Exaggeration of Avatar Flexibility in Virtual Reality

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ABSTRACT
Empowerment of movement through superhuman strength and flexibility is a staple of action video game design. However, relatively little work has been done on the same in the context of Virtual Reality and exergames, especially outside the most obvious parameters such as jumping height and locomotion speed. We contribute a controlled experiment (N=30) of exaggerating avatar flexibility in a martial arts kicking task. We compared different settings for a nonlinear mapping from real to virtual hip rotations, with the aim of increasing the avatar's range of movement and kicking height. Our results show that users prefer medium exaggeration over realistic or grossly exaggerated flexibility. Medium exaggeration also yields significantly higher kicking performance as well as perceived competence and naturalness. The results are similar both in 1st and 3rd person views. To the best of our knowledge, this is the first study of exaggerated flexibility in VR, and the results suggest that the approach offers many benefits to VR and exergame design.

CCS Concepts
•**Human-centered computing** → *HCI design and evaluation methods;* **Empirical studies in HCI;** *Interaction paradigms; Virtual reality;*

Author Keywords
Games; Virtual Reality; Exergames; Movement-based games; Flexibility

INTRODUCTION
Games can empower players beyond reality, giving them superhuman abilities for overcoming challenges and exploring fantasy worlds. Such superhuman abilities can be argued to support basic psychological needs such as the feeling of competence, which has been identified as a central intrinsic motivation in video games [21]. As perceived competence is also central to sport and exercise motivation [20, 11], this raises the question of whether one could and should empower movement and give people superhuman abilities in the real world, or perhaps in virtual or mixed reality exergames, i.e., digital games that motivate physical activity.

In the real world, indoor activity parks using trampolines and other motion-empowering equipment appear to be a rising trend (e.g., [17]). In context of exergames, researchers have boosted the avatar's jump height with a combination of computer vision and customized game physics [6], optionally also combined with a real trampoline as the playfield, which can be called *mixed reality empowerment* [7, 9]. However, although defying gravity is a central challenge in movement and a source of inspiration in games [8], we are also severely constrained as movers by limited flexibity, especially in activities like dance, gymnastics, or martial arts. Thus, as suggested by Hämäläinen and Kajastila [7], trying to artificially boost flexibility appears a viable research topic.

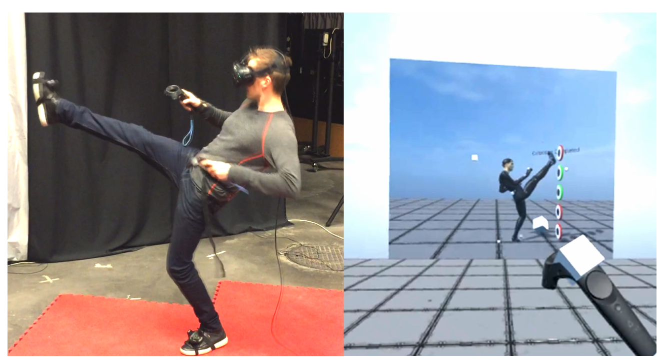

Figure 1. Left: the user wearing a VR helmet and trackers. Right: the user's view, with moderate flexibility exaggeration. We tested both a 1st person view and the 3rd person side-perspective view shown in the figure.

In this paper, we present the first controlled experiment (N=30) of the effects of exaggerating the flexibility of a body-tracked avatar. The setup is shown in Figure 1. We implemented

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the exaggeration in a martial arts kicking task, using a HTC Vive virtual reality headset with additional trackers on the user's feet and back. The exaggeration was implemented as a nonlinear mapping between the rotations of the player's and avatar's hip joints, as shown in Figure 3.

Our results indicate that players prefer moderate exaggeration over realistic movement, and it also improves self-reports of competence and movement naturalness. Verbally, participants described the exaggeration as natural, fun, and empowering. On the other hand, too high exaggeration makes movements imprecise and unnatural. Since our method is straightforward to implement, our work indicates that flexibility exaggeration is a useful tool for VR and exergame design and research.

