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Attentional Demand of a Virtual Reality-Based Reaching Task in Nondisabled Older Adults

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Abstract

Attention during exercise is known to affect performance; however, the attentional demand inherent to virtual reality (VR)-based exercise is not well understood. We used a dual-task paradigm to compare the attentional demands of VR-based and non-VR-based (conventional, real-world) exercise: 22 non-disabled older adults performed a primary reaching task to virtual and real targets in a counterbalanced block order while verbally responding to an unanticipated auditory tone in one third of the trials. The attentional demand of the primary reaching task was inferred from the voice response time (VRT) to the auditory tone. Participants' engagement level and task experience were also obtained using questionnaires. The virtual target condition was more attention demanding (significantly longer VRT) than the real target condition. Secondary analyses revealed a significant interaction between engagement level and target condition on attentional demand. For participants who were highly engaged, attentional demand was high and independent of target condition. However, for those who were less engaged, attentional demand was low and depended on target condition (i.e., virtual > real). These findings add important knowledge to the growing body of research pertaining to the development and application of technology-enhanced exercise for elders and for rehabilitation purposes.

Keywords

Attention; Attentional focus; Exercise; Motivation; Older adults

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Introduction

Virtual reality (VR)-based exercise, which combines physical exercise and a computer-simulated environment, has become a popular medium for enabling physical activity in the elderly and disability populations (de Bruin, Schoene, Pichierri, & Smith, 2010; Lange et al., 2010; Rizzo et al., 2011; Weiss, Rand, Katz, & Kizony, 2004). Compared to conventional exercise training, VR-based exercise has been shown to be more effective in helping healthy, non-disabled elders achieve better postural control and functional mobility, higher balance confidence, and lower fall risk (Duque et al., 2013; Singh et al., 2012, 2013; Szturm, Betker, Moussavi, Desai, & Goodman, 2011). The embedded “gaming factor” of VR-based applications has been shown to increase older adults' engagement level and facilitate their exercise compliance (Bala S. Rajaratnam, Fang, Jun, Chai, & Shan, 2010; Lange et al., 2010; Pichierri, Wolf, Murer, & de Bruin, 2011; Weiss, Rand, Katz, & Kizony, 2004). People who performed VR-based exercise have reported higher engagement and greater motivation in exercise participation compared to those who received conventional exercise training (Gil-Gomez, Llorens, Alcaniz, & Colomer, 2011; Lange et al., 2010; Pichierri et al., 2011; Thornton et al., 2005).

However, the perceptual and cognitive aspects (e.g., attentional demand) inherent to VR-based applications are commonly overlooked (Pichierri et al., 2011). The attentional demand of a task, which is known to affect an individual's performance (Nagamatsu et al., 2011; Ojha, Kern, Lin, & Winstein, 2009), is not clearly understood for VR-based applications. Although VR-based exercise has been consistently regarded as a beneficial technology, previous studies have focused exclusively on the motor performance improvements and the engaging (gamification) features of the technology. VR has been used mainly to provide a safe and simulated environment where individuals perform tasks under different attentional conditions (i.e., single vs. dual-tasking) (Kizony, Levin, Hughey, Perez, & Fung, 2010; Nagamatsu et al., 2011; Shine et al., 2013). However, until now, the attentional demand of VR-based applications itself has not been investigated directly.

Singh and colleagues (2012) suspected that, compared to conventional exercise, VR-based exercise is more attention demanding because of the added requirement for processing visual stimuli (Singh et al., 2012). VR environments have been developed not only to provide ample visual information, but also a variety of other sensory stimuli such as auditory information (Kenyon & Ellis, 2014). The inherently multimodal nature of VR, which requires coordination of varied types of sensory information, may require more attention from participants than the natural, non-VR environment. In combination with the sensory processing requirements, we posit that VR-based exercise requires additional attention due in part to its engaging characteristics. That is, when participants manifest a high engagement level, it is likely that greater attentional resources will be allocated to the task. Though direct investigation of participants' engagement level on task attentional demand does not exist, previous studies do provide insight into the relationship between engagement level and attentional demand (Cho et al., 2002; Proffitt, Lange, Chen, & Winstein, 2015; Tomporowski & Tinsley, 1996). Tomporowski and Tinsley (1996) and Cho et al. (2002) suggest that intrinsic motivation (e.g., engagement) can influence task-related attention span of both older adults (Tomporowski & Tinsley, 1996) and children (Cho et al., 2002),

respectively. As such, we propose that VR-based exercise will require greater attention than will conventional exercise and further, that there will be a positive correlation between engagement level and attentional demand.

