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Evaluating the Plausibility of Edited Throwing Animations

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Abstract

Animation budget constraints during the development of a game often call for the use of a limited set of generic motions. Editing operations are thus generally required to animate virtual characters with a sufficient level of variety. Evaluating the perceptual plausibility of edited animations can therefore contribute greatly towards producing visually plausible animations. In this paper we study observers' sensitivity to manipulations of overarm and underarm biological throwing animations. In our first experiment, we used Dynamic Time Warping to edit the biological throwing motions, and modified the release velocity of the ball accordingly. We found that observers are more tolerant to speeding up of the original throwing motion than to slowing down, and that slowed down underarm throws are perceived as particularly unnatural. In our second experiment, we modified separately horizontal and vertical components of the release velocity of the ball, while leaving the motion of the thrower unchanged. We found that observers are more sensitive to manipulations of the horizontal component in overarm throws, and of the vertical component in underarm throws. As in the first experiment, we found that observers are most disturbed by decreases in the velocity of the ball in underarm throws. Our results provide valuable insights for developers of games and VR applications by specifying thresholds for the perceptual plausibility of throwing manipulations.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three Dimensional Graphics and Realism—Animation;

1. Introduction

Physical events are an essential part of virtual reality applications and computer games. The study of visual perception of physical distortions has a long history, originating with studies on Naïve Physics [Boz59, MCG80]. In recent years, researchers in the field of Computer Graphics have started to investigate observers' sensitivity to physical distortions in realistic mechanical simulations involving simple objects [ODGK03, RO09, YRPF09] or virtual human characters [RAP08, HMO12]. An important application of these studies is to provide guidelines for motion editing operations. As animators may need to introduce physical distortions in animations in order to achieve a particular goal, measuring observers' sensitivity to anomalies can contribute greatly towards producing visually plausible animations [BHW96]. While interactions between simple inanimate objects and between virtual human characters have received attention, little is known about visual perception of interactions between virtual human characters and simple inanimate objects. In this paper, we studied observers' sensitivity to anomalies in virtual throwing animations.

Animation budget constraints during the development of a game often call for the use of a limited set of generic motions. Manipulations of the release velocity of a ball could then be helpful, such as in sports games where a character has to throw a ball at different distances on the pitch (e.g., EA Sports Madden NFL™, Sony CE MLB 12: The Show™, 2K Sports NBA 2K12™). In our first experiment (Section 4), we used Dynamic Time Warping (DTW) to edit biological throwing animations, and modified the release velocity of the ball accordingly. The virtual character performed the throw in two possible ways, either overarm or underarm. We found that speeded up throws are perceptually more plausible than slowed down throws, and that slowed down underarm throws are perceived as particularly unnatural by observers. Their large tolerance for speeded up motions suggests that DTW may be used to achieve large increases in the ball throwing distance. In our second experiment (Section 5), we modified separately horizontal and

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vertical components of the release velocity of the ball, while leaving the motion of the thrower unchanged. We thus introduced a physical mismatch between the motion of the thrower and that of the ball. We found that observers are more sensitive to manipulations of the horizontal component of velocity in overarm throws, and of the vertical component in underarm throws. As in the first experiment, we found that observers are most disturbed by decreases in the ball velocity in underarm throws. Compared to the results for DTW, the modifications of throwing distance tolerated by the observers are much lower, and this suggests that this editing operation may be used only for relatively small manipulations of the throwing distance. Our results provide valuable insights for developers of games and VR applications by specifying thresholds for the perceptual plausibility of two simple kinds of manipulations of throwing actions.

2. Background

Researchers in Naïve Physics have shown that students with high school physics instruction have striking misconceptions about elementary mechanics [Cle82]. For instance, in paper-and-pencil tests they predict that a ball rolling inside a curved tube will follow a curved trajectory even when it exits from the tube, whereas it should instead move in a straight line [MCG80]. In some cases, while people fail in these abstract situations, they perform well when presented with virtual simulations of physical events [KPWH92].

