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Feasibility of VR Technology in Eliciting State Anxiety Changes While Walking in Older Women

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***Abstract*— Virtual reality (VR) technology offers an exciting way to emulate real-life walking conditions that may better elicit changes in emotional state. We aimed to determine whether VR technology is a feasible way to elicit changes in state anxiety during walking. Electrocardiogram data were collected for 18 older adult women while they navigated a baseline walking task, a dual walking task, and four walking VR environments. Using heart rate variability (HRV) analysis, we found that all four of the VR environments successfully elicited a significantly higher level of state anxiety as compared to the walking baseline, with 84% of participants eliciting a significantly lower HRV in each of the four VR conditions as compared to baseline walking. VR was also found to be a more reliable tool for increasing state anxiety as compared to a dual task, where only 47% of participants demonstrated a significantly lower HRV as compared to baseline walking. VR, therefore, could be promising as a tool to elicit changes in state anxiety and less limited in its ability to elicit changes as compared to a traditional dual task condition.**

I. INTRODUCTION

An inherent limitation of lab-based data collection during walking is that it is not sufficiently naturalistic, meaning that we cannot replicate the environments and situations that a participant may face in their daily living. Virtual reality (VR) is a promising tool for narrowing the gap between conditions in the lab and out of it [1]. VR technology has been used to simulate relevant environments in adjacent fields, such as postural control research [2]. Another ideal space for use of VR technology is in mobility research, due to our need to create real-world walking conditions within the safety of a lab space. In addition to better characterizing walking conditions, we believe that using VR technology would allow us additional insight into the relationship between state anxiety (the short-term reaction to an anxiety-inducing event) and challenges in mobility [3] [4]. To do this, however, we first need to validate that the environments we provide to participants are successfully eliciting the changes to state anxiety that we would expect.

Anxiety detection is likewise a field with exciting methodological innovation, from the introduction to alternate methods of detection to incorporating wearables as valid tools for scientific inquiry [5] [6]. For the analyses in this paper, we will focus on one of these physiological signals: electrocardiography (EKG). The EKG feature extracted for analysis will be the R peaks of the signal [7]. R peak extraction will allow for analysis of heart rate variability (HRV) [8]. We will use HRV to characterize changes in state anxiety. Previous work has shown that heightened anxiety is accompanied by reduced HRV [9]. This is a direct result of the decreased parasympathetic activity seen in conjunction with anxiety [8]. Therefore, it is expected that tasks without an anxiety-inducing stimulus should produce higher HRVs as compared to tasks with an anxiety-inducing stimulus.

II. METHODS

Eighteen community-dwelling older adult women were included in the study (Table I). Participants were asked to walk on an instrumented treadmill at a self-paced rate for a single task walking condition (ST condition), a series subtraction dual task walking condition (DT condition), and four VR conditions. In addition to the walking conditions, the participants were asked to take the Activities-specific Based Confidence Scale (ABC) to assess the walking confidence of each participant, the Motion Sickness Susceptibility Questionnaire (MSQ) to assess motion sickness, and the Acrophobia Questionnaire Anxiety Scale to assess acrophobia levels [10] [11] [12]. The four VR conditions include two simulations of a walk in a local park and two simulations of a novel desert environment, which were created in Unity and presented using a HTC Vive (Manufactured by HTC, Taiwan) headset. The park conditions featured a clear pathway or an obstructed pathway with obstacles such as rocks, puddles, and small moving animals. The desert conditions featured either a pathway at ground level (desert ground) or an elevated pathway at cliff level (desert elevated). Shorthand for the conditions is PC (park clear), PO (park obstructed), DG (desert ground), and DE (desert elevated).

TABLE I: Participant Demographics

	Mean (SD) (n=18)
Age (years)	68.3 (4.3)
Height (m)	1.7 (0.1)
Weight (kg)	66.4 (11.5)
ABC Score	92.2 (7.3)
Acrophobia Score	33.0 (21.7)

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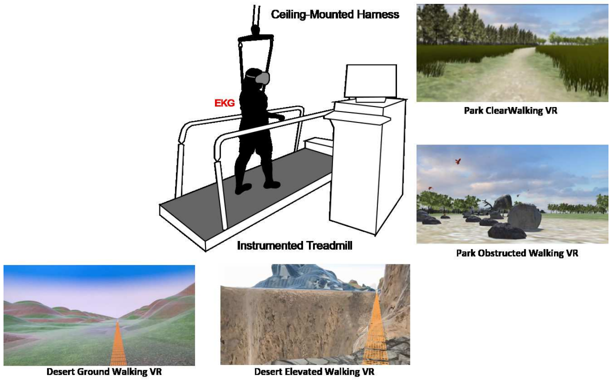

Fig. 1: A depiction of the experimental set up for the VR walking tasks.