The expected high attentional demand of VR-based exercise can either impair or enhance an individual's performance. Previous studies have demonstrated that tasks with high attentional demand could be a challenge to individuals, especially older adults. Elders required greater attentional resources than young adults when the attentional demand of a locomotor task increased (Ojha et al., 2009). Further, Nagamatsu and colleagues (Nagamatsu et al., 2011) also showed an increasing failure rate in mobility judgments when elders' attention was divided by additional secondary information. On the contrary, other studies suggest that the distracting secondary information does not always degrade individuals' performance. Motor performance and learning can be enhanced under a demanding (dual-task) condition if the secondary information engages similar processes as the primary task (Goh, Sullivan, Gordon, Wulf, & Winstein, 2012; Hemond, Brown, & Robertson, 2010). Due to these potentially conflicting bodies of evidence, and given the rapid increase in proliferation of VR technology in senior centers, rehabilitation facilities, and homes, an understanding of these factors is essential to optimize its application for the elderly and disability populations.

Therefore, the primary aim of this research is to investigate the attentional demand of a VR-based exercise in older adults. We used a repeated-measures, within-subject design, and a dual-task paradigm to compare the attentional demand of a standing reach task performed by older adults under two experimental conditions; one (a VR-based exercise) in which they reached toward a virtual target projected on a screen and the other (a conventional, non-VR-based exercise) in which they reached toward a real target (tennis ball) suspended in front of them on a pole. We hypothesized that the virtual target condition would require more attentional demand than the real target condition. The secondary aim is to explore the relationship between attentional demand and exercise (game) engagement to better understand the motivational factors and interactions associated with VR-based exercise programs.

Methods

Participants

Twenty-two older adults (age range, 59-88 years; Table 1; all right handed) with no standing balance deficits were recruited from the Center for Successful Aging (California State University, Fullerton) and a convenience sample near the University of Southern California, Health Sciences Campus. Three out of the 22 participants required hearing aids for both ears; a majority (21/22) needed eyeglasses while reading or writing. Participants were asked to wear their hearing aids and/or eyeglasses if needed during task performance. Before the beginning of the tasks, the investigators confirmed that there were no uncorrected hearing or visual problems that could impact performance of the reaching task. Prior to participation, all volunteers read and signed an Informed Consent form according to the standards of the University of Southern California Health Sciences Institutional Review Board.

Experimental Design and Task

The participants were asked to perform a goal-directed arm reaching task under two target conditions: virtual and real.

Virtual Target Condition—The “Jewel Mine” VR game developed by the Institute for Creative Technologies (University of Southern California) was designed to encourage dynamic standing balance activities and included two initial postural states – standing and stepping. The “Jewel Mine” VR game was developed in the context of a multi-game training tool for people with disabilities (<http://ict.usc.edu/prototypes/jewel-mine/>) (Lange et al., 2011). The postural states are intended to simulate what might occur in the natural environment as one reaches for objects. The stepping state is considered more balance demanding than the standing state. The stepping state may be used as a more challenging condition for training balance ability of people with impairments of mobility.

In the game scenario, participants travel virtually and passively through a jewel mineshaft at a fixed speed and collect jewels (virtual targets) at each stopping point (where a set of eight targets are presented). The virtual targets are highlighted one at a time for each reach trial in a pseudo-random order at eight spatial locations (equally spaced around an imaginary ring parallel to the participant's frontal plane) (Figure 1). The eight target presentations around the imaginary ring represented a single target set. Once participants successfully reached the last virtual target in a set, they would travel through the virtual mine to the next set of eight targets. Participants were asked to complete seven sets (56 reach trials) in each postural state (Figure 1). Reaching distances were calibrated for each participant before data collection to assure they were an arm's-length (average 0.5m) and one-step-forward (average 1.5m) in the standing and stepping postural states, respectively. During the standing postural state, participants were asked to reach with their hand for the target while standing in a stationary location. During the stepping state, participants were asked to take one step forward while reaching for the target. Participants were instructed to return to their initial standing position (indicated by a blue box on the floor, Figure 1) with their reaching arm positioned back at the side after each reach trial. Participants reached at a self-determined pace; there was no movement initiation signal (i.e., “go” signal) provided. Also, to simulate a more natural scenario, the investigators did not specify the reach arm or stepping foot to be used to accomplish the task.