BACKGROUND AND RELATED WORK

Our work falls in the broader domain of intentionally non-realistic user-avatar movement mappings in games and virtual reality. In the following, we divide such work into the categories of exaggeration, attenuation, and otherwise modified movement. Our work can also be considered as providing *augmented feedback* for sport and exercise, which is an active area of research in sport science. For a review of how augmented feedback can be both beneficial and harmful for movement skill learning, the reader is directed to the review by Sigrist et al. [22]. However, our work is focused on other aspects of player experience than skill learning.

Movement exaggeration

Many games and research experiments exaggerate movement to give players the power to defy gravity and experience the associated empowerment [8]. For example, Hämäläinen et al. [6] report that players of a martial arts game with exaggerated jump height started to believe in the exaggeration and were surprised of their feeble abilities when the exaggeration was turned off. The game also had exaggerated horizontal movement speed, and players preferred moderate exaggeration with a factor of 1.5 over grossly exaggerated movement, because the latter made it difficult to accurately kick and punch targets. Kajastila et al. [9] extended on-screen jump exaggeration with a real trampoline, and also presented quantitative evidence that on-screen exaggeration can increase player arousal while still allowing one to learn a real-life jumping skill. Hämäläinen and Kajastila [7] also hypothesized about the connection between movement exaggeration and intrinsic motivation dimensions such as perceived competence, but did not provide any evidence. Our work is inspired by their suggestion of flexibility exaggeration as a topic for future work.

We are also inspired by Bleiweiss et al. [3] who blend predefined animations with real-time tracking data in order to make in-game movement more expressive and stylish. This includes melee movements, which is close to our kick task. However, Bleiweiss et al. [3] focus on the technical system and do not provide data on the effects of their approach on user experience. Our experiment complements their study, and we also investigate a continuous nonlinear user-avatar mapping as an alternative to using predefined animations. Our approach should provide more user control over the movement, although it may be a viable aesthetic choice to also blend in handcrafted animations.

Movement attenuation

The opposite of movement exaggeration can also have positive effects. For example, giving the impression of weaker performance through so-called "speed deception" may result in better performance in endurance practice, which has been demonstrated with exercise bikes in both real [14] and virtual environments [12].

Outside sports, range and spatial extent of movement can be adjusted for social implications. It may be desirable to decrease spatial extent to make non-verbal communication less awkward and prevent invading personal space in multicultural social VR [10].

Other ways of modifying movement

One goal of modified virtual movement and visual feedback can be to ultimately modulate the user's real-world movements. For example, one can give an illusion of walking infinitely forward while in reality making the user walk in a circle in a limited space [19]. Similarly, reaching movements may be redirected to a single physical prop such that the user believes touching different objects, while still getting stronger feeling of immersion [1].

There are also systems and interfaces that map user movements into altogether different ones, for example, to mitigate the differences of the user standing in front of a sensor while the avatar is swimming or flying [13, 5]. It may also be desirable to only map and exaggerate a subset of the movement information to the virtual world, as in the Oscillate VR experience [24], where the user swings on a real playground swing, but flies straight in the virtual world such that forward movements of the swing amplify the forward momentum of the VR flight. On the other hand, if tracking data is limited to begin with, one may use machine learning and artificial intelligence techniques to synthesize plausible full-body movement [15].

Learning of fine-motor skills may also get advantage of modified feedback. Observing right hand's finger movements mapped to the left virtual hand has resulted in better gain in a learning task [16].

THE EXPERIMENT

In the present study we wanted to test if exaggerated movement brings benefits in a martial arts kicking task in virtual reality. We used a within-subjects design with level of exaggeration and viewing perspective (1st person vs. 3rd person) as the manipulated variables. The dependent variables were kicking performance and self-reports of movement naturalness, competence, motivation, self-presence, and affect.