In recent years, researchers in Computer Graphics have become interested in evaluating how much a physically correct animation can be modified and still look perceptually plausible [BHW96]. Understanding whether observers are sensitive to physical distortions in mechanical events is important in order to develop plausible simulations while saving time on details that observers cannot perceive. For instance, the behaviour of a single inanimate object [KPWH92, NLB*07], and sensitivity to errors in 3D rigid body collisions between simple objects [ODGK03, RO09] have been investigated. Motion capture has also been used to evaluate observers' sensitivity to errors in the motion of virtual human characters [CHK07], or in physical interactions between virtual characters [HMO12]. Reitsma et al. [RAP08] compared observers' ability to detect errors in the ballistic motion of a virtual human character and of a virtual ball, and found greater sensitivity to variations in the coefficient of gravity when the actor was a human character. Majkowska et al. [MF07] also studied user sensitivity to errors in aerial human motions, and found that subjects were not sensitive to even significant changes in angular momentum during ballistic motion.

A small number of studies have been concerned with visual perception of mechanical interactions between human characters and inanimate objects. Throwing actions, as discussed in this paper, are instances of these kinds of mechanical events. Runeson and Frykholm [RF83] displayed point-light characters throwing an unseen 2.5kg sandbag at different distances, and found that estimates of the length of the throw were accurate. Munzert et al. [MHH10] found that observers finely discriminated the traveled distances of a 600g ball when point-light displays of the arm of the thrower were shown. Knoblich and Flach [KF01] showed video clips of people throwing light darts towards a target, and found that non-kinematic cues such as the direction of the thrower's gaze influence observers' ability to predict the final position of the dart. Hecht and Bertamini [HB00] presented 2D stick characters and mannequin-like 3D characters performing throwing actions, and found that observers were relatively insensitive to added acceleration during the first phase of the ballistic motion of the projectile.

Concurrent with these perceptual studies, several researchers also focused on editing human motion to satisfy new constraints and distortions. Early works studied retargeting motions on new characters [Gle98], introducing additional kinematic [Gle97] and dynamic constraints [SKG03], as well as changing the trajectory of a motion [Gle01]. If different approaches edit the motion using spacetime optimization problems [LHP06], different real-time solutions also exist [SO06]. In this paper, we are interested in evaluating how observers perceive throwing animations manipulated using two simple editing methods: modifying the speed of the human and ball motions accordingly, or creating a physical mismatch between them.

3. Setup

3.1. Motion Capture

We recorded the full body movements of a right-handed male actor (*thrower* hereafter). The thrower was non-professional and did not have any specific experience with sports involving throwing a ball. All throws were performed with the right arm using a standard tennis ball as projectile (diameter ≈7cm, mass ≈60g). Another person served as receiver, but was not recorded. The receiver stayed in front of the thrower at a distance of 5m. The thrower was instructed to look in front of him during the throw, and to avoid lateral movement of the ball. The trajectory of the ball was thus mainly displaced in two dimensions with respect to the thrower: forwards and upwards.

As we wished to determine if observers' sensitivity to errors in throwing animations depended on the way in which the throw is performed, the thrower was instructed to throw the ball to the receiver in two alternative ways: either with an *overarm* motion or with an *underarm* motion (Figure 1, and see supplementary video for detailed examples). We then registered three takes for each kind of throw. Other takes were discarded due to excessive lateral movement of the ball.

Motion capture was conducted using a 19 camera Vicon optical system, and 55 markers were placed on the body of the thrower. To simultaneously capture the motion of the hand and of the fingers, we placed six extra markers on each hand:

two markers on the thumb and one marker on the fingertip of each finger, as in [HRMO12]. We also placed four markers on the tennis ball, so that they formed the vertices of a tetrahedron and did not have any appreciable influence on the trajectory of the ball. This allowed us to estimate the position of the center of the ball during the entire captured motion. The body and the ball motions were captured at 120Hz.

