Effect of Height Perception on State Self-Esteem and Cognitive Performance in Virtual Reality

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Abstract. Tall stature has long been regarded as a socially desirable asset. Past literature has uncovered a positive correlation between height and cognitive ability, with evidence indicating that subjective evaluations of self-worth are highly susceptible to changes in body image. In this study, we aimed to investigate whether implementing a deliberate increase in height perception can affect individuals' state self-esteem, working memory, and visuospatial competency. Adapting the theoretical model of height-career success relationship, it is hypothesized that height alteration would lead to higher levels of positive self-appraisals, as well as better objective and subjective cognitive performance. In this pilot study, we leveraged an immersive virtual reality system to manipulate individuals' height. Participants conducted a series of letter recall and mental rotation tests, estimated their cognitive performance, and completed the State Self-Esteem Scale in a virtual environment. While improvements in working memory and spatial skills were observed in the increased height condition, ratings of self-perceived performance did not significantly differ. Among all facets of self-esteem, only appearance self-esteem showed a significant increase under the influence of height enhancement. This may suggest that benefits of taller height perceptions are sensitive to stature-related self-evaluations, even in the absence of external appraisals.

Keywords: Height · Virtual reality · Spatial ability · Mental rotation · Working memory · Self-esteem

1 Introduction

Across human history, societal bias in favor of tall stature has transcended cultural boundaries and become imperceptibly normalized in regular judgement and decision-making processes. Numerous studies have indicated that height is positively associated with leadership emergence, which can be further mediated by interpersonal dominance, vitality, and intelligence [2, 11]. From the evolutionary perspective, physically

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formidable organisms tend to be perceived as more resourceful in holding power, which in turn leads to higher self-esteem and contributes to the success in achieving a higher social rank within groups [13].

The impact of height-associated benefits is also well-manifested in people's socioeconomic status. Past literature has suggested that teenage height may serve as a promising predictor of success in adulthood, as taller individuals are typically endowed with better educational attainment, positive employment prospects, and higher earnings [8, 22]. According to Persico et al. [19], even in the same occupational field, the tallest quarter of the population may find themselves in more superior job positions. Moreover, taller workers in general enjoy an extra thirteen percent salary when compared to those in the 25th percentile, demonstrating a conspicuous wage disparity. It is clear that height outweighs a considerable variety of individual characteristics and serves as an important indicator for evaluation of capabilities and success.

Despite the strong preference for tall statures in societal settings, the reasoning behind this height premium remains a widely debated controversy. A number of studies have argued that tall children are on average more intelligent and thus more likely to outperform their peers in cognitive assessments [27]. The proven association between height and cognitive ability is evident throughout the lifespan. In particular, it was found that taller populations, who presumably possess stronger cognitive skills, tend to pursue more intellectually stimulating professions and receive higher earnings, rather than lending themselves to physically strenuous jobs that are lower-paying in general [7].

On the other hand, Judge and Cable's [12] theoretical model of the height–career success relationship examined a sequence of mediators that may account for the advantages of being tall. To start with, the model emphasizes the impact of height on self-esteem, which is defined as individual's overall sense of self-worth and competence [5]. Past literature has uncovered a profound relationship between subjective evaluations of height and self-worth. This association was found to be mediated by the effect of self-consciousness, which illustrates the significance of perception and reflection in formation of body image disturbance [3, 19]. Self-appraisals owing to height influences can also be mediated by social esteem, which refers to judgmental inferences directed from others to oneself, or in the case of height-related research, a construct operationalized as perceived stature [21]. While self-esteem is generally regarded as an endurable trait, its susceptibility to environmental stimuli often leads to momentary fluctuations in daily interactions.

Under the influence of rapid technological advancements in recent decades, mass media has played a critical role in transmitting societal perceptions of idealized body image, reinforcing the notion that physical attractiveness is linked to tall stature [9]. In particular, interactive digital platforms have further intensified public engagement in maladaptive self-evaluation processes. Body image dissatisfaction is directly correlated to appearance-related social comparisons [26]. Previous work has shown that shorter individuals are susceptible to suffering from low self-esteem, which would sequentially exert a negative influence on their social competence and psychological well-being [25]. Furthermore, self-esteem influenced by body morphology ideals would affect both objective and subjective performance, thus mediating the relationship between appearance and workplace success in terms of earnings and leadership emergence [12].