The virtual environment

The virtual 3D environment in our test consisted of an empty floor and a set of round disc-like targets, together with a human character as the user's avatar (Figure 2). The scene was presented to the player with a HTC Vive head-mounted display. In addition to the default two hand-held controllers, we had three Vive Tracker devices attached to the user, one at the

Figure 2. The player's avatar and the five targets (illustrating locations of all targets – in the actual game they appeared one at a time).

small of the back and one on the instep of each foot. The six-point tracker setup, instead of a full mocap suit, was adopted for practical reasons and for applicability outside research labs, e.g., in VR arcades.

The players' motion was mapped to the avatar such that the trackers directly determined the position and orientation of corresponding body parts (head, back, hands and feet) of the virtual body. The elbow and knee positions were calculated from these with inverse kinematics.

The configuration was calibrated with the user in a T-pose such that the avatar's height and length of its legs matched those of the user. The targets were discs of 30 cm in diameter. They were placed 1.5 m in front of the virtual character, at five different heights (min 20 cm and max 100 % of the avatar height). In the game setting we applied restrictions on which direction the foot should approach (e.g. not vertically), in order to avoid accidental hits.

When performing exaggerated kick motion, the virtual tracker position (foot instep) was placed in a higher angle (relative to the hip) than the actual tracker, and the inverse kinematics was calculated based on this, resulting in the impression of a more flexible hip joint.

In order to avoid hyperextension and allow natural walking, the mapping from real to virtual hip angle was nonlinear, following the curves in Figure 3. In our subjective evaluation prior to the experiment, we found that the piecewise linear curve is perceptually smooth enough, and is easier to adjust than other curve parameterization that we considered.

The virtual setup was visualized in two alternative ways: 1st person perspective as seen by the avatar's eyes, or a 3rd person perspective where the avatar was displayed from the side on

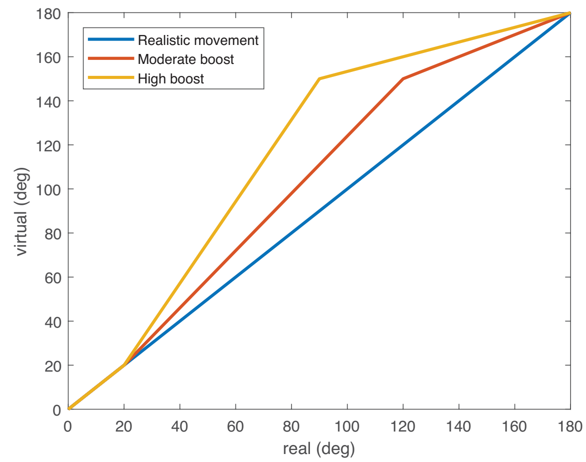

Figure 3. The mapping of hip-to-foot angle while exaggerating hip flexibility. Zero angles correspond to standing, i.e., the foot is directly below the hip joint.

a virtual screen (Figure 1). Our interest for 3rd person view comes from our earlier exergame studies and the success of action games that utilize a 3rd person view, e.g., to allow the user to better identify with the avatar and appreciate its visual design.

Participants

31 participants (25 male, 6 female) were recruited using email, social media and leaflets. The age range was 21 to 51 (mean 29.4). Height range was 147 to 190 cm (mean 175). Most participants were somewhat familiar with virtual reality, 7 had used VR devices multiple times before, only 6 had never tried any kind of VR. One movie ticket was given as compensation for participating.

One participant was omitted from the analysis due to missing data, resulting in final $N = 30$.

Procedure

The player's task was to hit the front face of each target by kicking with their dominant foot within the six seconds time the target was visible. 25 targets of variable heights (five height values, each 5 times in random order) were shown in each experimental condition. Between conditions, there was a pause to fill a questionnaire.

As the manipulated variables we had three levels of exaggeration (realistic, moderate boost and high boost) and the two visual perspectives (1st person and 3rd person), resulting in a 2x3 within-subjects design with a total of 6 experimental conditions and a total of 150 repetitions of the kicking action. To avoid carryover effects, balanced Latin square counterbalancing was used.