3.2. Physics of Projectiles

The motion of a thrown object can be divided into two phases: the motion before it is released (*preparatory motion*) and the motion after the release (*ballistic motion*). When thrown in the air, an object that is subject only to the force of gravity and to air resistance is called *projectile*. If we neglect air resistance, a projectile always follows a parabolic trajectory, defined by its horizontal and vertical velocities at the time of release (v_{h_0} and v_{v_0} respectively). More precisely, the parabolic trajectory of a projectile is characterized by the following two equations:

$$v_h(t) = v_{h_0} \quad \text{and} \quad v_v(t) = gt + v_{v_0} \tag{1}$$

where $v_h(t)$ and $v_v(t)$ are horizontal and vertical velocities, g is the coefficient of gravity and t is time. The parabolic trajectory of a projectile is then obtained by integrating these equations over time, and depends on the release position of the projectile.

While equation 1 refers to the ballistic phase of the motion, the release velocities v_{h_0} and v_{v_0} are determined by the motion of the object during preparatory motion. In the case of a throw performed by a human, preparatory motion refers to all the movements of the human's body that influence the release velocities of the projectile, such as the motion of the arm and shoulder.

In order to manipulate the velocity of the projectile, we first needed to determine the time of release t_0 to discriminate the preparatory and the ballistic phases. To automatically compute t_0, we selected the set of eight markers on the right hand of the thrower (s_t), and another set (s_p) consisting of the four markers on the projectile. We then computed the sum of the squared distance between every combination of pairs of markers (m_t, m_p):

$$d = \sum_{m_t \in s_t} \sum_{m_p \in s_p} dist(m_t, m_p)^2 \tag{2}$$

where $dist(m_t, m_p)$ is the Euclidean distance between markers m_t and m_p. Then, t_0 corresponded to the time when the derivative of d exceeded a manually selected threshold, i.e. when the variation of the distance between the ball markers and the hand markers differed from capture noise.

We then used the captured trajectory of the projectile during the ballistic phase to automatically compute the release velocities that best fitted the whole ballistic motion. Table 1 shows the average release velocities of the ball over the three takes of overarm or underarm throws, with the corresponding standard deviations. These parameters differed by no more than 5% between takes of the same kind of throw. Note that in overarm throws the horizontal component exceeds the vertical component, whereas the opposite is true for underarm throws.

	v_{h_0} (m/s)	v_{v_0} (m/s)
Overarm	5.58 ± 0.16	3.32 ± 0.08
Underarm	4.41 ± 0.03	5.50 ± 0.11

Table 1: *Average and standard deviation of the horizontal (v_{h_0}) and vertical (v_{v_0}) release velocities for the two types of captured human throws.*

4. Full Throw Editing Experiment

In this experiment, we studied observers' sensitivity to simultaneous manipulations of preparatory and ballistic motions in biological human throwing animations. As the release velocity of the projectile depends on the preparatory motion, we used DTW to modify the speed of the biological throwing motion, and manipulated the release velocity of the projectile accordingly. We were interested in studying to what extent biological throws can be slowed down or speeded up while still being perceived to be natural. We were also interested in evaluating if the tolerance to these manipulations depends on the type of throw (overarm or underarm).

4.1. Dynamic Time Warping

Modifying the speed of a motion to speed it up or slow it down is called Time Warping. Similarly, Dynamic Time Warping (DTW) handles non-uniform compressions or dilatations of parts of a motion by varying the speed modification over time. This is commonly used in computer animation to synchronize motion sequences with different durations [BW95].

In the case of throwing motions, the release velocity of the projectile depends on the preparatory motion of the human character. In this experiment, we used DTW to modify the speed of the biological throwing motion, and manipulated the release velocities of the projectile accordingly. According to physics, this corresponds to modifying the horizontal and vertical components of release velocity by the same percentage as the speed modification of the preparatory motion. This modifies the magnitude of the release velocity without changing the angle of release of the projectile. As the release velocity is influenced only by the throwing gesture, we modified the speed of the motion of the human character only during the throwing action. This action was defined by the period of time including the moment of release, with a local minimum release velocity of the arm at the boundaries of the throw phases, (i.e., preparatory, release and follow-through).