While theories accounting for benefits of being tall have been well established, limited attention has been paid to the effect of height-related changes on an individual level. If tall stature is associated with psychological and social advantages, would doses of height alteration experiences serve as a potential intervention for individuals suffering from unfavorable consequences of having a short stature?

One safe and convenient way of answering this question would be to utilize the novelty of immersive virtual reality (VR) for inducing altered body perceptions through lifelike immersions [32]. The integration of this advanced technology into clinical interventions and experimentation has received rising popularity in the field of mental health and clinical psychology (e.g., [24]). To date, increasing number of studies on body morphology manipulation have utilized digitalized virtual avatars to examine body-representation and its associated well-being effects. In particular, past literature has found that self-perceptions of virtual representations are correlated with self-esteem and body esteem in adolescence [29]. Many considered variables other than stature, for instance, weight and body shape, to develop preventive interventions and treatments for patients suffering from obesity and eating disorders [20, 23]. Manipulation of height in VR was tested in research that focused on height rather than other body ideations, which suggest that deliberate reduction in a person's height would lead to more negative self-evaluations and increased levels of paranoia [6]. Implementing direct alteration of an individuals' stature can ensure strict control for potential confounding effects of other indicators of body morphology, which may be prevalent in the creation of self-avatars.

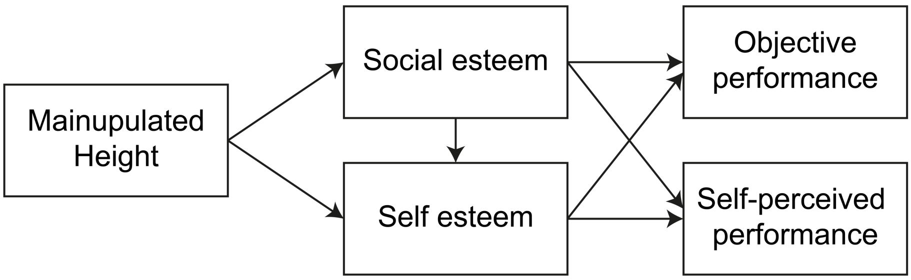

Fig. 1. Height-performance relationship theoretical model, adapted from Judge and Cable [12]

Here, we aim to investigate whether deliberate manipulation of a person's height in VR would influence one's self-evaluation and competence in cognitive assessments. Following the general theoretical basis of Judge and Cable's [12] model of the physical height and career success, we developed a hypothesized model of height-performance relationship. The model suggests that virtual height alternation would enhance individual's esteem, which would in turn lead to better objective and self-perceived performance (Fig. 1). (Note that adapted from Judge and Cable [12] model, social esteem and self-esteem are both mediating factors, however, we are not investigating social esteem in the current pilot study.) It is hypothesized that when compared to the initial stature, individuals with increased height would elicit higher levels of self-esteem, in particular, height-related appearance appraisals. In addition, we predict that when given a taller virtual stature, participants would demonstrate improved memory and spatial skills and hence better cognitive performance in both objective and subjective measures. To test these hypotheses, we invited healthy volunteers to experience an immersive VR system under differing height perceptions in order to compare their levels of self-esteem, memory skills and spatial ability.

2 Methods

2.1 Participants

Twelve healthy volunteers were recruited at the University of Hong Kong to take part in this pilot study. Two participants were excluded from the data analyses due to technical complications. Thus, the final sample size consisted of ten Chinese participants (7 females, M_{age} = 26.6 years, SD_{age} = 5.62 years, age range: 20–35 years), with body height ranging from 154 cm to 178 cm (M = 161.9 cm, SD = 8.80 cm). All participants had adequate stereopsis, normal or corrected-to-normal vision, and no cognitive impairment. Participants gave written informed consent and received payment for their participation. They were free to withdraw at any point of the study without negative consequences. The study was approved by the local Research Ethics Committee of the University of Hong Kong.

