The feasibility of using virtual reality to induce mobility-related anxiety during turning

Raffegeau, Tiphanie E.,1  Fawver, Bradley,1  Clark, Mindie,1 Engel, Benjamin T.,2 Young, William R.,3 Williams, A. Mark,1 Lohse, Keith R.,1\* & Fino, Peter C.1\*

1 University of Utah, Department of Health, Kinesiology, and Recreation, Salt Lake City, Utah USA

2 University of Utah, Eccles Health Science Library, Salt Lake City, Utah USA

3 Exeter University, Department of, United Kingdom

\*Co-senior authors

Corresponding Author:

Tiphanie E Raffegeau, PhD

383 Colorow Drive, Box #6

Salt Lake City, UT 84108

[tiphanie.raffegeau@utah.edu](mailto:tiphanie.raffegeau@utah.edu)

twitter: @raffegeau

Abstract (250 words, currently 271 words): Our aim was to determine the efficacy of a virtual reality (VR) height illusion for eliciting mobility-related anxiety in healthy adults during turning. A secondary aim was to determine if the effect of mobility-related anxiety diminished across time spent in the VR environment. Ten participants (*M* age = 28.5+ 8.5 years, five women) turned at self-selected and fast speeds on a 2.2 m long walkway in two simulated environments: (1) ground elevation, (2) high elevation, 15 meters above ground. Portable sensors measured peak turning velocity at the lumbar spine. Between blocks trials, participants rated their cognitive (i.e. worry) and somatic (i.e. tension) anxiety, confidence, and mental effort. Results showed a significant Height × Speed × Trial interaction (*p* = 0.013) for peak turning velocity. At low elevation, the effect of Trial was negative, but not significant (*p* = 0.381), but at high elevation, the effect of Trial (*p* = 0.001) was positive and significant, showing people increase their turning speed with added trials on average. At self-selected speeds, no effects were revealed (all *p* > 0.188). At fast speeds the effect of Height was significant, but not Trial (*p* = 0.270), or the Trial × Height interaction (*p* = 0.092). On average, the virtual height illusion attenuates peak turning velocity, especially at fast speeds. In the high elevation, participants reported greater levels of cognitive (*p* = 0.008) and somatic anxiety (*p* = 0.007), reduced confidence (*p* = 0.021), and greater mental effort (*p* < 0.001) compared to the low elevation. VR shows promise for inducing mobility-related anxiety safely during dynamic motor tasks and for future use in older adult populations.

Keywords: Elevation, Fear of Falling, Inertial Sensor, Mental Effort, Turning

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

1. Introduction

Fear of falling, or mobility-related anxiety, profoundly impacts postural control [1], walking behavior [2], and recovery after a loss of balance [3]. Studying mobility-related anxiety is complicated by the challenge of imposing postural threat without causing actual risk to the participant. As a result, researchers have resorted to manipulating anxiety and evaluating associated physiological/behavioral consequences using simple postural tasks such as standing [4] or constrained locomotor tasks such as treadmill walking with a safety harness [5]. However, over 40% of daily steps involve turning [6] and 800-1000 turns are performed each day [7], while few, if any, studies have examined the effect of mobility-related anxiety on turning. Given the advanced balance demands of turning [8,9] and the increased risk [10] and high prevalence of falls while executing a turn [11], the influence of mobility-related anxiety on turning performance is of particular interest. Therefore, a critical step in understanding the interactions between mobility-related anxiety and locomotor behavior is to characterize the effect of mobility-related anxiety on real-world locomotor tasks such as turning.

Pioneering studies of the relationship between anxiety and gait use expensive hydraulic lifts to raise the support surface and induce mobility-related anxiety while participants stand at increased heights [12], but such approaches may not be appropriate for more dynamic tasks such as turning without sophisticated safety equipment. Alternatively, virtual reality (VR) technology provides a unique opportunity to probe the underlying mechanisms of mobility impairments using relatively safe, low-cost VR equipment. VR is an effective means of eliciting mobility-related anxiety; a virtual height illusion can elicit similar standing postural control responses as real-world height manipulations [13]. Yet, many existing VR-based studies have only examined abstract simulations or motor tasks (e.g., treadmill-based walking)[5] that may not generalize to daily walking behavior. Additionally, it remains unclear if participants become impervious to the virtual height illusion with prolonged exposure. The potential utility of VR technology to investigate ecologically valid, complex locomotion, such as turning, has yet to be fully realized.