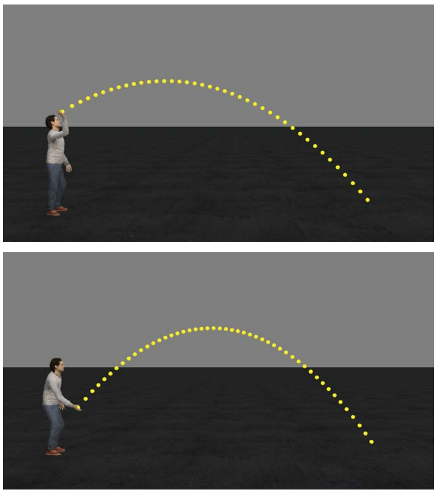

Figure 1: *Examples of biological overarm (up) and underarm (bottom) throws.*

In order to manipulate the release velocity of the throw, we modified the duration of the throwing action by the corresponding amount and recomputed the new time of release. To ensure continuity with the other phases of the motion, we defined a timewarping function using a monotonous and $\mathcal{C}^2$ continuous spline. The modified parabolic trajectory of the projectile was then recomputed according to Equation 1 using the modified release velocities. Such editings are reasonably straightforward to perform and would therefore be typical in real-time applications such as games.

4.2. Psychophysical Method

To accurately determine the perceptual threshold for the modification of the throwing speed, we used a randomly interleaved staircase design [Cor62], with fixed up and down steps. The staircase (or up-down) method is an effective psychophysical technique for identifying thresholds, since it ensures that most of the trials are presented near the threshold for that particular observer. The *ascending* staircase starts with the unmodified throw and increases the magnitude of speed modification until the observer perceives the stimulus as *modified*. The magnitude of speed modification is then decreased (in smaller steps) until the observer perceives the stimulus as *natural*, then increased until it results in another *modified* response. This 'up-down' process is repeated, until a pre-specified number of reversals is obtained. As suggested by Garcia-Perez [GP01], we used a down/up step ratio of 0.871, and set the stopping condition to 8 reversals. This ascending staircase is complemented by a *descending* staircase, which starts at a clearly superthreshold level (i.e., the stimulus is glaringly modified) and decreases until a *natural* response is given. It then reverses course, and follows the same reversal process as previously described. To avoid observers anticipating the next stimulus (and hence biasing their response), trials from several staircases are interleaved; the trials then appear random to the observer.

This psychophysical method gives us a sufficient number of binary responses around the absolute threshold level to fit a psychometric curve to the data. The psychometric curve is a mathematical model representing how the observers' response to the stimuli varies depending on the variation of these stimuli. This procedure allows us to calculate the Point of Subjective Equality (PSE), i.e., the magnitude of speed modification of the original throw at which the throw is perceived as *natural* 50% of time, and the Just Noticeable Difference (JND), i.e., the magnitude of speed modification of the PSE necessary to improve the detectability of the modifications by 25%.

4.3. Stimuli

Based on a pilot study, the *Magnitude* of modifications of the original motion speed varied between 0% and 90%. The *Sign* of the manipulation of the speed was either a decrease (slowing down) or an increase (speeding up). We used two *Throws* (overarm or underarm), and in order to avoid the counfounding factor of having multiple takes per throw in the staircase procedure, we selected only one take of each captured throw. We chose the take with the release velocity closest to the average velocity of the three captured takes. Therefore, we had four staircases: 2 Throw (overarm, underarm) $\times$ 2 Sign (slowing down, speeding up). In order to avoid any anticipatory effect, we randomly interleaved the presented experimental conditions.

