ratings. 1 is negative (very unnatural/boring), 5 is positive (very natural/fun)

naturalness, and fun. Participants also completed the user experience questionnaire. Finally, they answered a post-questionnaire to determine which track-scheme combinations participants preferred. The entire session took approximately 60 minutes. This methodology was approved by the Carleton University Research Ethics Board.

Participants
Our 19 participants (9 female) had a mean age of 23.26 years old (SD=4.4yo). Sixteen were right-handed, two left-handed and one was ambidextrous. Ten reported playing games frequently, eight occasionally and one never. Nine participants had used a flexible method of input, 5 of those participated in our first study. They received a $10 CAN gift card as compensation.

Results & Analysis
The results of the statistical analysis can be found in Table 2.

Performance. We measured time, collisions, and boosts used. Every participant played both tracks with every control scheme apart from one participant who did not play with the navigation control scheme. We analyzed the values for the second trial, to avoid measuring the initial learnability of the track/scheme combinations. We performed a repeated measures ANOVA with a Greenhouse-Geisser correction on each measure for the speed track, and found significant differences between control schemes. We used post hoc tests using the Bonferroni correction to investigate pairwise comparisons.

Trial Experience. We ran a Friedman test on each experience rating, then conducted post-hoc analysis using a Wilcoxon signed-rank test with Bonferroni correction applied ($p < 0.017$) on significant main effects. Results are displayed in Figure 8.

User Experience Questionnaire. We performed the same ANOVA as for the performance data. Overall UEQ scores can be found in Figure 9.

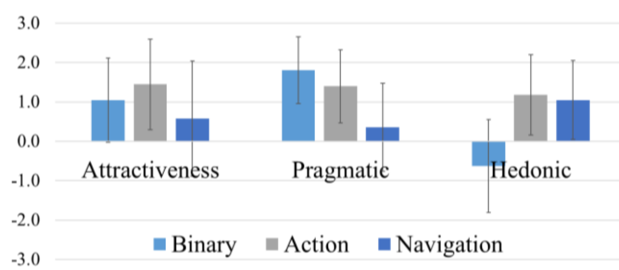

Figure 9. Overall UEQ Scores

Post-Questionnaire

A Friedman test comparing control schemes by rank for the speed track showed no significant preference. For the precision track, navigation ranked lowest (χ^2 (2) = 22.333, $p < 0.001$). Participants preferred the speed track overall, 33 votes to 24 votes (each participant had three votes as they were asked to choose their preferred track for each of the three schemes). Participants split their track preference for the binary scheme (9 votes to 10 votes), the action scheme weighed more towards the precision track (6 votes to 13 votes), and participants preferred the navigation scheme on the speed track (18 votes to 1 vote).

Participants split the votes for most fun between the two tracks using the action scheme, each receiving 7 votes. The navigation scheme received 4 total votes and the binary scheme only received 1. The navigation scheme on the precision track was voted least fun, receiving a total of 17 votes with other schemes only receiving 1 vote each.

Discussion

Binary is Familiar

We believe that participants' familiarity with binary input in other games made it easier for them to pick up and use more boosts on the speed track, lowering their completion times, similarly to study one. The binary scheme received the highest pragmatic scores and, observationally, took the least time to learn and become comfortable with on the practice track. These results, alongside binary's high naturalness scores, further support H1 in stating that binary is the easiest scheme to pick up and perform well. Multiple participants stated in their comments that "binary was the most predictable" of the three control schemes.

Although participants could learn and perform well with the binary scheme, it was not the most preferred scheme to use. This shows a lack of correlation between performance and interest, fun, or attractiveness. Binary schemes are very familiar to gamers, and that lack of creativity within the scheme might be the cause of its low scores in terms of hedonic quality, attractiveness, and overall preference.

Gestures Are Intriguing

Our results reveal that the gesture-based schemes were more appealing and preferred over the binary scheme overall, confirming our second hypothesis. Action and navigation ranked highest in fun, hedonic quality, and received the most votes for the most fun scheme overall at the end of the study. Hedonic quality includes stimulation and novelty as descriptive factors and participants seem to have found the gesture-based schemes both stimulating and novel based on the results of the questionnaires along with their comments. Participants described gesture-based schemes as "unconventional, but what [they] were hoping for". They also stated that the gesture-based schemes "bring the user more into the actual gaming experience", commenting on their ability to immerse our participants into games such as our racing game O.R.B.S. We believe that these unique control schemes and input methods force users to focus more on what they are doing, possibly immersing them more in the entire experience. The freedom to bend and twist the controller in 3D space provides a natural interaction in terms of how people interact, almost instinctively, with everyday objects (with their hands, in 3D space).

Participants Still Prefer Action

We hypothesized that the navigation scheme would perform well and be preferred based on comments from participants in study one. This hypothesis was not supported: the action scheme performed better was preferred over the navigation scheme. This result is similar to that of the first study.

These results demonstrate that users prefer using gestures to control the racer's speed (action scheme) and describe this scheme as "easy to learn," "more relaxing", and "adding excitement to the tracks". They liked being able to control their speed around corners and near boost pads allowing them to avoid collisions with walls and allowing them to pick up more boosts, which, in turn, lowered their completion time on the speed track.

