

A Comparative Study of Experiences in VR and Real-World Ball-Throwing Tasks

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Abstract: In recent years, virtual reality (VR) has garnered attention in the fields of sports and rehabilitation, with reports highlighting its effectiveness not only on physical aspects but also on mental and cognitive functions. While the use of VR's immersive qualities and its potential to reduce the mental burden of exercise is expanding, its effectiveness often relies heavily on the skills of its developers. A systematic understanding of the utility of VR experiences is therefore necessary. This study investigated whether the widely reported phenomenon of underestimation in VR extends to perceived time and perceived task counts. Experimental results showed that in VR environments, participants underestimated the number of play counts to 0.53 times the actual number ($p < 0.01$), while perceived time was approximately consistent with actual time at 1.19 times. In real-world environments, perceived counts were 0.91 times the actual number, and perceived time was significantly overestimated to 1.56 times the actual time. Additionally, some participants highly rated their sense of body ownership even under the same environmental conditions, and these individuals tended to perceive time and task counts more accurately. This suggests that enhancing the sense of body ownership could potentially provide a means to control such underestimation phenomena. These findings suggest that VR has the potential to contribute to reducing cognitive burdens associated with exercise experiences.

Keywords: Virtual Reality, exergame, underestimation, flow, perception

1. INTRODUCTION

1.1 Utility of VR Exercise

In recent years, numerous studies have highlighted the utility of virtual reality (VR) in sports and rehabilitation. Once a VR environment is established, it provides a convenient setting for exercise and rehabilitation, free from constraints like space limitations or weather conditions. This makes VR particularly suitable for use in hospitals and care facilities. Additionally, for lighter exercise routines, VR serves as an accessible option that lowers the barriers to starting physical activity, even in small personal spaces.

Beyond its role as a new medium for exercise, VR offers advantages such as gamification, which enhances the enjoyment of physical activity, and the ease of tracking performance metrics in a digital environment. Particularly in the field of rehabilitation, studies have reported VR's benefits not only for physical improvements but also for mental and cognitive functions [1]. Leveraging VR's strengths, including its immersive quality, has led to a growing trend of incorporating VR into rehabilitation programs.

For example, VR exergames designed for the rehabilitation of patients with multiple sclerosis have shown superior effectiveness compared to traditional exercises in improving physical, cognitive, and psychosocial conditions, as well as reducing fatigue [2]. Similarly, VR applied to seated rehabilitation for stroke patients demonstrated enhanced mobility in lower limb rehabilitation compared to standard treatment [3]. Even among healthy individuals, VR exergames that focus on vertical jump training effectively strengthened lower body muscles and increased motivation [4]. Studies comparing VR exercises to offline exercises have also reported broader joint ranges of motion and greater activation of the prefrontal cortex, as measured using near-infrared spectroscopy [5].

Research suggests that VR-based exercise games may

reduce the mental burden of exercise, with studies emphasizing both the enjoyment and the reduced effort associated with VR [6]. Popular VR fitness games, such as Beat Saber (Meta), BoxVR (FitXR Limited), and Superhot VR (SUPERHOT Team), have been highly rated for their entertainment value. Notably, Holopoint (Alzan Studios LLC), an archery action game, received the highest enjoyment ratings in previous studies [6]. Other research indicates that immersive VR positively affects motivation, enjoyment, and engagement during exercise, with high-immersion VR delivering greater benefits than low-immersion VR or traditional non-VR exercises [7].

Thus, VR-based exercise offers advantages beyond enjoyment, such as enabling performance enhancements through strategies like White Lie manipulations, where avatars or objects are presented in ways that are not possible in real-world settings. However, the reliance on game design for enjoyment indicates that these effects are heavily dependent on the skills of developers. To maximize the benefits of VR-based exercise beyond its logistical advantages, a deeper understanding of VR-specific effects is required.

1.2 The "Underestimation" Phenomenon in VR

Independent of specific content, VR has been reported to be an effective tool for reducing perceptions of pain and effort [8]. The immersive nature of VR, which increases sensory input through visual and auditory stimuli, diverts attention from real-world sensations, thus diminishing pain signals and alleviating discomfort [9].

Since its inception, VR has been known to cause users to underestimate distances [10, 11]. Studies suggest that this underestimation can be controlled through environmental design, such as adjusting the size of the virtual environment [11] or modifying acoustic reverberations [12]. Similarly, VR has been reported to affect perceptions of time; for instance, cognitive tasks performed in VR led to a 22.18% reduction in perceived

time compared to non-VR experiences [13].

1.3 Preliminary Research and Study Objectives

In a previous VR experiment [14], free-response feedback from participants frequently included comments such as “Time flew by.” This prompted an investigation into the discrepancies between perceived time and the number of attempts compared to actual measurements. Results showed that perceived attempts were 0.38 times the actual count, while perceived time was 1.08 times the actual duration, suggesting that VR may induce underestimation of play counts.