To display the biological human motions, we selected a virtual character who roughly matched the morphology of our actor. The captured body motion was then mapped onto a skeleton, where joint angles were computed and used to drive the virtual character. We selected a camera viewpoint to the right of the thrower (Figure 1), where the fixed position of the camera was chosen to maximize the amount of preparatory and ballistic motion information available to participants. The ball was displayed with a bright-yellow photographic tennis ball texture (similar to the real captured tennis ball), and the ground was displayed with a dark grey asphalt-like textured plane. The background was light-gray, and shadows were not rendered. These settings were chosen to enhance the contrast between the ball and the rest of the virtual environment, thus making the visual tracking of the ball easier. Because we wanted the participants to focus on the trajectory of the ball during its flight phase, and not on the reaction with the environment once the ball landed, the ball disappeared before making contact with the ground. For some modified throws, the ball went outside of the border of the screen. We did not simulate air resistance because this would have a negligible perceptual effect on the trajectory of the ball. As some of the animations presented a highly

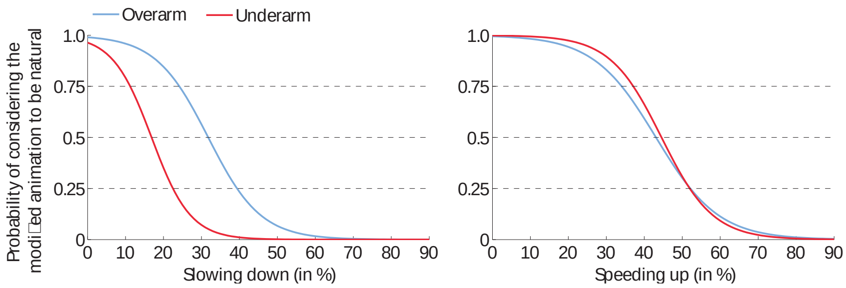

Figure 2: *Overall psychometric curves representing the probability of 'natural' responses for each magnitude of slowing down and speeding up of the original motion, for overarm and underarm throws.*

dynamic motion of the ball, all the stimuli were displayed at 1600×1200 and at 85Hz on a 21-inch CRT screen.

In each trial, participants had to indicate whether the presented animation was *natural* or *modified*. They were given some information on how motion capture data is created. Participants were told that some of the animations had been modified, and explicitly told that the throwing motion of the virtual character could appear excessively fast or slow. To facilitate the task, the participants were allowed to feel the weight of a real tennis ball before and during the experiment, and they were told that the tennis ball displayed in the animation had the same weight than the real one. Eleven volunteers took part in this experiment (5F-6M, aged between 20 and 50). They were all naïve to the purpose of the experiment, came from various educational backgrounds, and received a book voucher for their efforts.

4.4. Results and Discussion

For each experimental condition, we used the Matlab psignifit toolbox [FHW11] to fit a logistic psychometric curve to the data, both to each participant and to the overall merged results. The overall psychometric curve for each condition is presented in Figure 2. The overall PSEs and JNDs are reported in Table 2.

		Slowing down	Speeding up
Overarm	PSE	31.8% ± 5.8%	43.1% ± 7.3%
	JND	6.9% ± 2.0%	8.2% ± 1.6%
Underarm	PSE	16.9% ± 4.1%	44.5% ± 5.2%
	JND	5.1% ± 0.5%	6.8% ± 1.4%

Table 2: *Mean PSEs and JNDs with standard errors for the Full Throw Editing Experiment.*

To evaluate how speed modification and throw influence the PSE, we performed a two-way Repeated Measures Analysis of Variance (ANOVA) on individual estimated PSEs with within subjects factors: 2 Sign × 2 Throw. We used Newman-Keuls post-hoc tests to further explore interaction effects. Table 4 summarizes the main results, which show that participants are significantly less sensitive to speeding up throws than to slowing them down, especially for underarm. The same analysis was performed on JNDs and showed no main or interaction effect, showing that the response strategy was consistent over the four experimental conditions.