As objective performance measurements, we counted the number of targets hit on each round, and recorded for each kick the time used from showing a target to the hit. In addition, we tracked motion trajectory of the foot, although that information was not used in the present study.

After each round the participants were asked to fill a questionnaire (Appendix A) to subjectively evaluate the the user experience, namely sense of presence, self-presence, flow, emotional feelings, intrinsic motivation, nausea, (balance), confidence, and physical fatique. The questions were a selection of those used in earlier studies [4] [23] [18]. Answers were given by choices in 7-point Likert items.

In addition to verbal statements, we asked participants to graphically mark their experience in two-dimensional charts with continuous (low–high) scales: Arousal-Valence to indicate emotional state, and Challenge-Skill as a quick flow-state assessment. The emotional axes were described with verbal expressions such as "high arousal: you felt stimulated, aroused, excited, tense, and lively", for example.

Before the test participants were informed that they need to complete six kicking tasks, and the two different perspectives were explained. Nothing was mentioned about the exaggeration before all of the six conditions were completed.

After the test, we followed up on email to gather more qualitative data about the experience. We asked the participants to describe how the boosted movement felt, using up to three adjectives. We got 17 responses to the email before submitting this manuscript.

RESULTS

The performance measurements were converted into an index of kicking performance by dividing the number of successful target hits by the average time to a hit after the target was presented. These values were scaled such that an imaginary top performance (25 hits, each in 0.2 seconds) would make value 1.0. We used the actual time-to-hit as part of our measure because in a typical action game, speed and accuracy are both important factors of success. As the performance measure does not have intuitively natural units, we normalized it to a (roughly) 0-to-1 scale (just to avoid cumbersome numbers in the presentation). The performance index statistics for each experimental condition are represented in Figure 4 and in Table 1.

From answers to the questionnaire, four compound psychometric indicators were calculated as averages of individual items as follows:

- Self-presence (Figure 5): "the avatar's body was my own body" and "the avatar was me".
- Naturalness (Figure 6): "the movement felt natural", "I felt I was in control" and "I was able to maintain balance".
- Motivation (Figure 7): "I enjoyed this activity", "I put a lot effort", "activity held my attention", "I felt creative and original", "I think this is an important activity and it has some value to me", and negation of "I felt pressured and tensed"
- Competence (Figure 8): "Before the task I felt that I could do the task", "I felt confident in doing the task", "After the task I felt good about the way I was able to complete it", "Skill", and negation of "Challenge"

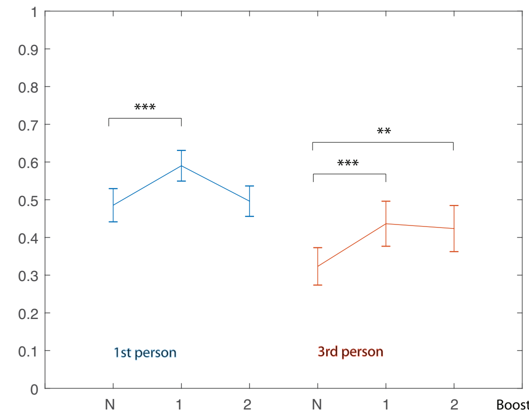

Figure 4. Performance of players in the task. In this and subsequent figures exaggeration levels are indicated as N=normal, 1=moderate boost, 2=high boost; bars present standard deviations around the means; significant differences are shown as * p < 0.05, ** p < 0.01, *** p < 0.001.