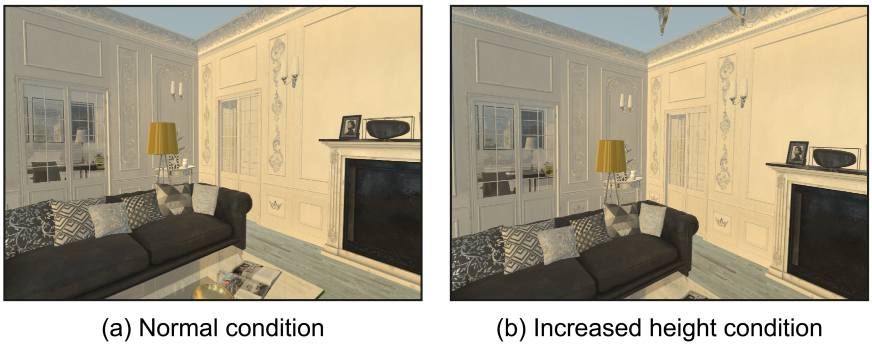

Fig. 2. Sample view of the virtual scene in (a) normal condition (control) and (b) increased height condition (30 cm increased)

2.2 Apparatus

The experiment was conducted using a head mounted display (HMD). The HMD (VIVE Pro; HTC, New Taipei City, Taiwan) included separate 3.5” displays for each eye (with measured luminance of 143 cd/m^2), each with a resolution of 1440 × 1600 pixels at a refresh rate of 90 Hz, yielding a 110° horizontal field of view. Fresnel lens is located in front of the displays to render visual content at optical infinity. Head tracking was facilitated by combining internal accelerometer and gyroscope, and external infrared tracking data. The display was connected to a 64-bit Windows 10 PC with an Intel® Core™ i7-7700K CPU @4.20 Ghz processor, 16 GB Ram, and a NVIDIA® GeForce® RTX 2080 Ti graphics card. We presented a virtual apartment with realistic furniture (Fig. 2a) developed in Unity (version 2018.4.6f1; Unity Technologies, San Francisco, CA, United States) and rendered using SteamVR (Valve, Bellevue, WA, United States). The viewpoint tracking system updated the location and orientation of the virtual stereoscopic camera to provide lifelike VR rendering [14].

In the experimental condition, we increased participants' height by 30 cm (Fig. 2b), which was the approximate size of a head, with regard to all aspects of the virtual experience. Except the perceptual manipulation, an identical virtual scene was leveraged for both conditions. Throughout the experiment, when required, digitized virtual screen displays (70 cm × 70 cm) were shown in front of the participants at eye level in order to present the cognitive task stimuli and instructions in the virtual apartment.

2.3 Experimental Design

The independent variable of interest was virtual height manipulation. Performance in letter recall and mental rotation tasks, denoted by the percentage of correct response, as well as participants' level of self-esteem serve as the outcome variables of the study.

2.4 Procedure

Upon arrival to the laboratory, participants provided written informed consent to participate in the research study. The experimenter explained the cognitive test by presenting an example of the letter pairs and spatial rotation problem on a computer monitor. The participant did not practice the given task but were asked if they understood the procedures involved. In addition, they were asked to complete a short demographic survey and a baseline SSES questionnaire. The experimenter then introduced the apparatus and assisted the participants in putting on the HMD. In the virtual environment, a practice trial of the cognitive test was utilized to ensure that all participants understood the timing of each experimental stage. Feedback on response accuracy was not provided. However, participants could ask clarification questions and were prompted to respond if they did not do so in the designated task phase.

Each participant took part in two blocks of trials based on random assignment: the normal height condition and the increased height condition. Each block started off with a 2-minute VR exposure, which featured an interactive object search task to elicit self-conscious comparison between the given environmental cues and one's physical height, so as to consolidate the novel height perception in this illusion of reality. They were also asked to walk around and search for objects hidden in the virtual scene. This interactive task was immediately followed by 10 randomized trials of cognitive tests, which included both letter recall and mental rotation tasks. Then, participants were asked to complete the self-esteem questionnaire and estimate their performance. There was a 5-minute break between conditions where the HMD would be removed from the participants for reset of VR height manipulation. The duration of time required to complete all assessments was approximately 35 to 40 minutes. Throughout the experimental process, participants were not informed of the height alteration in the VR system and remained naïve to the aim of the study. We manipulated the height perception in the VR program before participants put on their HMD to avoid a sudden shift of visual perspective.