The results suggest that observers are relatively tolerant to speeding up throwing motions, independently of the kind of throw (≈44% speeding up of the original motion tolerated 50% of the time). Tolerance for slowing down is generally lower (with -31.8% of the original speed accepted 50% of the time for the overarm throw), and particularly low for the underarm throw (-16.9%). Our findings show that observers' sensitivity to speed modifications does not only depend on the general action being performed (a throw), but also on finer features of the action (overarm vs. underarm).

To sum up, DTW can be used to achieve big increases in the throwing distance, i.e., the horizontal distance between the thrower and the landing position of the ball. In our experiment, a 43.1% speeding up resulted in a 75% increase in the overarm throwing distance, and a 44.5% speeding up resulted in a 99% increase in the underarm throwing distance. However, observers are more sensitive to slowed down motions, resulting in a 52% decrease in the original throwing distance for the 31.8% slowed down overarm throw, and a 28% decrease in the original throwing distance for the 16.9% slowed down underarm throw. The latter result suggests that DTW can be used to decrease the throwing distance of an underarm throw only by a small amount.

5. Ballistic Motion Editing Experiment

In the first experiment we demonstrated that DTW can be used to modify the throwing distance of the ball by a large amount. However, DTW requires the modification of the motion of the virtual character and of the ball. In our second experiment, we were interested in evaluating if throwing animations can be modified using a simpler editing operation. We evaluated the perceptual effect of manipulating only one component of the release velocity of the projectile, while leaving the other component of velocity and the motion of the virtual character unchanged. This editing operation introduced a physical mismatch between preparatory and ballistic motions, because the latter was modified while the former remained unchanged. As in the first experiment, we also tested if the sensitivity to manipulations depends on the way in which the throw is performed.

5.1. Stimuli

The ballistic motion was modified by manipulating the original release velocity of the ball, while the preparatory motion remained unchanged. Based on a pilot study, we selected a set of *Magnitude* modifications of the original release velocity: 15%, 30%, 45%. The *Sign* of the manipulation could be either a decrease or an increase in velocity. Also, the *Components* of the original release velocity were modified independently (horizontal or vertical component) by modifying one of the two components and keeping the other one unchanged: we thus modified the ratio between horizontal and vertical components of release velocity, changing the angle of release of the ball. The modified parabolic trajectory of the projectile was then recomputed according to Equation 1 using the manipulated release velocities.

We used the three takes of each captured throw (overarm and underarm, see Section 3.1). The small differences between takes (See Table 1) did not affect the fundamental mechanics of the throwing action, as suggested by the similarity of the release velocities of the projectile between the three takes of each kind (difference of no more than 5%). Because of the relatively large number of experimental factors for this experiment, we chose a 2-Alternative Forced Choice protocol (2AFC), where participants had to indicate whether the trajectory of the ball was *correct* or *incorrect*. They were instructed that an incorrect trajectory could be too high, too shallow, too long, or too short compared to the force exerted by the virtual character. A total of 168 stimuli were randomly shown to participants. There were 144 modified animations: 2 Throw (overarm, underarm) × 2 Component (horizontal, vertical) × 2 Sign (decrease, increase) × 3 Magnitude (15%, 30%, 45%) × 3 takes × 2 repetitions. In addition, the six unmodified takes were presented four times each, for a total 24 unmodified animations. As in the first experiment, the participants were allowed to feel the weight of a real tennis ball before and during the experiment. We used the same environment and camera viewpoint than in the first experiment (see Section 4.3). Similarly, all the stimuli were displayed at 1600×1200 and at 85Hz on a 21-inch CRT screen. Fifteen volunteers took part in this experiment (5F-10M, aged between 20 and 55). They were all naïve to the purpose of the experiment, came from various educational backgrounds, and received a book voucher for their efforts.