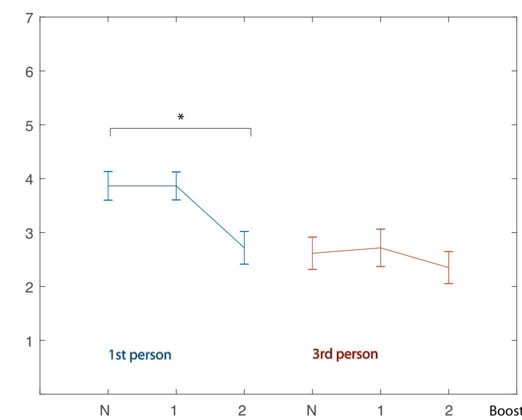

Figure 5. Self-presence with the avatar.

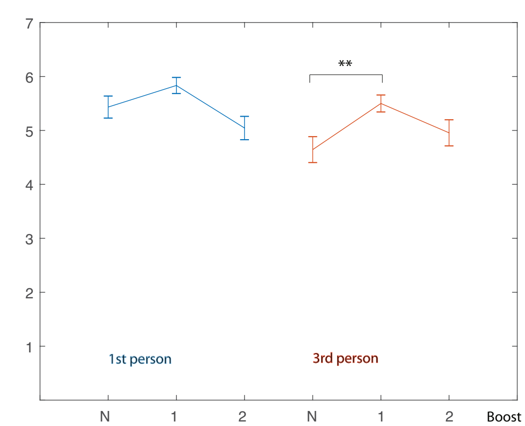

Figure 6. Naturalness of motion.

Table 1. Mean values of the results (SD in parenthesis)

Perspective / boost	Performance	Presence	Naturalness	Motivation	Competence
1st / N	0.49 (0.13)	3.87 (1.49)	5.43 (1.14)	5.82 (0.80)	4.92 (0.83)
1st / 1	0.59 (0.12)	3.87 (1.45)	5.83 (0.83)	5.93 (0.91)	5.45 (0.61)
1st / 2	0.50 (0.12)	2.72 (1.70)	5.04 (1.21)	5.61 (1.02)	5.11 (0.68)
3rd / N	0.32 (0.14)	2.62 (1.67)	4.64 (1.34)	5.62 (1.00)	4.43 (0.95)
3rd / 1	0.44 (0.17)	2.72 (1.94)	5.50 (0.88)	5.50 (1.19)	5.05 (0.96)
3rd / 2	0.42 (0.17)	2.35 (1.66)	4.96 (1.35)	5.49 (0.86)	4.84 (0.91)

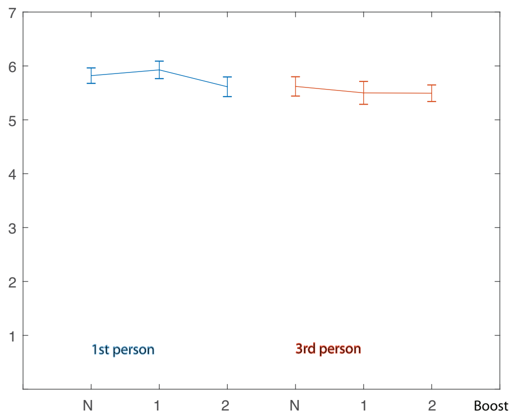

Figure 7. Motivation of the player.

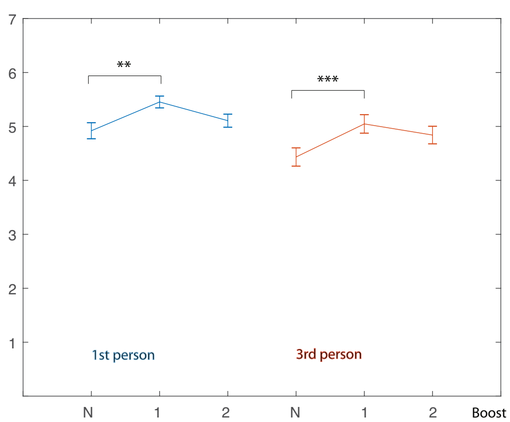

Figure 8. Competence in performing the task.