The VR environments were responsive to the participant's self-paced treadmill walking, so that the environment moved cohesively alongside the participant. An example of some of the VR scenario experienced by the participants can be seen in (Fig. 1). The order of the four VR conditions was also counterbalanced. EKG data were collected from the participants for the duration of each trial using the Delsys Trigno EKG Biofeedback Sensor with a sampling rate of 1926 samples per second.

The EKG data were synchronized to determine task start and end times. Of the 108 possible trials, 17 trials were missing from analysis due to either collection error or insufficient information to successfully synchronize task start and end time. The data were then filtered to reduce motion artifacts and run through an adapted open source BioSPPy python package using ECG scalogram detection algorithm. The location and time of each R peak in the EKG data were identified, allowing calculation of HRV as $HRV = \frac{\Sigma(RR_i - \overline{RR})^2}{n-1}$ where RR is the R-R interval time. Poor peak detection performance was defined as missing more than one R peak across the task time. Of the 91 trials analyzed, 67 trials had no missing peaks while 24 trials had at least one missing peak. Any trial with a poor peak detection was subjected to a visual inspection to identify and mark missed peaks. HRV was only calculated for a trial once the trial was determined to have no mislabeled peaks. Data synchronization and peak detection were done in Python.

For statistical analyses, HRV F scores were calculated for the following four comparisons for each individual: DT-ST, DE-ST, DG-ST, PO-ST, PC-ST, DE-DG, and PO-PC, where $F = \frac{HRV_1}{HRV_2}$ and HRV_1 is the condition expected to produce a higher HRV. The DT-ST, DE-ST, DG-ST, PO-ST, and PC-ST comparisons were used to evaluate the ability of the dual task and each VR environment to elicit changes in state anxiety and the DE-DG and PO-PC comparisons were used to identify the effect of elevation and obstacle navigation in eliciting changes in state anxiety. In addition to anxiety detection comparisons, the attenuation of the participant to the VR environment was assessed for the DE-ST, DG-ST, PO-ST, and PC-ST comparisons by comparing the HRV for the first 30 seconds of the task to the HRV for the last 30 seconds of the task, where $F = \frac{HRV_1}{HRV_2}$ and HRV_1 is the last 30 second's HRV, which is expected to produce a significantly higher HRV if attenuation to the environment is present. If a significant attenuation result is seen, it is indicative of a participant who was initially showing higher levels of anxiety but then adjusted to the environment. The Holm-Bonferroni method was used to create adjusted α_i based on an experiment-wide $\alpha_e = 0.05$ for each of these comparisons, where a p-value smaller than α_i would indicate that state anxiety was heightened in the first condition as compared to the second for the participant. The stability of using HRV across all VR trials was also evaluated by calculating a mean square error (MSE) estimate for variability in HRV not due to changes in VR task, which was defined as the weighted means of the HRVs. Finally, linear models are fit between the result of the DE-DG comparison and the acrophobia score to assess the effects of participant acrophobia on elevation-induced anxiety and the PO-PC comparison and components of the ABC score (specifically average score, minimum sub-score, and crowded walking sub-score) to assess the effects of participant balance confidence on obstacle navigation-induced anxiety. All statistical analyses were done in R Studio 1.3.1093.

TABLE II: Task HRVs

Task	Mean (SD)	Task	Mean (SD)
DT (n=16)	0.029 (0.018)	ST (n=15)	0.041 (0.025)
DE (n=14)	0.012 (0.010)	DG (n=14)	0.018 (0.020)
PO (n=17)	0.018 (0.016)	PC (n=15)	0.021 (0.022)

III. RESULTS

Average resulting HRVs for each task can be found in (Table II). HRV F scores were significant for 47% of individual DT-ST comparisons, 93% of DE-ST comparisons, 82% of DG-ST comparisons, 93% of PO-ST comparisons, 69% of PC-ST comparisons, 36% of the elevation effect comparisons, and 25% of the obstacle effect comparisons within the anxiety detection subgroup of analyses. Attenuation to the VR environments was seen for 21% of DE comparisons, 57% of DG comparisons, 17% of PO comparisons, and 13% of PC comparisons. The boxplot distributions of both the anxiety detection and attenuation effect comparisons can be seen in (Fig. 2). The calculated variability in HRV due to instability of HRV as a metric (defined as MSE of the measurement) was equal to 0.00031, which accounts for only 0.16% of the variability of the HRV metric.