2.5 Assessments

Cognitive Tests. To evaluate the objective performance of participants under normal and heightened perceptions, a series of cognitive tests were adopted based on Steed et al.'s [28] experimental framework. We integrated letter recall and mental rotation tasks to assess individuals' cognitive abilities in terms of memory skills and spatial functioning respectively. In this study, a total of 20 independent trials were equally divided into two blocks through random assignment. The task stimuli and instructions were presented on the aforementioned virtual screen display, which was positioned in front of the participants in the immersive virtual environment. All stages were subjected to fixed durations of time and conducted in a continuous sequence automatically (see Fig. 3).

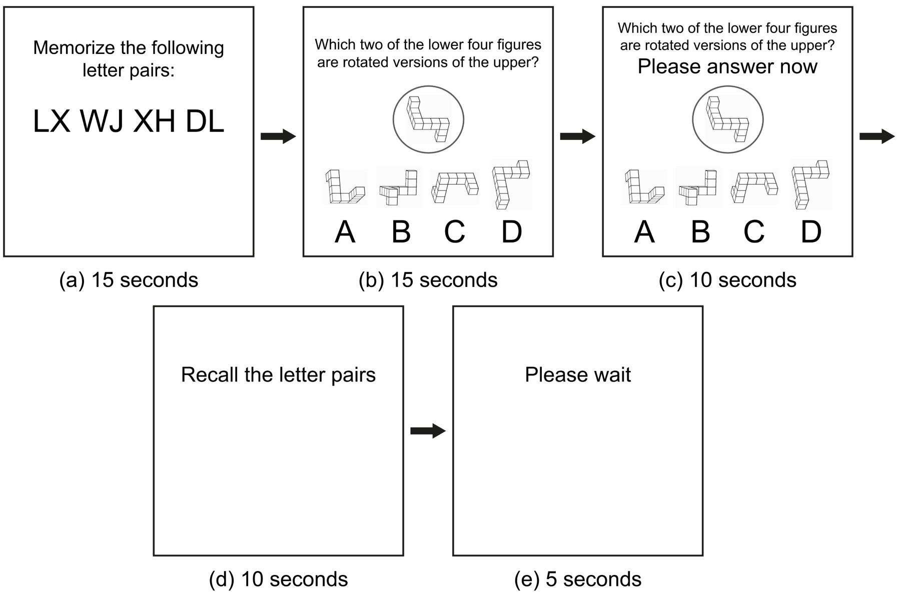

Fig. 3. Sequential demonstration of a sample trial of the cognitive test (a) exposure to letter pairs, (b) exposure to 3D figures, (c) completion of mental rotation task, (d) recollection of letter sequence, and (e) between-task short break

To compare participants' self-perceived subjective performance in the normal and increased height conditions, upon completion of all cognitive test in each block, we asked participants to estimate their accuracy rates in both the letter recall task and mental rotation task.

Letter Recall Task. Letter recall task established on Goldin-Meadow et al.'s [7] cognitive test was leveraged to measure participants' working memory capacity. In each trial, we presented four distinctive letter pairs to facilitate the memorization and recollection process. In accordance with prior work, it was found that relative to letter sequence consisting of both vowels and consonants, those formed solely by consonants can yield a more optimum level of difficulty for testing [7]. Hence, each trial of the letter recall tasks adopted in this study was developed based on eighty randomized consonant letters.

In the initial phase of each trial (Fig. 3a), participants were asked to memorize the visually presented letter sequence within a 15 s exposure period. Subsequent to stimuli exposure, participants experienced a 25 s retention interval. In this phase, the mental rotation task was conducted without the presence of any visual prompt with respect to the letter pairs (Fig. 3b, c). This was immediately followed by a 10 s recollection period in order to facilitate serial recall and verbal report of the memorized letter pairs (Fig. 3d). Participants' responses were recorded and scored by the experimenter, and reported as percentage correct in later analysis. Each correct letter pair was awarded with one mark, thus a maximum of forty marks could be attained in each block. No marks were given for letter pairs with noted transposition errors and incorrect combination of letters.