The purpose of this study was to determine the efficacy of using a realistic VR simulation to induce mobility-related anxiety during turning in healthy adults. A secondary aim was to determine the rate of adaptation to the VR illusion. We developed this method with the aim of using the approach in the future to investigate fear of falling in older adults and examine the viability of using VR for studying the effects of the mobility-related anxiety on dynamic locomotor tasks.

2. Methods

All procedures were approved by the University’s Institutional Review Board and informed consent was provided. Participants were excluded if they had any neurological, orthopedic, or cardiovascular conditions that would affect walking, or if they suffered from excessive motion sickness or vertigo Altogether, 10 healthy participants (*M* age = 28.5+ 8.5 years, five women) reported normal visual (Snellen eye test [14]), cognitive (Stroop [15], Trail Making Test [16]) and physical function (SPPB [17], TUG [18], DGI [19]).

Participants wore their usual corrective eyewear and were fitted with an HTC Vive (version 2.0, Bellevue, WA) head-mounted display (HMD) presenting a 0.40 m x 2.2 m virtual path in two types of immersive environments: (1) ground level (low elevation; Figure 1b), and (2) at 15 meters above ground to induce anxiety (high elevation; Figure 1a). A real-world path (0.02 m high, 0.40 m wide, and 2.20 m long) matched the VR path dimensions and location in the virtual simulation (Figure 1c). Participants wore motion trackers (HTC Vive, version 2.0) on both ankles to provide a continuous representation of their feet in the virtual environment that was depicted as a pair of tennis shoes. Foot tracker position and rotation was recorded at 90 Hz using gyroscopes and two lighthouse-based infrared sensors to track each object. Inertial sensors (APDM Inc, Portland, OR) containing tri-axial accelerometers, gyroscopes, and magnetometers were placed on the lumbar spine and both feet to measure accelerations and recorded data at 128 Hz.

Participants were fitted with the HMD, instructed to adjust the inter-pupillary distance, and underwent a familiarization period prior to the experiment. The familiarization period lasted for two minutes, during which the participant was encouraged to walk along the pathway and gain a sense of where they were in relation to the real-world walkway. The researchers used this period to ensure the accuracy of the walkway representation and foot trackers. If the participant reported their feet or the walkway were not accurately represented in the virtual setting, the system was recalibrated. A research assistant followed participants at all times to ensure safety. Prior to high elevation trials, participants stood at the beginning of the walkway to be ‘transported’ 15 m above ground instantaneously (i.e. 100 ms). In a pseudorandom and counterbalanced order, blocks of five turning trials were performed in high and low elevation settings (Figure 1). Participants walked to the end of the path, turned around 180°, and returned to the starting position. To elicit a maximum peak turning velocity, both high and low elevation turning trials were completed at two speeds: a self-selected comfortable walking speed and at the participants’ ‘fastest comfortable pace’.

Between blocks, participants reported cognitive (i.e., worry) and somatic (i.e., arousal) components of anxiety as well as confidence about their ability to complete the task using an 11-point Likert-scale (Mental Readiness Form 3, MRF-3) [20]. Participants also rated the levels of mental effort required to complete the task using the Rating Scale of Mental Effort (RSME) [21]. The instructions for all self-report measures emphasized that participants should indicate their feelings during the most recent block of trials.

Inertial sensor data were analyzed using a custom Matlab program (version 2018b, Natick, MA). Sensor-based coordinates were rotated to align with the global inertial frame.[22] Angular velocities were filtered using a phaseless 4th order, 6 Hz low-pass Butterworth filter, and the peak yaw angular velocity was extracted for each turning trial.

Linear mixed-effect regression (LMER) models were fitted to the data to determine the effect of walkway height on peak turning velocity and self-reported ratings of anxiety, confidence, and mental effort. Models included the effect of speed (self-selected vs. fast) and trial number (1-5), and all two- and three-way interaction to investigate the effect of height, instructed speed, and adaptation across repeated trials, on turning velocity. Height and Speed variables were contrast coded for ease of interpretation (Low = -1, High = +1, Self-selected = -1, Fast = +1). The reference condition for the Trial variable was the first trial.