5.2. Results and Discussion

As a preliminary analysis showed no main effect or interaction of takes, participants' responses were averaged over takes and repetitions. We then performed a four-way repeated measures ANOVA on this data on the percentage of *incorrect* responses with within subject factors: 2 Throw × 2 Component × 2 Sign × 3 Magnitude. We used Newman-Keuls post-hoc tests to further explore main and interaction effects. Table 4 summarizes the significant results. Figure 3 shows the mean percentage of *incorrect* responses for the overarm and the underarm throws for each modified component. While appropriate to study a large number of experimental factors, the psychophysical method we used in this second experiment does not allow a precise calculation of the individual PSEs. However, Table 3 reports the overall estimated mean PSEs for each experimental condition.

	Horizontal		Vertical	
	Decrease	Increase	Decrease	Increase
Overarm PSE	-26.4%	24.1%	-28.7%	38.8%
Underarm PSE	-24.3%	40.0%	-17.5%	28.5%

Table 3: *Mean PSEs for the different conditions of the Ballistic Motion Editing Experiment.*

We found that manipulations of the greater component of velocity (horizontal for overarm throws and vertical for underarm throws, see Table 1) were easier to detect than manipulations of the smaller component. This result may be due to the fact that manipulations of the greater component of velocity produce larger absolute modifications of the original trajectory of the ball compared to manipulations of the smaller component. Similarly to the Full Throw Editing Experiment, decreases in the ball velocity for the underarm throw were the less accepted manipulations (see Table 3).

To compare these results with the Full Throw Editing Experiment, we estimated the overall mean PSEs for each experimental condition (Table 3) and evaluated the corresponding modification of the throwing distance. In the case of manipulations of the horizontal component, the magnitude of manipulations equals the modification of the throwing distance. This results in modifications of around ±25% of the original throwing distance for all the conditions, except for the underarm throw where the throwing distance can be increased up to 40%. In the case of manipulations of the vertical component, manipulations corresponding to the PSEs result in modifications of around ±15% of the throwing distance, except for the increase in the vertical component of the underarm throw (24% increase of the original throwing distance).

To sum up, the pattern of sensitivity to manipulations of horizontal and vertical components of velocity depends on the type of throw. The PSEs for the studied manipulations hardly exceed ±30%. This demonstrates that observers are quite sensitive to physical mismatches between the preparatory motion and the ballistic motion. As the preparatory motion seems to provide observers with enough information to predict the ballistic motion accurately, observers detect physical mismatches between these two phases quite easily (see also [RAP08]). The maximum amount of modification of throwing distance considered to be perceptually plausible

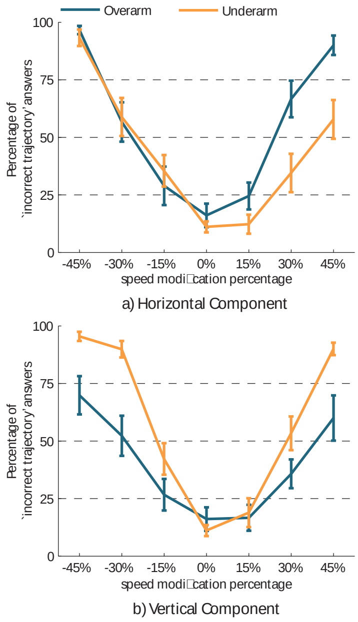

Figure 3: *Mean percentages of 'incorrect' responses in the Ballistic Motion Editing Experiment for each Magnitude of manipulation, for the different Throws and manipulated Components of release velocity.*

by observers is an increase by 40% in the underarm throw. This means that the simple editing operation studied in this experiment can be used only for small manipulations of the throwing distance.