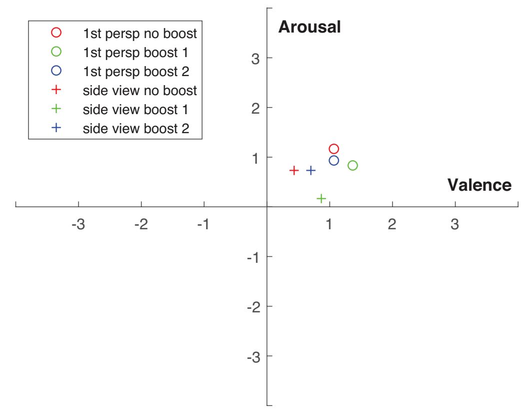

Figure 9. Participants' self-estimates of affect.

Means and standard deviations of the measured variables under different conditions are presented in Table 1.

The drawings for Arousal-Valence and Challenge-Skill were converted into integer values in the range from -3 to +3. Mean values of these under each test condition are shown in Figures 9 and 10.

ANALYSIS

Our a-priori hypothesis was that exaggeration will affect all our measured variables when compared to the baseline with no exaggeration. Further, we hypothesized that the effects persist in both 1st and 3rd person perspectives. However, we did not hypothesize about differences between the perspectives. We tested the hypotheses using t-tests (paired, two-tailed, with Bonferroni correction for five simultaneous comparisons).

The results support the hypotheses that kicks with a moderate boost, in either perspective, make the player perform better ($p < 0.001$, Figure 4) and feel more competent ($p=0.0021$ for 1st person, and $p=0.00055$ for 3rd person view, Figure 8) than without a boost. Further exaggeration diminished the effect, but in the 3rd person view it elicited better performance ($p=0.0056$) than the realistic condition. These observations go hand in hand with the feeling of naturalness (Figure 6) though significant only for moderate boost in side view ($p=0.0017$).

Moderate exaggeration had no significant effect on self-presence (i.e. how much the participant experienced the avatar was the real self), whereas high exaggeration had a negative

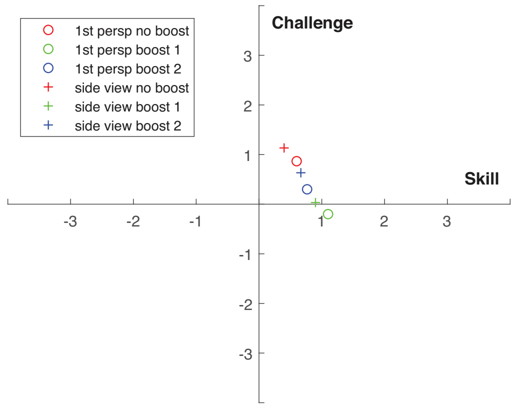

Figure 10. Participants' self-estimates of flow.

Figure 11. Adjectives that participants used to describe how the exaggerated movement felt

effect (p=0.011) in 1st person perspective (Figure 5). In the motivation indicator, there were no significant differences between any of the conditions (Figure 7).

The graphical estimations of affect and flow were almost uniformly scattered and the means were close to zero. Thus we did not pursue further statistical analysis of them. In Figures 9 and 10 one might see a moderate indication that appropriate boost feels better (more positive valence) and is emotionally more relaxed (lower arousal) than the other conditions. A similar observation in the Challenge-Skill is that with the moderate boost players feel more skilled and see the task less demanding (lower challenge). However, these are only qualitative observations without statistical significance.

Overall atmosphere in the test was good and all but one participant stated that the experiment was pleasant. However, eight participants got bored during the kicking sessions due to the repetitive nature and ease of the process. Five participants would have liked to get more feedback on their performance inside the VR environment and auditive feedback, for both hits and misses, was suggested. Most participants were able to reach even the highest targets without assistance of exaggeration (though some failed if the highest target appeared first). Three participants stated that they didn't notice any difference in the movement between the boost settings. Three female participants also said that the appearance of the avatar was misleading and felt wrong.