Navigation is Difficult to Learn and Understand

The navigation scheme performed the worst and ranked the worst overall in study two, although this scheme received some positive feedback in regards to hedonic quality. While we did not focus on the learnability of the gestures in this study, our observations and participant comments led us to believe that there is a steeper learning curve for gesture-based schemes, especially the navigation scheme. We noticed that participants took longer in the practice course with the navigation scheme over the binary and action schemes. We did, however, notice large improvements in completion times and collision counts between their practice trials and recorded trials when using the navigation scheme. This suggests that with practice, their performance could increase, a feature to explore in a separate study.

Consistent Input as a Requirement

Users often have continuous control over their speed and turning in modern racing games such as Mario Kart 8 [22] and Forza Motorsport [40], which helps to slow down around corners and speed up when the track straightens out. It is also critical to have continuous control of the racer's direction to take turns at different angles and be able to precisely navigate through and around obstacles. We did not give participants continuous control over both speed and direction concurrently in our schemes, which participants commented on in both gesture schemes. We found lower performance and pragmatic qualities for gesture-based schemes compared to the binary scheme. We believe that consistent control over speed and direction simultaneously is a necessity to perform well in racing games. A solution might be to implement analogue sticks and triggers into the prototype, providing the ability to control both speed and direction continuously.

One interesting observation is that the binary scheme out-performed both gesture-based schemes, yet did not provide participants with any continuous input. We believe this is due once again to the participants' familiarity with standard control schemes, and the similarity between the speed and direction input, both discrete. This could suggest that control consistency is important in racing games regardless of whether or not it is discrete or continuous control.

GENERAL DISCUSSION AND RECOMMENDATIONS

Overall, participants performed best with the binary scheme. Participants had limited time to familiarize themselves with the control schemes and most participants had not used flexible input methods in the past. Taken into account that most participants frequently played games, this is result consistent with those of McEwan et al. [17], who found that more naturally mapped controls was not linked to an increase in performance compared to traditional controls.

Participants found gesture-based schemes intriguing, they were often excited to pick up and use the gesture-based schemes, even if their performance was not as good. The action and navigation schemes, for the most part, received high hedonic quality scores, and participants often chose them as their favourite. When implementing deformation gestures into current games, we suggest finding game mechanics with natural mappings to bend and twist. We also believe that deformation gestures should only be mapped to key-actions (actions that are critical in terms of game performance) if they represent a natural mapping. If no natural mapping is possible, we suggest to map them to novel in-game actions that increase the fun and enjoyment of the game, but are not critical in terms of performance.

The action scheme outranked and outperformed the navigation scheme in almost all cases. We recommend mapping bends and twists to in-game actions, as opposed to in-game navigation. We also recommend mapping gestures to a minimal number of actions as more gesture mapping make the experience more complex leading to higher levels of frustration and worse performance.

Finally, the ergonomics of the controller and input methods caused a few issues in both studies. We noticed that participants struggled with learning how to twist the controller properly along a middle (invisible) axis, even after explanations. Their lack of understanding and poor twist input caused unexpected reactions in-game which likely lowered their performance and increased their frustration when required to twist. The few participants who did understand how to twist properly ranked the navigation scheme higher and performed better than those who did not Users should be taught how to perform gestures properly and should be shown how their gestures affect the game.

Limitations

Our primary limitation regards the prototype, specifically the unreliability of the bend sensors, and in some cases, the buttons, where the output of the sensors would change over time. We regularly calibrated and applied filters in the second study to compensate, but a better designed controller might improve this issue. Second, while we tested various genres of games using discrete and continuous gestures, we left many genres untouched. We were also not able to test complex game mechanics with our prototype as the prototype itself was quite simple. We believe that with a more complex prototype that implemented input methods such as analogue sticks, left and right triggers, or the ability to sense different degrees of the bend/twist, we could have tested more complex mechanics. Finally, we acknowledge the small sample size in each of our studies.

CONCLUSION

Our goal in this paper was to determine if and where deformation input could fit in with standard gaming input methods. We created a flexible prototype with six buttons and four gesture inputs (bends and twists). We separated the in-game mechanics in terms of actions and navigation and assigned one control scheme to each. We compared them against a traditional control scheme using buttons (binary scheme). We ran two studies, evaluating the schemes with discrete input in arcade games in study one, and with continuous input in a racing game in the second study. We found that the binary scheme performed best and required the least amount of work, but the gesture-based schemes were stimulating and novel. The action scheme performed better than the navigation scheme, and was preferred.

By combining gesture input with standard input in our prototype, we created a user experience that was not only novel, but was stimulating and full of potential. Simple actions, naturally mapped to gestures, tend to be preferred amongst users, and are performed significantly better than more complex and abstract actions. We believe that with sufficient practice, bend gestures will also have the potential to increase performance, in both old and new games alike, but further testing is required. The combination of deformation gestures with standard button input gives users access to more methods of input without requiring them to move their fingers around to reach different buttons. We believe that more advanced and precise functionality can come from combining physical deformation gestures with buttons. Our design recommendations can aid researchers and game developers alike to improve on this hybrid technology to create game experiences where gestures are both preferred and perform well.

For future work, we will look at the learnability of bend gestures in combination with standard methods of input with longer play time. It would be interesting to map continuous input to different mechanics in different genres of games. While we used existing games, it would be worthwhile to investigate games designed specifically for bending and twisting.

ACKNOWLEDGEMENTS

This work was supported and funded by the National Sciences and Engineering Research Council of Canada (NSERC) through a Discovery grant (402494-2011), and a Create grant (465639-2015). We thank Victor Cheung, Alex Eady, Lee Jones and Travis Swan for their help on this paper.

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