However, the experiment also employed a manipulation called White Lie, which altered the appearance of objects during gameplay. This made it unclear whether the observed effects were due to VR itself or the White Lie. Furthermore, it could not be ruled out that people generally tend to underestimate play counts regardless of the context.

To address these issues, this study compares the same task performed in VR and real-world environments to analyze differences between perceived and actual play time and counts. The aim is to determine whether VR-induced underestimation extends to time and effort during exercise experiences. Clarifying the factors underlying discrepancies between perceived and actual experiences is important for designing VR-based exercise programs, particularly in terms of reducing perceived exertion, sustaining motivation, and adjusting subjective time perception. Especially in rehabilitation contexts, manipulating perception—such as initially causing patients to underestimate the amount of exercise performed to encourage continued participation, then later revealing their actual exercise duration and task volume to foster a sense of achievement (“I could actually do that much!”)—may effectively enhance motivation and optimize exercise duration.

2. METHODS

2.1 Task Design

We developed a simplified VR ball-throwing task that relies solely on physical calculations, without performance manipulation. In the VR setup, participants performed target-throwing without holding a physical ball. For safety reasons, underhand throwing was required. The target position was individually adjusted based on participants’ throwing ability. A hit was defined as the ball’s initial contact with any part of the target. Bounces or subsequent rolling contact were considered invalid.

2.2 VR Ball-Throwing Implementation

The VR system utilized an HTC Vive Pro Eye HMD, two Tracker 2 devices, and two Base Stations. Trackers were attached to the participant’s dominant shoulder and palm to capture throwing motions and replicate them in the VR environment. For natural rendering in VR, the ball’s diameter was set to 6 cm, and the target was a circular object with a 30 cm diameter.

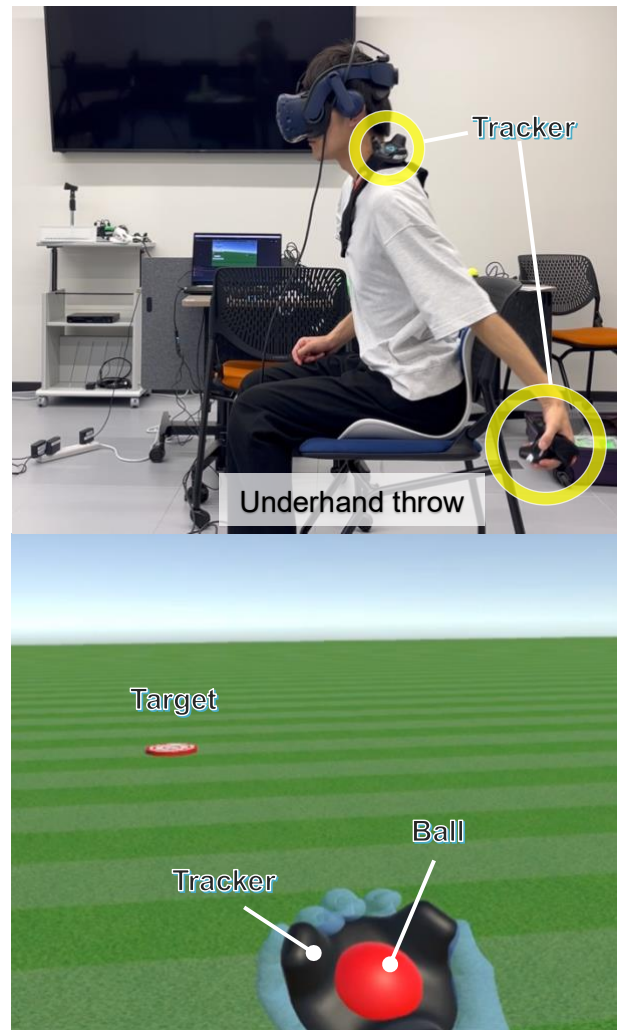


Fig.1 Experimental setup for VR. (Upper: participant view, lower: VR screen view.)

Given that depth perception in VR can be challenging, we incorporated clear feedback: white smoke and an audible sound effect were triggered upon a successful hit. The system continuously recorded the ball’s landing positions during the task. In the VR condition, participants did not hold a physical ball, nor was any tactile or haptic weight feedback provided. This setup intentionally differed from the real-world task in order to clearly examine experiential differences between VR and real-world ball throwing.