The game was run on a laptop with Open NI/NITE software (OpenNI.org, <http://openni.ru/openni-sdk/>) and presented on a screen positioned in front of the participants. Participants' movement kinematics were recorded with a Microsoft Kinect™ camera (Microsoft, Redmond, WA), a validated method of real-time motion capture (Kurillo et al., 2013; Mobini, Behzadipour, & Saadat Foumani, 2014; Obdržálek et al., 2012). Participants were instructed to stay within six to eight feet from the Kinect™ camera as indicated by the blue box outline on the floor (Figure 1). This was done to minimize a maximum error of 17mm for the hand joint, with the largest error along the z-axis (distance from the camera) (Mobini et al., 2014). The representation of the hand position was calculated as the center of the hand (see <https://msdn.microsoft.com/en-us/library/jj131025.aspx> for more details on skeleton tracking and joints tracked). In addition, each participant received visual motion feedback

from an on-screen avatar representing the participant's skeleton. When the target was successfully reached, the jewel would disappear with sparks simultaneous with an audible pleasant sound.

Real Target Condition—The real target was a tennis ball attached to the end of a 1-meter long pole, positioned at eight different spatial locations by one of the experimenters (Y-A. C., Y-C. C., or R. P.) in order to simulate the virtual target condition. The experimental setting for the real target condition, including calibration process and target order, was the same as that of the virtual target condition, with the exception of the replacement of the virtual jewel target by the tennis ball. To ensure identical target locations in both target conditions, participant-specific calibrations were conducted prior to each postural state. Post-processing data analysis confirmed that the target distances were consistent between the two conditions for all targets (Wade, Proffitt, Requejo, Mulroy, & Winstein, 2012).

The order of target conditions was counterbalanced across participants. The two postural states under each condition were always performed in the same order (standing followed by stepping). Furthermore, to rule out the possibility of specific movement strategy selection (i.e., dominant vs. non-dominant side) under different task demands (Bryden & Husczyński, 2011; Bryden, Mayer, & Roy, 2011; Mamolo, Roy, Rohr, & Bryden, 2006), we compared the amount of right arm/right leg use in each target condition. A 2 (target condition) $\times$ 2 (postural state) repeated measures ANOVA and a paired *t*-test revealed no significant differences in arm or leg selections, respectively, between the virtual and real target conditions. Participants generally used the same strategy and favored their right dominant hand for reaching and right leg for stepping forward across both target conditions.

Dual-Task Paradigm

A dual-task probe paradigm was used to measure the attentional demand during reaches in both target conditions. The primary task was the reaching task described above; the secondary task was a voice response to an auditory stimulus. While performing the reaching task, the participants wore headphones (Model AHS515, Altec Lansing Inc., New York City, NY) and a microphone hanging comfortably from a neck strap (Model 33-3012, RadioShack, Fort Worth, TX). They were instructed to respond to an unanticipated auditory tone presented through headphones (1000 Hz, 500 ms, sine wave tone) as soon as possible by verbalizing a “bah” sound. Fifteen out of 56 reaching trials (26.8%) were pseudo-randomly probed with the tone (probe trials, Figure 1). An experimenter (Y-A. C. or Y-C. C.) manually triggered a tone after the participant initiated the reach and according to a pre-specified trial list. If a tone was triggered either before the reaching movement started or after the movement ended, it was considered an invalid trial and excluded from further analysis.

Given the known effect of probe timing on reaction time, we examined the time of the tone for all probe trials. Post-processing confirmed that across target conditions and postural states, for the majority of valid probe trials (79.21%), the tone was triggered *after* peak velocity of the wrist. A 2 (target condition) $\times$ 2 (postural state) repeated measures ANOVA on probe timing revealed no significant differences between target conditions for either

standing or stepping states. As such, timing of the tone can be ruled out as a confounding factor for interpretation of the VRT results. Finally, to minimize trade-off between the primary and the secondary tasks, instructions to place priority on the reaching task were given at least once before initiation of each postural state.

Before the reaching task was initiated, VRT for the baseline single-task condition were obtained (Figure 1). Participants remained in a standing position (without reaching) and were asked to verbally respond to an auditory tone as soon as possible (30 trials delivered with a variable inter-trial interval to reduce anticipation).