To determine whether differences in turning behavior from the low to high elevation environment were associated with changes in self-reported anxiety, confidence, and mental effort, change scores were calculated for each participant in both the self-selected and fast speed trials. The dependent measures were averaged for each speed in both low and high elevation trials, and the difference between the high and low elevation was calculated for each speed (high elevation − low elevation). Spearman’s rho (**) rank correlations evaluated the relationship between changes in self-reported anxiety, confidence, and mental effort and change in turning velocity. The significance threshold for all statistical analyses was set at ** = 0.05. To promote transparency and future use, we have shared our data, analyses scripts, and the VR program on github for the reader’s reference (see here for VR program: <https://github.com/benbeezy/VR_gait> and here for data/analyses: *insertlinktoKeith’sgithub* ).

3. Results

Parameter estimates for peak turning velocity as a function of Height, Speed, and Trial are reported in Table 1. The regression analysis revealed a significant effect of Height (*p* = 0.031), such that overall, people decreased their turning velocity at high elevations. Participants also increased their turning velocity when instructed to turn quickly, on average, supported by a significant effect of Speed (*p* < 0.001). However, these effects were superseded by significant Height × Speed (*p* = 0.006) and Height × Speed × Trial interactions (*p* = 0.013). To understand these interactions, we examined smaller models to test Speed × Trial effects at different heights and Height × Trial effects at different speeds.

The model was first decomposed by walkway height. At high elevations, there was a significant effect of Speed (*p* = 0.002), but was superseded by a Speed × Trial interaction (*p* = 0.017). This interaction was driven by the fact that in self-selected speeds the effect of Trial was negative, but not significant (*p* = 0.381), whereas at fast speeds the effect of Trial was positive, and statistically difference from zero (*p* = 0.001). At low elevations, the effect of Speed was significant (*p* < 0.001), exhibiting a much larger increase in turning speed than at high elevations, but there was not statistically significant effect of Trial (*p* = 0.851), nor a Speed × Trial interaction (*p* = 0.353).

Next, the model was decomposed by turning speed. At self-selected speeds, there was not a statistically significant effect of Trial (*p* = 0.985), Height (*p* = 0.250), nor a Height × Trial interaction (*p* = 0.188). As such, people tended to decrease their turning velocity when walking at high elevations, but not to a degree that was statistically significant nor that changed across time. At fast speeds, the effect of Height was statistically significant (*p* < 0.001), showing a large decrease in velocity when turning quickly at high elevation. However, there was not a statistically significant effect of Trial (*p* = 0.270), nor a Trial × Height interaction (*p* = 0.092).

Parameter estimates for self-reported ratings of cognitive anxiety (i.e., worry), somatic anxiety (i.e., tension), confidence, and mental effort are reported in Table 2. Mixed-effect regression tests revealed significant main effects of Height for cognitive anxiety (*p* = 0.008), somatic anxiety (*p* = 0.007), confidence (*p* = 0.021), and mental effort (*p* < 0.001). Participants self-reported greater levels of worry, tension, and mental effort, as well as less confidence in their ability to do the task, when turning in the high elevation virtual environment. No main effects of Speed or Height × Speed interactions were documented for self-reported ratings of cognitive anxiety, somatic anxiety, confidence, or mental effort (all *p*’s > 0.100, Table 2).

Spearman’s rank correlations were used to evaluate the relationships between change scores (high elevation – low elevation) in self-report ratings and turning speed. No statistically significant correlations were found between peak velocity change scores and any change scores for self-report measures during either self-selected speed (Δ Cognitive Anxiety: *ρ =* -0.168, *p* = 0.642; Δ Somatic Anxiety *ρ =* -0.079, *p* = 0.827; Δ Confidence *ρ =* 0.006, *p* = 0.987; Δ Mental Effort *ρ =* -0.037, *p* = 0.919) or fast speed (Δ Cognitive Anxiety: *ρ =* -0.194, *p* = 0.591; Δ Somatic Anxiety *ρ =* -0.093, *p =* 0.799; Δ Confidence *ρ =* -0.082, *p* = 0.823; Δ Mental Effort *ρ =* -0.068, *p* = 0.853) turning trials. However, change in RSME ratings of mental effort were strongly and positively related to change in ratings in the MRF-3 at self-selected (Δ Cognitive Anxiety: *ρ =* 0.905, *p* < 0.001; Δ Somatic Anxiety *ρ =* 0.960, *p* < 0.001; Δ Confidence : *ρ =* 0.858, *p* = 0.001), and fast speeds (Δ Cognitive Anxiety: *ρ =* 0.876, *p* < 0.001; Δ Somatic Anxiety *ρ =* 0.862, *p* = 0.001; Δ Confidence : *ρ =* 0.975, *p* < 0.001) confirming that participants increased mental effort and successfully perceived the height illusion.