Mental Rotation Task. To examine participants' spatial ability, spatial tasks based on the Vandenberg and Kuse Mental Rotation Test were formulated using 3D figures in the Library of Shepard and Metzler-type Mental Rotation Stimuli [17, 18]. In this task, participants were first shown five figures in a 15 s exposure period (Fig. 3b). All stimuli were in rotation around the horizontal axis and presented in an identical white frame against a white background. A reference stimulus was positioned on top of four potential matching blocks, which were positioned in various orientations and labelled as option "A", "B", "C" and "D" respectively. Participants were asked to orient mental representations of the stimuli for dynamic comparisons, then verbally report two figures that shared the same configuration with the reference stimuli in the subsequent 10 s response period (Fig. 3c). Participants' responses, represented by two different alphabets, were recorded and scored by the experimenter, and reported as percentage correct in later analysis. One score was awarded for each correct response, which can accumulate to a maximum of twenty marks per condition. In addition to being a stand-alone assessment of visuospatial ability, the mental rotation task also serves the purpose of inducing cognitive load in the letter recall process.

State Self-Esteem Scale (SSES). We used the State Self-Esteem Scale, a well-validated and psychometrically sound measurement, to measure momentary fluctuations of individual self-esteem subsequent to height manipulation [10]. It comprises twenty self-report items, each rated on a 5-point Likert scale (1 = Not at all, 2 = A little bit, 3 = Somewhat, 4 = Very much, and 5 = Extremely). Three subscales were used to conduct multidimensional assessment in the specific facets of appearance, performance, and social self-esteem. In the current study, participants were asked to rate the SSES for how they perceive themselves in relation to their experience in the virtual environment.

2.6 Data Analysis

Following a within-group experimental design, paired-sample t-test analyses were carried out using jamovi (version 1.2.27). Outcome variables were compared between the normal and increased height conditions. The order of conditions was counter-balanced in order to minimize potential confounding influence of the sequence, for instance, cognitive fatigue and learning effects. We checked for normality using Shapiro-Wilk test.

3 Results

3.1 Letter Recall Task

Figure 4a shows the letter recall task performance in the normal and increased height conditions. The within-group experimental design was tested with a paired-sample t-test to examine the effect of height manipulation on working memory capacity with regard to serial recall performance. Participants under the influence of heightened virtual perception remembered 23.78% more letter pairs when compared to the normal height condition. The difference in mean proportion of correctly recalled letter pairs across conditions was statistically significant, $t(9) = 2.56$, $p = 0.031$, Cohen's d = 0.809. In terms of subjective performance, the self-report estimation of correctly remembered letter pairs in the increased height condition was 8% higher than that of the control condition. However, the results were not confirmed statistically, $t(9) = 1.58$, $p = 0.149$, Cohen's d = 0.499.

3.2 Mental Rotation Task

Figure 4b shows the mental rotation task performance in the normal and increased height conditions. We conducted a paired-sample t-test to compare the mean proportion of correctly solved spatial tasks under the effect of differing height perceptions. Our results indicated that participants identified 17.48% more correct mental rotation figures when they became taller in the virtual environment. The difference in performance across conditions was confirmed statistically, $t(9) = 2.68$, $p = 0.025$, Cohen's d = 0.846. However, participants' subjective estimations of correctly solved mental rotation problems did not differ significantly across the two conditions, $t(9) = -0.345$, $p = 0.738$, Cohen's d = -0.109.

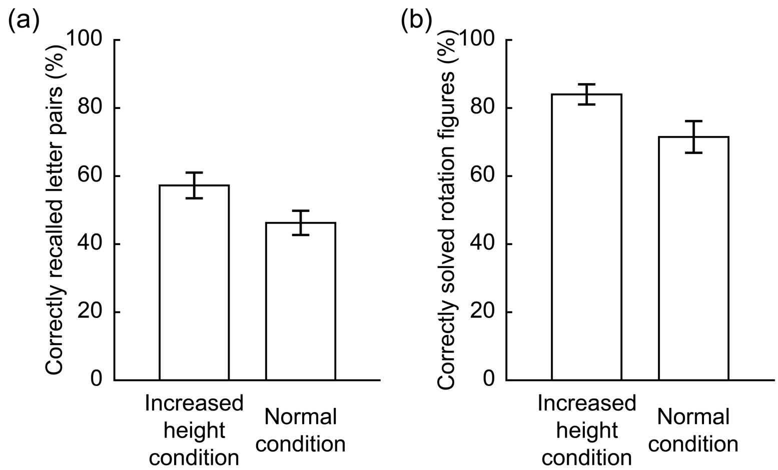

Fig. 4. Performance in cognitive tests (a) letter recall task and (b) mental rotation task in the normal and increased height condition expressed in terms of percentage correct. Error bars indicate SEM across participants.