2.3 Real-World Ball-Throwing Preparation

For the real-world task, ball-throwing was conducted outdoors on asphalt. The equipment included official boccia balls (86 mm diameter, 275 g weight) and octagonal targets (25 cm × 25 cm), which were fixed to the ground with tape. Participants sat on a chair, as in the VR task, and threw balls underhand. They initially had 10 balls at their disposal, throwing at their own pace. Thrown balls were retrieved and returned the thrown balls. For trials without targets, landing positions were

Table 1 Comparison of actual and perceived task duration and play counts in VR and real-world environments

Participant No.	Environment Tested First	Perceived/Actual Time Ratio		Perceived/Attempts Ratio		Perceived Time (min)		Perceived Attempts	
		VR	Real-World	VR	Real-World	VR	Real-World	VR	Real-World
1	Real-World	0.94	1.69	0.36	0.86	5	7	40	30
2	Real-World	1.25	1.62	0.48	0.73	5	7	45	30
3	VR	0.79	1.12	0.47	0.65	3.5	5	40	30
4	VR	1.09	1.67	0.52	0.70	5	7	50	35
5	VR	1.21	2.26	0.42	1.11	5	10	40	40
6	Real-World	2.34	2.22	0.65	1.30	10	10	80	52
7	Real-World	1.19	1.18	1.00	1.05	5	5	90	60
8	VR	0.71	0.70	0.34	0.88	3	3	30	30
ave.		1.19	1.56	0.53	0.91	5.19	6.75	52	38

marked with tape. The experiments took place in August 2024 during a heatwave, with temperatures exceeding 30°C even in the mornings and evenings.

2.4 Procedure

Eight healthy adult participants (5 males, 3 females, mean age = 25.1 ± 5.8 years) completed both the VR and real-world ball-throwing tasks. Half began with the VR task, and the other half started with the real-world task. To minimize the impact of perceived difficulty on time and attempt estimations, participants' difficulty levels were adjusted through the following steps, and measurements were taken during their final adjusted trial:

1. Initial 10 throws for setting the position of the target

They performed 10 underhand throws aiming for maximum distance to familiarize themselves with the motion and measure their throwing ability.

2. 10 target throws with difficulty adjustment

Based on the longest throw from the initial 10, multiplied by 1.2, the target was placed at an individualized distance. The target distance was adjusted as needed.

3. 20 target throws with difficulty adjustment

4. Timed 4-minute target-throwing task

Participants were instructed to continue target-throwing until told to stop, without being informed of the duration. After 4 minutes, they were asked to estimate their throwing time and the number of throws.

5. Questionnaire

Investigating the differences in perception and performance metrics between virtual reality (VR) and real-world environments using subjective and objective measures—fatigue, enjoyment, difficulty, sense of ownership, and operability—assessed using a five-point Likert scale.

All participants completed the above procedure in both the VR and real-world environments.

3. RESULT

3.1 “Underestimation” Phenomenon

The total duration of the experiment, including the difficulty adjustment phase in each environment, ranged from just under 10 minutes to approximately 15 minutes. Table 1 presents the results of the main trials. The actual task duration was 4 minutes in both environments. The average number of attempts was 42.4 ± 7.6 in the real-world environment and 98.0 ± 12.3 in the VR environment. Participants underestimated the number of attempts in the VR environment to approximately 0.53 times the actual count ($p < 0.01$). In contrast, perceived time was slightly overestimated to 1.19 times the actual duration, although the difference was negligible.

In the real-world environment, participants slightly underestimated the number of attempts, with a perceived-to-actual ratio of 0.91. However, the perceived time was significantly overestimated to 1.56 times the actual duration, indicating a stronger perception of extended playtime. Comparing perceived time between the two environments, participants in both settings reported longer durations than the actual time. However, the discrepancy was smaller in the VR environment ($p < 0.05$).

3.2 Quantitative Analysis of Perception and Performance in VR and Real-World Environments

3.2.1 Subjective Evaluations: Fatigue and Enjoyment

A paired t-test revealed significant differences in perceived fatigue between the VR and real-world environments ($t = -2.58, p = 0.03$). Participants reported lower fatigue in VR (mean = 3.25) compared to the real-world environment (mean = 3.5). In terms of enjoyment, VR was rated significantly higher than the real world ($t = 2.84, p = 0.02$), with means of 3.13 and 2.13, respectively. These findings suggest that while VR reduces physical exertion, its game design elements, such as visual and auditory feedback, enhance overall enjoyment. Additionally, there was no significant difference in reported physical fatigue between VR

(mean = 3.375, SD = 1.267) and real-world conditions (mean = 3.250, SD = 1.035); paired t-test: $t(7) = 0.228$, $p = 0.826$. Correlation analysis also showed no significant relationship between physical fatigue and perceived task counts in either the VR condition ($r = 0.237$, $t(6) = 0.60$, $p = 0.56$) or the real-world condition ($r = 0.228$, $t(6) = 0.57$, $p = 0.59$).

3.2.2 Throwing Efficiency

Throwing efficiency, defined as the number of throws per unit time, was significantly higher in the VR environment ($t = 5.92$, $p < 0.01$). The average efficiency in VR was 0.38 throws/sec., compared to 0.15 throws/sec. in the real world. This difference highlights VR's ability to eliminate non-throwing tasks, such as retrieving balls, which optimizes the activity flow.