4. Discussion

We examined the efficacy of a virtual height illusion for eliciting mobility-related anxiety during a complex movement in healthy adults. Given that participants may become desensitized to virtual and/or height manipulations, a secondary objective was to determine if the effectiveness of the VR illusion changed across multiple trials. The elevated walkway height reduced peak turning velocity and confidence while increasing worry, tension, and mental effort, suggesting the VR illusion is an effective manipulation inducing both subjective self-reported changes and objective indices of mobility-related anxiety. A three-way interaction between turning speed, walkway height, and trial, suggested that the effect of the VR illusion on peak turning speed may change as a result of the constraints of walking speed and the number of trials.

When walking at high elevations, participants consistently decreased their peak turning velocity, supporting the effectiveness of the VR illusion. We are unaware of similar studies evaluating the effect of anxiety on complex behaviors such as turning for direct comparison; however, this result is consistent with other published reports indicating that individuals reduce their gait velocity when on an elevated walkway [23,24]. Manipulating the speed of the locomotor task revealed that when turning at higher elevations, participants felt less comfortable achieving their peak turning velocity. We were surprised to find that effects of the height illusion on turning velocity were strong at fast speeds and was not detectable at self-selected speeds. Participants’ apparent resistance to the effect of height at self-selected speeds could result from a reduced threat of falling at slower speeds for healthy adults. Alternatively, this result could be due to a ‘floor effect’ in peak turning velocity at self-selected speeds, whereas greater changes to speed were detectable during fast turns. Future studies should include additional motor outcome measures to clarify this distinction.

Self-report measures of affective responses supported the effectiveness of the VR height illusion. Greater levels of cognitive and somatic anxiety have been previously reported when individuals are exposed to the threat of a balance perturbation [25]. We speculate that reduced confidence and greater levels of cognitive and somatic anxiety might be indicative of a perceived sense of threat to stability in the virtual simulation, even though participants were standing two cm off of the ground in the real world. Participants also reported a greater levels of mental effort to turn within the elevated virtual environment, which aligns with previous published reports showing that individuals devote added attentional resources to stand and walk at high elevations [23,24]. The fact that turning at high elevations is more attention demanding is not surprising considering executing a turn requires more attentional resources than linear walking [26], which was predicted to be exacerbated by mobility-related anxiety. At high elevations, people tend to direct their attention toward movement processes, threat relevant stimuli, and self-regulatory strategies when performing a dynamic postural task (rise to toes) [12]. However, given the lack of intra-trial measures of affective responses, it is unclear what features of the turning task required more mental effort while walking in the threatening environment. Future studies should further evaluate the perceptual-cognitive processes necessary to regulate complex movement behavior within threatening environments through direct and indirect measures of attention.

We analyzed associations between height-induced changes (high elevation– low elevation mean scores) in self-report measures and turning behavior to ascertain whether the direction of effects was consistent across participants. While studies have shown that changes in simple reaction time correspond to ratings of mental effort [21], none of the self-report measures were correlated with changes to peak turning velocity. One potential explanation for the lack of significant correlations is peak turning velocity is not a refined enough measure to detect significant correlations with affective ratings. However, ratings of mental effort were positively and strongly associated with affective measures, showing that the change from low to high walking environments similarly impacted perceptions of affect and mental effort. Self-report measures may be more sensitive to changes in anxiety than gross indices of motor speed, particularly during complex movements where multiple strategies can be effective. Measures of turning quality may be reflective of underlying changes in cognitive and perceptual processing [27], and in the future, researchers should pursue the relationships between turning strategies and affective responses to environmental threat.

A secondary aim of this study was to determine if the effectiveness of the VR illusion diminished across time. Our findings suggested that changes in turning performance across trials might occur when walking in elevated virtual environments (i.e., positive ** coefficients for Trial main effects and interactions), with participants tending to increase their peak turning velocity across trials. This type of habituation is a significant concern for researchers seeking to use VR for research purposes. The validity of the VR illusions and comfort of the participant within the virtual environments may change across trials, potentially nullifying the effects of anxiety manipulations. Although results confirm that the VR illusion was successful, less than five trials may be more ideal for capturing the effects of anxiety before participants become acclimated to the environment.