6. Conclusion and Future Work

In this paper we presented two experiments addressing the perceptual effect of two kinds of editing operations in throwing animations: modifying the velocity of both the character and the projectile, or manipulating the release velocities of the projectile alone. We have shown that DTW can be used by animators to achieve big increases in the throwing distance (99% increase in throwing distance for the underarm throw considered to be correct 50% of the time). However, the sensitivity to timewarped biological throws depends also on the interaction between the throw being performed by the virtual character (overarm vs. underarm) and the sign of the manipulation (speeding up vs. slowing down). In the second experiment, we have shown that the sensitivity to manipulations of the two components of release velocity of the projectile also depends on the way in which the throw is performed. Relatively small increases in the throwing distance are achievable using this simple editing operation (40% increase in throwing distance for the overarm throw considered to be correct 50% of the time). Interestingly, we found in both experiments that observers are most disturbed by short-distance underarm throws. This may be due to the fact that we have a general preference for overarm throws over underarm throws when aiming at short distances, which gives us better control of the direction of the projectile.

These results are important for motion editing purposes. Throwing animations that require small changes of the throwing distance may be modified by manipulating only the horizontal and vertical components of the release velocity of the projectile, leaving unchanged the motion of the thrower. However, DTW has to be used to achieve bigger manipulations without compromising the realism of the animation. These manipulations allow animators to cover a wide range of throwing distances without extensive motion capture sessions. Of course, the results of our experiments also suggest that animators need to take into account the type of throw when editing animations. The supplementary video demonstrates how these guidelines can be used in a simple throwing game where a set of throwing motions are edited to reach new throwing distances.

In our experiments all the correct animations were characterized by a throwing distance of 5m. To test the effect of manipulations on a wider range of throwing distances would have required an impractically large number of stimuli. For the same reason, we tested only the two most common throwing motions (overarm and underarm) from the vast set of possible throwing actions. The camera viewpoint was fixed, and set to maximize the visual information available to the participants: tolerance to modified animations might be larger with other arbitrary camera viewpoints. In order to study the interaction between the manipulated component and the type of throw, in the Ballistic Motion Editing Experiment we manipulated only one component of release velocity while keeping the other one unchanged. This procedure was used in previous works on ballistic motion editing [RAP08], and it is useful if the animator needs to modify, for instance, only the length of the throw while keeping its height constant. However, it would be interesting to study the perceptual effect of combining manipulations of both components while leaving the preparatory motion unchanged. Horizontal and vertical release velocities can also be manipulated by changing the time of release of the ball. While the above mentioned choices were well-justified for a first-stage experiment, future research on the perception of throwing animations will involve a wider range of throwing distances and actions, will evaluate the effect of the camera viewpoint on the perception of physical distortions, and will evaluate the perceptual effect of simultaneous manipulation of both components and of the time of release while leaving the preparatory motion unchanged.

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Full Throw Editing Experiment – 2 *Throw* × 2 *Sign*

Effect	F-Test	Post-hoc
THROW	$F_{1,10} = 5.368, p < 0.05$	Greater sensitivity on average for underarm throws
SIGN	$F_{1,10} = 5.666, p < 0.05$	Greater sensitivity on average for slowing-down
THROW × SIGN	$F_{1,10} = 11.085, p < 0.01$	Greater sensitivity for slowing-down, in particular for underarm throw

Ballistic Motion Editing Experiment – 2 *Throw* × 2 *Component* (COMP) × 2 *Sign* × 3 *Magnitude* (MAGN)

Effect	F-Test	Post-hoc
MAGN	$F_{2,28} = 176.038, p \approx 0$	Sensitivity is proportional to magnitude
SIGN	$F_{1,14} = 8.251, p < 0.05$	Greater sensitivity on average for decreases
THROW × SIGN	$F_{1,14} = 8.253, p < 0.05$	↪ but only for underarm throw
THROW × COMP	$F_{1,14} = 65.377, p < 0.00005$	Greater sensitivity for the main component of velocity
THROW × COMP × MAGN	$F_{2,28} = 6.037, p < 0.01$	↪ but only for 30% and 45% levels of magnitude
COMP × SIGN × MAGN	$F_{2,28} = 5.725, p < 0.01$	Small random effect independent of throw

Table 4: *Significant results for the presented experiments.*

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