Qualities of exaggerated movement

Figure 11 shows a word cloud of the adjectives from the post-test email query, word sizes corresponding to frequencies. This provides qualitative evidence that the exaggeration felt natural and fun, with many adjectives also related to feeling empowered and competent, e.g., easy, empowering, powerful, limitless, helpful, confident, and energetic.

Some users also used negative terms such as "confusing", possibly because we did not specify whether the participants should only consider the overall better performing moderate exaggeration instead of both moderate and high exaggeration. One participant specifically commented that the moderate setting felt "good, unexpected, uplifting", whereas the high setting felt "confusing and weird".

Interestingly, one participant commented that *"I didn't notice there was boosted movement, but I remember being very surprised that I was able to hit the high targets, initially it was kind of bizarre, like 'Wow am I really that good?'"*, further supporting our hypothesis about elevated perceived competence.

DISCUSSION

Taken together, our results indicate that moderate exaggeration of an avatar's movement can have several benefits. Our experiment complements previous studies on exaggerating locomotion speed and jump height, widens the palette of exaggeration approaches, and gives more tools for creating empowering, superhuman exercise experiences.

Although only some of the differences between our experimental conditions reach strong statistical significance, most of the figures show agreeing inverted U curves, indicating that moderate exaggeration is in general better than either fully realistic or grossly exaggerated movement. It remains as a task for the designer to fine-tune the exaggeration for each game or task.

Considering the significance of perceived competence in the sport and exercise motivation literature, our evidence for elevated perceived competence with moderate exaggeration is perhaps the most important of the results. Naturally, self-reports of perceived competence are highly dependent on the questionnaire items and experimental tasks used; our task is designed such that there are benefits for greater flexibility. On the other hand, the same applies to many common forms of exercise such as martial arts.

The qualitative data on the exaggeration also supports the view that exaggeration can make one feel more competent and powerful as a mover. Here, we replicate earlier findings of exaggerated jump height, which players have described as *"The feeling of being a superhero"*, and *"Because the avatar*

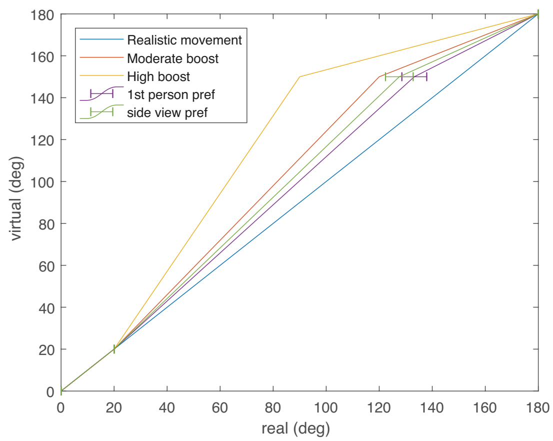

Figure 12. Participants's preferred levels of exaggeration (cf. Figure 3).

jumps with ease, it creates a feeling that I'm more competent too" [9].

Somewhat surprisingly, our data also indicates that exaggerated, non-realistic movement can actually feel more natural than fully realistic movement, in particular in a 3rd person view. On the other hand, this is in line with the surprisal expressed by players in Kick Ass Kung-Fu, when locomotion speed and jump height exaggeration was turned off [6]. A Kick Ass Kung-Fu player also commented that one starts to believe what one sees.

Our motivation indicator is the only dependent variable with no significant effects (Figure 7). In retrospect, we should modify the questionnaire, as all of the averaged items do not make sense in context of the simple and repetitive kicking task, e.g., "I felt creative and original". Also a possible limitation is that we simply averaged the six questions under Motivation indicator. Validation of this procedure should be taken into account in future studies.

Limitations

The main limitation of our system is that it has only been designed for and tested with a subset of martial arts kicks, including a front kick, side kick, and roundhouse kick. Extending the method to full martial arts combat or other movement styles will probably require fine-tuning and additional logic or control intelligence that turns the exaggeration off for movements where it is detrimental or unnatural, e.g., rolling on the ground.