4.1 Limitations

Although this pilot study was primarily conducted to determine the feasibility of using more-realistic virtual environments to induce anxiety during a complex movement task, several limitations are worth acknowledging. First, although we included a visual representation of the feet during the walking trials, foot size was not scaled for each participant. We did not observe any major issues with the ‘average’ virtual foot, but future studies should apply a scaling factor to match participants’ virtual foot representation to their actual foot size for comfortability within VR environments. Second, we selected one outcome measure of gross motor performance in the current study, but future work should seek to adopt additional measures of performance such as turning quality, gaze behavior, or head position data to provide a more comprehensive understanding of complex motor behavior. Third, our walkway was linear and demanded only a single 180° turn, but future studies should manipulate the complexity of virtual walkways and observe varying degrees of turning to generalize the results to more typical walking behavior.

5. Conclusions

The virtual height illusion successfully induced behavioral and self-reported changes as intended. Our approach shows promise for investigating anxiety-induced changes to locomotor behavior in future studies using older adult populations. Moreover, this method holds significant translational impact for clinical settings, where the aim is to ameliorate the negative effects of anxiety on mobility during real world navigation.

Conflict of Interest Statement

The authors have no conflict of interest to report.

Acknowledgements

We would like to thank Tezika Zhou for his help with the VR program and the undergraduate volunteers for the Cognitive Motor Neuroscience theme at the University of Utah for their hard work in collecting and preparing the data.

TABLES:

Table 1. Mixed effect regression model fit and parameters for peak lumbar turning velocity as a function of Height, Speed, and Trial.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Random-Effects | *Variance* | *SD* |  |  |  |
| Speed:Subject | 201.60 | 14.20 |  |  |  |
| Height:Subject | 766.50 | 27.69 |  |  |  |
| Subject | 4021.80 | 63.42 |  |  |  |
| Residuals | 1115.00 | 33.39 |  |  |  |
| Fixed-Effects | *β* | *SE* | *df* | *t* | *p* |
| Intercept | 199.03 | 21.62 | 10.50 | 9.21 | **< 0.001** |
| Height | -17.59 | 7.42 | 15.68 | -2.37 | **0.031** |
| Speed | 29.12 | 5.18 | 27.96 | 5.62 | **< 0.001** |
| Trial | 1.80 | 1.68 | 168.92 | 1.07 | 0.284 |
| Height × Speed | -11.38 | 4.09 | 168.82 | -2.78 | **0.006** |
| Height × Trial | 1.31 | 1.68 | 168.92 | 0.78 | 0.436 |
| Speed × Trial | 1.76 | 1.68 | 168.92 | 1.05 | 0.295 |
| Height × Speed × Trial | 4.21 | 1.68 | 168.92 | 2.50 | **0.013** |

*Note:* Estimates of model fit: Akaike information criterion (*AIC*), Bayesian information criterion (*BIC*), maximum log-likelihood (*logLik*), deviance, and residual degrees of freedom (*dfr*). Significance denoted by bolded *p*-value. Parameter estimates: slope estimate (**), standard error (*SE*), degrees of freedom (*df*), t-value (*t*), and p-value (*p*).

Table 2. Mixed effect regression model fit indices and parameter estimates for self-reported cognitive anxiety (worry), somatic anxiety (tension), confidence, and mental effort as a function of Height and Speed.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Fixed-Effects | *β* | *SE* | *df* | *t* | *p* |
| Cognitive Anxiety |  |  |  |  |  |
| Intercept | 3.35 | 0.48 | 21.99 | 7.02 | **< 0.001** |
| Height | 1.35 | 0.45 | 18.18 | 2.98 | **0.008** |
| Speed | 0.05 | 0.18 | 10.35 | 0.28 | 0.789 |
| Height × Speed | 0.05 | 0.11 | 9.93 | 0.48 | 0.645 |
| Somatic Anxiety |  |  |  |  |  |
| Intercept | 3.58 | 0.49 | 10.00 | 7.18 | **< 0.001** |
| Height | 1.48 | 0.44 | 10.00 | 3.37 | **0.007** |
| Speed | -0.03 | 0.17 | 10.00 | -0.15 | 0.887 |
| Height × Speed | -0.03 | 0.08 | 10.00 | -0.30 | 0.768 |
| Confidence |  |  |  |  |  |
| Intercept | 9.40 | 4.53 | 9.99 | 20.75 | **< 0.001** |
| Height | -1.10 | 4.03 | 9.99 | -2.73 | **0.021** |
| Speed | -3.90 | 1.46 | 1.00 | 0.00 | 1.000 |
| Height × Speed | 0.00 | 6.12 | 9.99 | 0.00 | 1.000 |
| Mental Effort |  |  |  |  |  |
| Intercept | 32.63 | 3.37 | 21.49 | 9.68 | **< 0.001** |
| Height | 13.13 | 3.19 | 18.60 | 4.12 | **< 0.001** |
| Speed | 2.28 | 1.54 | 11.52 | 1.48 | 0.165 |
| Height × Speed | -1.03 | 1.08 | 9.34 | -0.95 | 0.366 |