There was a significant negative linear relationship at $\alpha = 0.05$ between the p value of the elevation effect comparison and the acrophobia score with a Pearson's correlation coefficient of r=-0.66. A linear model regressing the elevation p value on to acrophobia score was significant for both slope (β_1) and intercept (β_0), with a linear model of $Y_i = -0.013X_i + 0.83 + \varepsilon$ at $\alpha = 0.05$. There was not a significant linear relationship at $\alpha = 0.05$ between

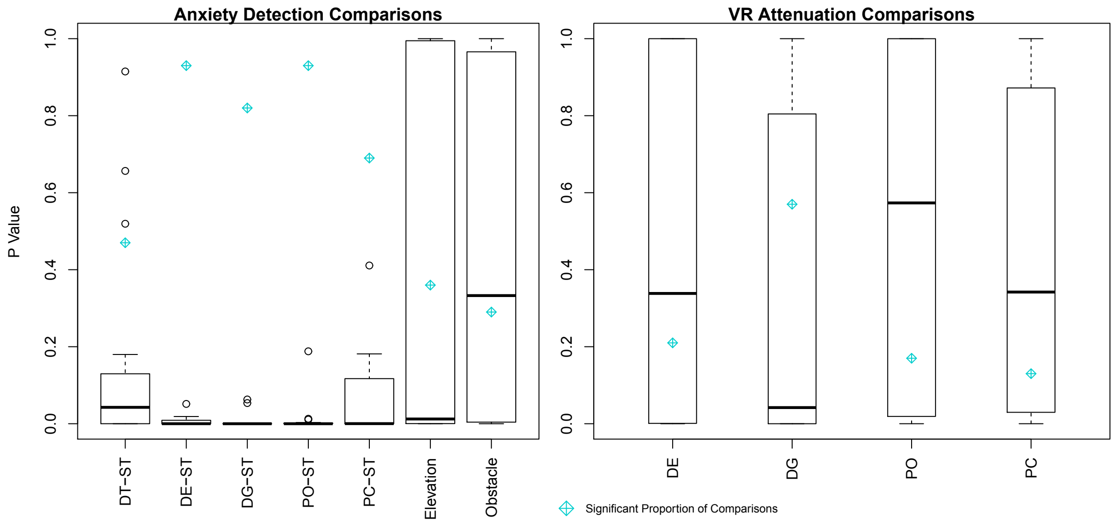

Fig. 2: The p values associated with each HRV F test performed across each of the seven anxiety detection condition comparisons and the four attenuation effect comparisons. From left to right, the anxiety detection comparisons done are to assess the effectiveness of the dual task (DT-ST), elevated desert VR (DE-ST), desert ground VR (DG-ST), obstructed park VR (PO-ST), clear park VR (PC-ST), elevation effect (Elevation), and obstructed path effect (Obstacle). From left to right, the VR attenuation comparisons are for the elevated desert VR (DE), desert ground VR (DG), obstructed park VR (PO), and clear park VR (PC). The proportion of significant comparisons for each test type are denoted with a blue crossed diamond.

the p value of the obstacle effect comparison and the ABC score or the ABC minimum sub-score, both with a Pearson's correlation coefficient of r=-0.02. A linear relationship between the obstacle effect comparison and the ABC sub-score most related to walking an obstructed path also had an insignificant effect, with r=0.30. Finally, there is not a significant relationship between participant motion sickness and HRV during VR walking at $\alpha = 0.05$.