3.3 State Self-Esteem

Figure 5 shows participants' overall level of SSES, as well as the appearance, performance, and social facets in the normal and increased height condition. We conducted a paired-sample t-test to examine the potential fluctuations in self-esteem induced by virtual height alteration. Results revealed that the SSES total score was higher in the increased height condition when compared to the normal height condition. However, the mean scores were not significantly different across conditions, $t(9) = 1.28$, $p = 0.233$, Cohen's d = 0.405.

To further investigate the effects of height manipulation on different domains of self-esteem, paired-sample t-tests were conducted to compare the SSES scores in each of the three subscales. We found that participants' appearance self-esteem was significantly higher under height manipulation when compared to the control scenario, $t(9) = 2.50$, $p = 0.034$, Cohen's d = 0.789. However, we found no evidence for significant changes across conditions in performance self-esteem, $t(9) = 0.77$, $p = 0.462$, Cohen's d = 0.243, and social self-esteem, $t(9) = 1.15$, $p = 0.279$, Cohen's d = 0.364.

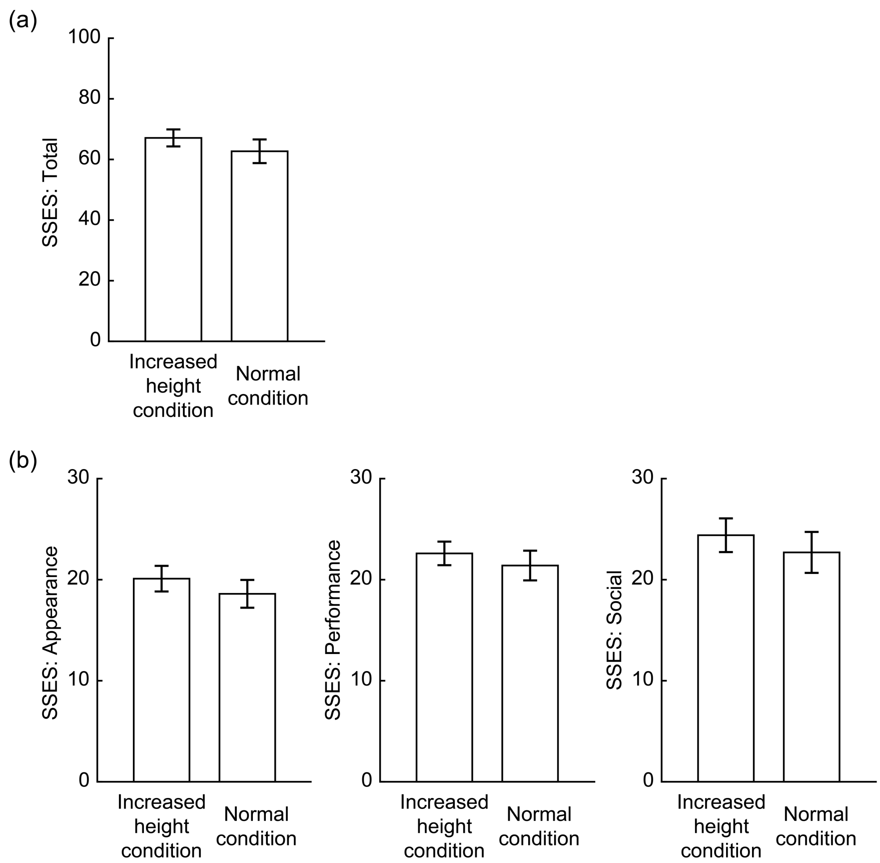

Fig. 5. (a) Total score and (b) specific facets of State Self-Esteem Score (SSES) in the normal and increased height condition. Error bars indicate SEM across participants.

4 Discussion

Over time, extensive literature has been devoted to investigating the underlying causes and deep-rooted effects of height-associated benefits in societal settings [12]. While the impact of stature on self-esteem and cognitive ability has garnered scholarly interest, few studies have yet attempted to address both constructs in a collective manner. In this pilot study, we manipulated participants' virtual height in an immersive VR system to examine their self-esteem, memory skills, and spatial ability under different situations.