*Note:* Estimates of model fit: Akaike information criterion (*AIC*), Bayesian information criterion (*BIC*), log-likelihood (*logLik*), deviance, residual degrees of freedom (*dfr*). Model parameters: slope (**), standard error (*SE*), degrees of freedom (*df*), t-value (*t*), p-value (*p*). Note that all models included random-effects of Subject, Height:Subject, and Speed:Subject, to account for the within-subject nature of the manipulations, but these statistics are omitted for brevity.



FIGURES

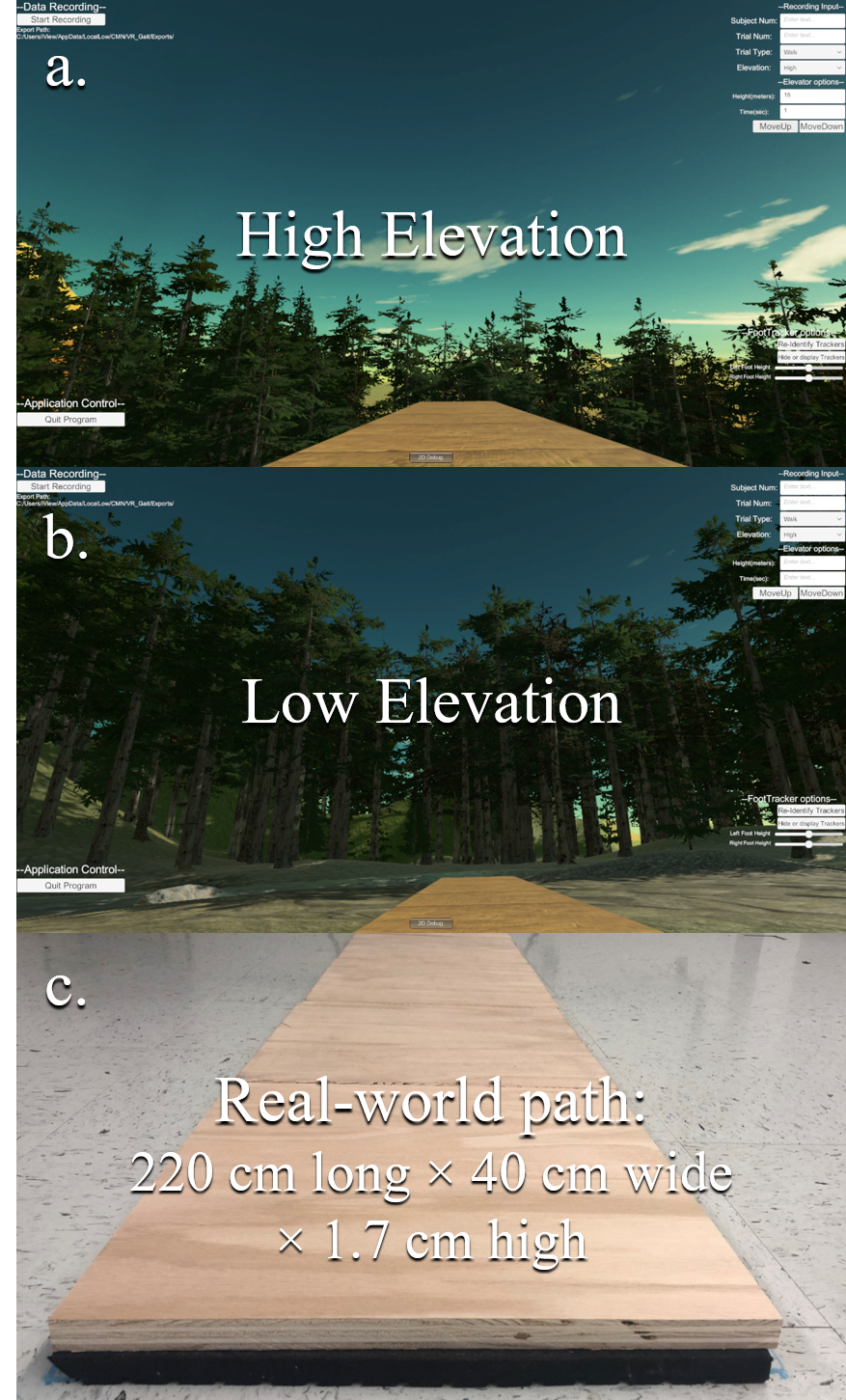


Figure 1a-c. Images captured from the high (a.) and low (b.) elevation settings in the VR paradigm and the matched real-world path (c.). Note, the VR view is from the researcher’s perspective and the participant interface does not include the menus pictured here.