IV. DISCUSSION

F test comparisons of HRV indicated that all four VR conditions had a significantly lower HRV as compared to the single task walking for a majority of walkers (Fig. 2). This suggests that these VR environments elicit increases in state anxiety. F test comparisons of HRV show that a lower proportion of participants had increases in state anxiety when completing a walking dual task as compared to walking though a VR environment. Across all participants, 47% of older women experienced heightened anxiety in the dual task as compared to 84% across the VR environments. This indicates that VR environments were a more reliable method of eliciting changes in state anxiety. It is also important to note that the VR environments were not all equally successful at eliciting changes in state anxiety. The DE and PO conditions were each eliciting significant increases in anxiety in 93% of participants while the DG environment elicited anxiety increases 82% of the time and PC elicits anxiety increases 69% of the time. These differences were not statistically different in a majority of participants, as evidenced by the low elevation and obstacle effect proportion of significant comparisons. The increase in reliability of the DE and PO environments may still indicate that the introduction of challenges to walking may result in increases in the reliability of a VR environment's ability to elicit changes in state anxiety.

A majority of participants had significant attenuation to the DG environment but not to any of the other VR environments. This, along with the differences in proportion of participants eliciting significantly higher anxiety for those environments as compared to single task walking, indicate how participants are reacting to their environments in more detail. Increased anxiety with low attenuation in the DE and PO environments likely means that participants were maintaining high anxiety across the length of the task due to the presence of challenges to walking, specifically the presence of elevation or obstacles. Increased anxiety with high attenuation may have been present in the DG environment because participants initially show elevated anxiety due to the unknown environment but quickly adjusted due to the lack of challenge from walking in that environment. Finally, increased anxiety in a lower proportion of participants with low attenuation in the PC environment indicated that participants were not responding to a walk in a park with as high a level of state anxiety as compared to a walk in either a challenging or more novel environment. The MSE of HRV was calculated in addition to the attenuation comparisons to determine the stability of HRV. Of the total variability of HRV, only 0.16% was accounted for by sources of variability other than task effects, with a MSE of 0.00031. This likely indicates that HRV has a high level of reliability as a measure of anxiety, with changes in variability being due to changes in task rather than system instability of a participant.

A significant linear relationship between the elevation effect comparison and acrophobia score indicated that increases in general acrophobia effectively translated into increased anxiety in an elevated walking VR environment. Of the two VR design elements tested (elevated path and obstructed path), elevation was the only specific design element found to provide significant increases in state anxiety. We additionally saw that the desert elevated condition had the highest proportion of significant comparisons for the older women tested across the groups. While the effectiveness of elevation was highly dependent on the acrophobia of a walker, it was a highly effective tool for eliciting changes in state anxiety in those individuals.

While the relationship between the elevation comparison and acrophobia was strong, there was not a similar result relating the obstacle comparison with a participant's ABC average score or minimum sub-score. This result can perhaps be explained by the ABC scale not having a sub-score that specifically addresses confidence in navigating obstacles, with the closest sub-score asking participants to assess their level of confidence in walking in a crowded mall and being bumped. When that specific sub-score was evaluated in relation to the obstacle effect comparison, the correlation was much stronger but was still not significant.

There were two main limitations to this study that can be addressed with future work. First, this study had a sample size of 18 individuals and contained some missing data. F tests of HRV analysis required both HRVs for a given comparison to be non-missing, meaning that any missing trials of data resulted in a decrease in the number of comparisons available for analysis. Future work will examine additional participants. The presence of so many significant results with such a small sample size does suggest that we will hopefully only strengthen the results seen as more participants are added to analyses. Secondly, HRV analysis required the accurate detection of as many R peaks as possible. A missed peak could have a big effect on the final HRV calculation. The experimental design of having individuals walk meant that the resulting raw EKG signal had some inherent noisiness, which was addressed relatively well by the peak detection pipeline and visual inspection to identify missed peaks. A low MSE in comparison to the total variability of the heart rate data does indicate that HRV is a stable method of assessing changes in state anxiety and was therefore ideal to use in spite of the labor-intensive method of assessing that peaks are correctly identified. Innovations in peak detection should continue to be explored to make the process of generating metrics of interest from the raw EKG signal as reliable and as valid as possible.

V. CONCLUSION

HRV analyses for older women navigating VR environments, a dual task, and a single task indicated clearly that VR was an effective tool for eliciting changes in state anxiety. VR was additionally a more effective tool as compared to a traditional dual task in eliciting state anxiety changes. The ability of VR to provide an environment that heightens anxiety was indicated by our results but environment design, such as elevation or obstacles may impact the changes in anxiety seen in individuals.

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