3.2.3 Sense of Ownership and Operability

A correlation analysis revealed a positive relationship between the sense of ownership and perceived/actual task metrics in the VR environment. Participants who reported a stronger sense of ownership exhibited a closer alignment between perceived and actual playtime ($r = 0.76$, $p = 0.04$) and throw counts ($r = 0.68$, $p = 0.08$). These findings suggest that enhancing the sense of ownership and operability in VR could improve users' accuracy in perceiving task-related metrics, thereby increasing the overall fidelity and effectiveness of the VR experience.

4. DISCUSSIONS

Although the authors hypothesized that the flow phenomenon might lead to underestimations, the commonly reported underestimation of perceived time [15] was not observed in VR or real-world environments. Flow experiences are known to be influenced by environmental factors [16]. Given that participants overestimated time in both environments, it is unlikely that a flow state occurred during the experiment.

The primary reason for the underestimation of throw counts in the VR environment is likely the absence of physical weight for the virtual ball. Humans are believed to estimate perceived time and task counts based on prior experiences, as evidenced by the observation that participants with a higher sense of body ownership in the VR environment—those who experienced sensations closer to real-world experiences—tended to estimate perceived counts and time more accurately. Furthermore, statistical analysis of participants' responses revealed significantly less fatigue reported in the VR environment compared to the real world. This suggests that the reduction in physical load due to the absence of ball weight made each throwing action feel lighter, which may have caused participants not to perceive it as equivalent to a normal throw. Another possible factor is that the flow phenomenon may influence not only perceived time but also the perceived quantity of actions, which could explain why participants underestimated play counts in both environments compared to the actual counts. In VR, where the sensory input is reduced

compared to the real-world environment, the immersion induced by this reduction might amplify the influence of the flow phenomenon on task frequency.

The longer perceived time in the real-world environment could be attributed to the impact of the heat, which may have distorted participants' perceptions or increased cognitive load. Additionally, while VR allowed participants to focus solely on throwing, the real-world setup required them to retrieve balls and perform additional steps, creating interruptions and increasing the overall sense of effort. Although we initially hypothesized that differences in perceived task counts between VR and real-world conditions could be attributed primarily to physical fatigue due to the difference in ball weight, the statistical results did not support this hypothesis. Specifically, no significant difference in physical fatigue ratings between conditions and no correlation between fatigue ratings and perceived task counts in either condition were observed. Thus, the difference in perceived task counts may rather result from fewer sensory cues and lower informational richness per trial in VR, potentially causing each action to feel subjectively lighter and leading participants to underestimate their perceived number of throws. This added complexity might have led to a greater perceived duration than the VR environment.

Standardizing conditions across VR and real-world environments is inherently challenging. However, such differences in effort and conditions, such as retrieving balls in the real world, naturally arise during real-world gameplay. These results highlight VR's practicality, enabling users to focus solely on desired movements and perform tasks that may not be feasible alone in the real world. The high throwing efficiency observed in VR further underscores its advantages, allowing users to concentrate exclusively on the intended actions. Even for a simple task like ball-throwing, participants reported finding VR more enjoyable than the real-world environment. This indicates that implementing tasks in VR has intrinsic value, even without elaborate content designs. Additionally, deliberately reducing the sense of body ownership could potentially promote underestimation effects, offering a novel application of VR to reduce perceived user burden during exercise.

Future studies should also examine intermediate conditions, such as utilizing large-screen monitors displaying identical VR visuals, to explore whether adding real-world visual cues could mitigate perceptual discrepancies, as previous AR/MR research indicates that increased environmental cues tend to reduce perceptual distortions observed in VR.

5. CONCLUSION AND FUTURE WORK

In the VR environment, participants significantly underestimated the number of attempts to approximately half of the actual count. Perceived time was slightly underestimated compared to the real-world environment but closely matched the actual duration. In contrast, in the real-world environment, perceived attempts closely

aligned with the actual number, but participants significantly overestimated perceived time to 1.56 times the actual duration.

While the precise cause of the underestimation of attempts remains unclear, the absence of physical interaction with a weighted ball in VR may have contributed. Future studies could involve VR setups that include a tangible ball to investigate the role of physical weight. Additionally, some participants highly rated their sense of body ownership even under the same environmental conditions, and these individuals tended to perceive time and task counts more accurately. This suggests that enhancing the sense of body ownership could potentially provide a means to control such underestimation phenomena.

Despite the preparation and relatively short task durations of around 10 minutes in each environment, the outdoor real-world experiments were conducted during a heatwave, with temperatures consistently exceeding 30°C. This suggests that heat may have influenced the participants' experiences. To address this, future experiments in cooler seasons are under consideration.

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