Outcome Measures and Data Analysis

The attentional demand of the primary task was quantified using the VRT to the auditory tone. The VRT was defined as the time lag between tone onset and voice onset. The tone and voice data were sampled at 1000 Hz and filtered with a 75 Hz 3rd order Butterworth high-pass filter using a customized MATLAB program (version R2010a, Mathworks, Natick, MA).

The reaching movement time (MT), defined as time lag between movement onset and offset, was measured to confirm the absence of a trade-off effect between the primary and the secondary tasks (Fisk, Derrick, & Schneider, 1986; Ojha et al., 2009; Wright & Kemp, 1992). Participants' reaching movement kinematics were recorded with the Microsoft Kinect™ camera. There is a visually detectable delay (i.e., 30ms latency) in computer processing and visual display of the virtual targets and avatar (Webster & Celik, 2014). In order to minimize this delay, the sampling rate of the Kinect™ camera was sacrificed from the highest rate of 30 Hz to a range between 11 and 14Hz. After resampling to 12Hz (the mean sampling frequency for data acquisition), the movement onset/offset were labeled on the kinematic data (i.e., wrist marker time series) with Visual3D™ software (v4, C-Motion, Inc., Germantown, MD) and defined as the first time the wrist movement tangential velocity was above/below 1 cm/s (Messier & Kalaska, 1999).

After completing the experimental tasks, participants' subjective engagement level was measured using a five-level Likert scale: *“The Jewel game/Tennis ball task was more engaging than typical exercises I have done before”* (1 = strongly agree; 5 = strongly disagree). This was followed by a semi-structured interview guided by an experienced clinician to understand participants' experiences during the two target conditions (see Appendix for interview guidelines).

Statistical Analysis

To reduce any familiarization or warm-up effects, the first 5 trials of the baseline condition and the first 8 trials (1st set) of each postural state were discarded from analysis (leaving 25 baseline trials and 48 reach trials/postural state for analysis). SPSS 18.0 (IBM, Armonk, NY) was used for all analyses. Significance level was set at $\alpha = .05$.

The response rates to the auditory tone (i.e., the number of probe trials with responses/total number of probe trials) of the two target conditions were compared using a paired *t*-test. To

validate our primary outcome measure (dual-task VRT), VRT during the four dual-task conditions (two target conditions $\times$ two postural states) was compared to that of the baseline single-task condition using a one-way repeated measures analysis of variance (ANOVA) with Bonferroni post hoc correction to determine the locus of the main effect. To rule out a trade-off effect on VRT, probe trial MT was compared to non-probe trial MT within the same postural state and target condition using a paired *t*-test.

To test our primary hypothesis, a 2 (target condition: virtual, real) $\times$ 2 (postural state: standing, stepping) repeated measures ANOVA was conducted with VRT as the dependent variable. Secondary analyses comparing participants' engagement levels (i.e., Likert scale score) between the two target conditions were performed using a paired *t*-test. Participants were categorized into three groups according to their Likert scale scores: high engagement (scores 1 and 2), neutral (score 3), and low engagement (scores 4 and 5). The attention-engagement relationship was tested using a backward-elimination multiple linear regression with VRT as the dependent variable; three factors were included in the regression model as independent variables: engagement group, target condition, and the engagement group $\times$ target condition interaction term.

Finally, the interview data were subjected to qualitative analysis to extract consistent themes. Two trained researchers (R. P. and a graduate student, C. C.) coded the qualitative interview data; the themes of participants' experience and feelings of the two target conditions were extracted using standard qualitative methods (Strauss & Corbin, 1997).

Results

Validation of Response Time Measure

Response time for each dual-task condition was significantly longer than that of the baseline single-task condition ($p < 0.001$; Figure 2a). There was no significant differences ($p > 0.05$, $n=19$, with kinematic data missing in three participants due to technical problems; Figure 2b) between MTs for probe and non-probe trial reaches within the same postural state and target condition (for the detailed comparison of reaching kinematics between target conditions, please refer to Wade et al., 2013). This indicated that participants prioritized the primary reaching task without slowing down their reach movement for the secondary voice response task. Therefore, the VRT measure was considered to be a valid and reliable reflection of attentional demand for the reaching task.