We also encountered some technical problems with the HTC Vive occasionally loosing track of a limb. Overall, the tracking was somewhat noisy and glitchy. The Inverse Kinematic package we used [2] also does not handle torso rotations, leading to persistently twisted shoulder line, for example, after a roundhouse kick. This happened with 3 participants. All the tracking issues probably affected the results, especially the ratings of movement naturalness and self-presence.

In the test we had only two discrete levels of exaggeration, out of which the moderate one appeared better. This level was determined to be reasonable in a pilot test but was not necessarily optimal. For more accurate tuning, we asked the participants after the main test to try out different boosting levels for kicking a target at 150 degree height, and tell us what they preferred. The results are shown in Figure 12.

The selection of items in our questionnaire was limited. We wanted to study multiple aspects of the player's experience, but to keep the test duration feasible, we could not utilize full versions of multiple instruments such as Perceived Competence Scale (PCS), Intrinsic Motivation Inventory (IMI), or Igroup Presence Questionnaire (IPQ). Instead, we did our best to compile a representative selection of questionnaire items.

Feelings of self-presence and naturalness may be affected by using a generic male avatar instead of a replica of the player. We did not have scanning/modeling technology available for the present study, but aim to explore that approach in future work. Note that in many martial arts games, character design is a big part of the aesthetic experience and not all games would benefit from a scanned avatar.

CONCLUSIONS

In summary, we have presented a first study of the effects of flexibility exaggeration in VR. We implemented a controlled experiment where the amount of exaggeration was manipulated in the context of a martial arts kicking task. Since we also tested a 3rd person view with a virtual screen, our results should also generalize to screen-based experiences, e.g., exergames played in front of a television using some body tracking technology.

Our results indicate that flexibility exaggeration, when not overdone, offers many benefits such as increased perceived competence and perceived naturalness of movement. Qualitatively, our participants described the exaggerated movement as natural, fun, and empowering. The results have connections to the literature on physical activity motivation, especially through the importance of perceived competence.

We believe our approach presents a new tool for body-centric interaction and exergame design. However, it remains as future work to study a possible direct effect of flexibility exaggeration and other forms of movement empowerment on exercise motivation, especially in longitudinal interventions as opposed to a one-off lab study. Our approach has also not yet been implemented and tested in a full-scale game; it may be that additional control intelligence is needed to turn off the exaggeration for movements where it would not look and feel natural.

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*Antti Granqvist and Jari Takatalo are no longer employed by Aalto University.

APPENDIX: THE QUESTIONNAIRE

1. General feeling about the session

Bad	1	2	3	4	5	6	7	Good

2. Select a value that describes the experience the best

The avatar's body was my own body	1	2	3	4	5	6	7	I was in the avatar's body
The avatar was me	1	2	3	4	5	6	7	The avatar was an extension of me
The movement felt unnatural	1	2	3	4	5	6	7	The movement felt natural

3. How much do you agree with the following statements

	Completely disagree						Completely agree
Before the task I felt that I could do the task	1	2	3	4	5	6	7
In the virtual environment I felt confident in doing the task	1	2	3	4	5	6	7
After the task I felt good about the way I was able to complete it	1	2	3	4	5	6	7
I felt like I was in control of the situation	1	2	3	4	5	6	7
I felt discomfort or nausea in the virtual environment	1	2	3	4	5	6	7
I was able to maintain my physical balance while doing the task	1	2	3	4	5	6	7
I enjoyed this activity very much	1	2	3	4	5	6	7
I put a lot effort into this	1	2	3	4	5	6	7
This activity held my attention completely	1	2	3	4	5	6	7
I felt pressured and tensed while doing this activity	1	2	3	4	5	6	7
I felt creative and original while doing this activity	1	2	3	4	5	6	7
I felt physically fatigued while doing this activity	1	2	3	4	5	6	7
I think this is an important activity and it has some value to me	1	2	3	4	5	6	7

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