In accordance with our hypotheses, the present findings revealed that increasing a person's height in virtual environment can significantly lead to better objective performance in cognitive tests. The results were illustrated by the increase in proportion of correctly remembered letter pairs and correctly solved mental rotation tasks. While the manipulation of height was moderately subtle and remained unnoticed throughout the experimental procedures, participants demonstrated stronger memory and spatial skills when they became taller in the virtual environment. In contrary to our hypotheses, the self-perceived performance of cognitive tests did not differ significantly across conditions. In fact, during our debriefing process, we casually explain and discuss the experiment with the participants. It is interesting to note that height-induced improvement in cognitive abilities was not consciously acknowledged by the majority of the participants. We speculate that this observation might be due to the varied changes in different domains of self-esteem. As height constitute a major component of appearance-related appraisals, rationales underlying the effect of height manipulation on increased appearance self-esteem is pronounced and straightforward. In spite of this, self-esteem remained largely unchanged in other subtypes. In particular, the insignificant findings with regard to performance self-esteem may shed light on the relatively consistent self-report ratings of cognitive tasks, indicating a close-knitted relationship between self-esteem and self-perceived performance. Nonetheless, the results confirmed that the effects of height alterations were sensitive to stature-related self-appraisals, even in the absence of external evaluations.

To the best of our knowledge, this is the first study to examine self-esteem, visuospatial ability, and memory skills under direct height manipulation in a virtual environment. The advantages of leveraging VR systems to implement our experiment comes in threefold. Firstly, immersive VR disengages participants from the external world to provide realistic experience in cognitive, affective, and behavioral domains, ensuring that the test conducted can achieve high ecological validity [22]. Secondly, studies have indicated that the traditionally prominent gender differences in mental rotation skills are predominantly diminished when tasks are conducted in virtual settings [15]. Therefore, the confounding sex effect in relation to visuospatial ability should not influence the findings in this study. (Note, however, that we did not formally test this in the pilot study). Thirdly, VR provides a convenient and accessible medium to induce effective height alterations. Yee and Bailenson [31] found that individuals assigned with taller avatar as digital representation of themselves were more confident and outperformed their shorter counterparts in a virtual negotiation task. Their findings confirmed the proteus effect and suggested that representational manipulations in VR are capable of yielding dynamic and rapid behavioral changes. However, it is to note that rather than rendering digitized self-avatars, the current study performed direct manipulation on individuals' height in VR. This is to eliminate the potential confounding influence of social esteem in relation to perceived representations, which may mediate the effect of height adjustment on self-esteem.

One limitation of the present findings inheres in the relatively small sample size of this pilot study. It is advised that future studies should aim to replicate results with a larger sample to facilitate mediation analysis. However, we implemented a within-group experimental design and found sufficient effect sizes for our results, which may mitigate concerns in relation to power and sample size. On this basis, future research could explore the potential mediating effect of other height-related variables, such as social dominance and leadership emergence, as well as cognitive abilities in other domains. Studies could also consider the potential of utilizing VR-based height alteration in improving people's cognitive abilities. In this study, we mainly focused on working memory and spatial ability as both are important indicators of academic achievements and social functioning [1, 16]. It is of interest to further examine how the incorporation of height manipulation into evidence-based VR interventions could benefit a variety of populations. For instance, it may hold the potential to maximize treatment outcomes for patients suffering from cognitive deficits. Promising prospects may also be found in enhancing self-perceived psychosocial functioning of children with idiopathic short stature [30]. Furthermore, the study can be further developed by employing advanced technology to refine the height alteration process. Full-body tracking equipment and eye-trackers are promising add-ons to elicit real-time realistic, synchronized, and individualized immersion experiences [4]. Alternative ways of manipulating a person's height in VR can also be investigated and compared against the current approach. Considering the impact of social esteem, researchers could display 3D avatars in virtual environments to stimulate users' visualization of their perceived height. The cave automatic virtual environment (CAVE) would also be an interesting replacement for VR systems facilitated by the HMD.

5 Conclusion

In this pilot study, we utilized an immersive VR system to compare individuals' state self-esteem, working memory, and visuospatial competence in differing virtual body heights. We adapted the height-career success theoretical model to predict height-induced enhancement in subjective self-evaluation and cognitive abilities. Our results indicated that increasing individuals' height in VR can elicit higher levels of appearance self-esteem, and improve objective performance in letter recall and mental rotation tests. However, we found no evidence for significant changes in self-perceived performance and overall self-esteem. Future research is needed to explore the potential of incorporating VR-based direct height manipulation in clinical trials and practical settings.

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