Figure 2a-d. Each participants change in self-report measures of (a.) Cognitive Anxiety (i.e. worry), (b.) Somatic Anxiety (i.e. tension), (c.) Confidence, and (d.) Mental Effort when walking in low and high elevation environments at self-selected (a-b) and fast (c-d) speeds.



Figure 3a-d. Each participants change in self-report measures of (a.) Cognitive Anxiety (i.e. worry), (b.) Somatic Anxiety (i.e. tension), (c.) Confidence, and (d.) Mental Effort when walking in low and high elevation environments at fast and self-selected speeds.

REFERENCES (30 reference limit)

[1] E. Keshner, W.R. Young, L. Avanzino, A.L. Adkin, M.G. Carpenter, New Insights on Emotional Contributions to Human Postural Control, Front. Neurol. | Www.Frontiersin.Org. 9 (2018) 789. doi:10.3389/fneur.2018.00789.

[2] W.R. Young, M. Olonilua, R.S.W. Masters, S. Dimitriadis, A.M. Williams, Examining links between anxiety, reinvestment and walking when talking by older adults during adaptive gait, Exp. Brain Res. 234 (2016) 161–172. doi:10.1007/s00221-015-4445-z.

[3] C.D. Tokuno, M. Keller, M.G. Carpenter, X. Gonzalo Márquez, W. Taube, Alterations in the cortical control of standing posture during varying levels of postural threat and task difficulty, J Neurophysiol. 120 (2018) 1010–1016. doi:10.1152/jn.

[4] T.J. Ellmers, G. Machado, T.W. Wong, F. Zhu, A.M. Williams, W.R. Young, A validation of neural co-activation as a measure of attentional focus in a postural task, Gait Posture. 50 (2016) 229–231. doi:10.1016/j.gaitpost.2016.09.001.

[5] J.R. Franz, C.A. Francis, M.S. Allen, S.M. O’Connor, D.G. Thelen, S.M. O’Connor, D.G. Thelen, Advanced age brings a greater reliance on visual feedback to maintain balance during walking, Hum. Mov. Sci. 40 (2015) 381–392. doi:10.1016/j.humov.2015.01.012.

[6] B.C. Glaister, G.C. Bernatz, G.K. Klute, M.S. Orendurff, Video task analysis of turning during activities of daily living, Gait Posture. (2007) 289–294. doi:10.1016/j.gaitpost.2006.04.003.

[7] M. Mancini, M. El-Goharu, S. Pearson, J. McNames, H. Schlueter, J.G. Nutt, L.A. King, F.B. Horak, Continuous monitoring of turning in Parkinson’s disease: Rehabilitation potential, NeuroRehabilitation. 37 (2015) 3–10. doi:10.3233/NRE-151236.Continuous.

[8] P.C. Fino, M.A. Nussbaum, P.G. Brolinson, Locomotor deficits in recently concussed athletes and matched controls during single and dual-task turning gait: preliminary results, J. Neuroeng. Rehabil. 13 (2016) 65. doi:10.1186/s12984-016-0177-y.

[9] D. Xu, L.G. Carlton, K.S. Rosengren, Anticipatory postural adjustments for altering direction during walking., J. Mot. Behav. 36 (2004) 316–26. doi:10.3200/JMBR.36.3.316-326.

[10] T. Yamaguchi, M. Yano, H. Onodera, K. Hokkirigawa, Effect of turning angle on falls caused by induced slips during turning, J. Biomech. 45 (2012) 2624–2629. doi:10.1016/j.jbiomech.2012.08.006.

[11] S. Robinovitch, F. Feldman, Y. Yang, R. Schonnop, P.M. Leung, T. Sarraf, J. Sims-Gould, M. Loughin, Video capture of the circumstances of falls in elderly people residing in long-term care: an observational study, Lancet. 381 (2013) 47–54. doi:10.1016/S0140-6736(12)61263-X.

[12] M. Zaback, M.G. Carpenter, A.L. Adkin, Threat-induced changes in attention during tests of static and anticipatory postural control, Gait Posture. (2016) 19–24. doi:10.1016/j.gaitpost.2015.12.033.

[13] T.W. Cleworth, B.C. Horslen, M.G. Carpenter, Influence of real and virtual heights on standing balance, Gait Posture. 36 (2012) 172–176. doi:10.1016/J.GAITPOST.2012.02.010.

[14] W.R. Young, M.A. Hollands, Can telling older adults where to look reduce falls? Evidence for a causal link between inappropriate visual sampling and suboptimal stepping performance, Exp. Brain Res. 204 (2010) 103–113. doi:10.1007/s00221-010-2300-9.

[15] A.R. Jensen, W.D. Rohwer, The Stroop Color-Word test: a review, Acta Psychol. (Amst). 25 (1966) 36–93. doi:10.1016/0001-6918(66)90004-7.

[16] I. Sánchez-Cubillo, J.A. Periáñez, D. Adrover-Roig, J.M. Rodríguez-Sánchez, M. Ríos-Lago, J. Tirapu, F. Barceló, Construct validity of the Trail Making Test: Role of task-switching, working memory, inhibition/interference control, and visuomotor abilities, J. Int. Neuropsychol. Soc. 15 (2009) 438–450. doi:10.1017/S1355617709090626.

[17] S. Perera, S.H. Mody, R.C. Woodman, S. Studenski, Meaningful change and responsiveness in common physical performance measures in older adults, J Am Geriatr Soc. 54 (2006) 743–9. doi:10.1111/j.1532-5415.2006.00701.x.

[18] E.L. Stegemoller, J.R. Nocera, I. Malaty, M.C. Shelley, M.S. Okun, C.J. Hass, N.Q.I.I. Investigators, Timed up and go, cognitive, and quality-of-life correlates in Parkinson’s disease, Arch Phys Med Rehabil. 95 (2014) 649–55. doi:10.1016/j.apmr.2013.10.031.

[19] T. Herman, N. Inbar-Borovsky, M. Brozgol, N. Giladi, J.M. Hausdorff, M. Jeffrey, The Dynamic Gait Index in healthy older adults: The role of stair climbing, fear of falling, and gender, Gait Posture. 29 (2009) 237–241. doi:10.1016/j.gaitpost.2008.08.013.The.

[20] V. Krane, The mental readiness form as a measure of competitive state anxiety, Sport Psychol. 8 (1994) 189–202. https://utah-illiad-oclc-org.ezproxy.lib.utah.edu/illiad/uum/illiad.dll?Action=10&Form=75&Value=1558140 (accessed March 25, 2019).

[21] F.R.H. Zijlstra, Efficiency in work behaviour: A design approach for modern tools, Delft University Press, 1993.

[22] R. Moe-Nilssen, A new method for evaluating motor control in gait under real-life environmental conditions . Part 1 : The instrument, Clin. Biomech. 13 (1998) 320–327. http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list\_uids=11415803.

[23] W.H. Gage, R.J. Sleik, M.A. Polych, N.C. McKenzie, L.A. Brown, The allocation of attention during locomotion is altered by anxiety, Exp Brain Res. 150 (2003) 385–94. doi:10.1007/s00221-003-1468-7.

[24] L.A. Brown, W.H. Gage, M.A. Polych, R.J. Sleik, T.R. Winder, Central set influences on gait Age-dependent effects of postural threat, Exp Brain Res. 145 (2002) 286–296. doi:10.1007/s00221-002-1082-0.

[25] K.J. Johnson, M. Zaback, C.D. Tokuno, M.G. Carpenter, A.L. Adkin, Repeated exposure to the threat of perturbation induces emotional, cognitive, and postural adaptations in young and older adults, Exp. Gerontol. 122 (2019) 109–115. doi:10.1016/j.exger.2019.04.015.

[26] K.L. Hollands, D. Agnihotri, S.F. Tyson, Effects of dual task on turning ability in stroke survivors and older adults, Gait Posture. 40 (2014) 564–569. doi:10.1016/j.gaitpost.2014.06.019.

[27] S. Mellone, M. Mancini, L.A. King, F.B. Horak, L. Chiari, The quality of turning in Parkinson’s disease: a compensatory strategy to prevent postural instability?, J. Neuroeng. Rehabil. 13 (2016) 39. doi:10.1186/s12984-016-0147-4.