Response Time for Virtual and Real Targets

The response rate to the auditory tone did not differ between virtual and real target conditions (virtual: $97.34 \pm 5.67\%$, real: $99.64 \pm 1.18\%$, $t_{21} = -1.90$, $p = 0.07$). More importantly, there was a significant main effect of target condition on VRT ($F_{1, 21} = 15.28$, $p = 0.001$, Figure 3). VRT was significantly longer for the virtual target condition than for the real target condition in both standing (virtual: 743 ± 205 ms, real: 643 ± 168 ms) and stepping (virtual: 861 ± 310 ms, real: 690 ± 309 ms) states (Figure 3). Due to the balance demand of the stepping state, we expected VRT to be significantly longer in the stepping than standing state across both target conditions (Lajoie, Teasdale, Bard, & Fleury, 1993;

Ojha et al., 2009). However, there was no main effect of postural state ($F_{1, 21} = 3.65, p = 0.07$) or target condition $\times$ postural state interaction ($F_{1, 21} = 1.86, p = 0.19$) on VRT.

Engagement Level

Participants' engagement level was significantly higher during the virtual target than the real target condition (average statement scores, virtual: 2.64 ± 1.4 , real: $3.59 \pm 1.2, p = 0.01$; lower score indicates higher engagement level). Eleven (50%) out of 22 participants reported that the virtual target condition was more engaging (high engagement group), and 5 participants responded that the virtual target condition was less engaging (low engagement group) than typical exercises they had done before (Figure 4). In contrast, only 4 participants reported high engagement and 11 participants (50%) reported low engagement during the real target condition. The opposite frequency pattern of engagement between target conditions (Figure 4) suggests that the virtual target condition is generally more engaging than the real target condition.

Attention-Engagement Relationship

Given the non-significant main effect of postural state, the VRT used in the regression model was collapsed across postural states for each target condition. Figure 5 demonstrates that participants who were highly engaged in the task showed similarly long VRTs regardless of target condition (high engagement group, virtual: 841 ± 225 ms, real: 817 ± 263 ms). However, for participants with lower self-reported engagement level (i.e., neutral and low engagement groups), the difference between virtual and real target VRT increased (VRT: virtual $>$ real. Neutral engagement group, virtual: 784 ± 257 ms, real: 664 ± 296 ms; low engagement group, virtual: 705 ± 114 ms, real: 613 ± 131 ms). The multiple linear regression revealed a significant interaction between engagement group and target condition on VRT ($F_{1, 42} = 7.77, p < 0.01, R^2 = 0.40$, Figure 5); this engagement by target interaction was the only significant factor left in the regression model and explained 40% of the variance in VRT.

Qualitative Analysis of Interview Data

A qualitative analysis of the interview data revealed that the virtual target condition required more concentration, whereas the real target condition was “simply a task” (Table 2; see Proffitt et al., 2015, for a more complete discussion of the interview data). The participants (10/22) perceived the virtual target condition as more challenging than the real target condition, with greater difficulty to discern target depth and a more random target order. The perceived challenge in the virtual target condition was unsolicited feedback actively reported by the participants. These target-specific perceptual differences were evident even though the target order and distance were the same in the two target conditions (Wade et al., 2012).

Discussion

We used a dual-task paradigm to compare voice response time of a secondary probe task while older adults performed a reaching task to virtual and real targets. To rule out alternative explanations for the main effect of target condition on VRT, we verified that target distance was not different between target conditions, and that the timing of the probe

tone and the reaching movement strategy (i.e., arm and leg selection) was not different between target conditions. Participants showed a longer VRT during the virtual target condition than the real target condition — a finding that is consistent with our hypothesis, but has not been directly tested until now. Secondary analysis confirmed a relatively high engagement level in the virtual target game, a finding that is consistent with previous studies of VR-based exercise (Clark & Kraemer, 2009; S. Lee & Shin, 2013; Rand, Kizony, & Weiss, 2004; Van Schaik, Blake, Pernet, Spears, & Fencott, 2008). The exploratory analysis of the attention-engagement relationship revealed a significant interaction of engagement level and target condition on attentional demand. This finding is new and somewhat unexpected. One plausible explanation for this interaction is that motivational state captured by engagement is an important mediator of attention. We expand upon this idea in the next section.

The longer VRT during the virtual target condition suggests that VR-based exercise demands more of older adults' attentional resources than non-VR-based exercise. Compared to the real target reaching task, participants' attention was more occupied by the virtual reaching task, leaving less attentional resources available for the secondary task. This is consistent with previous work suggesting that VR can attract and increase individuals' attention more effectively, as compared to a non-VR-based environment (conventional, computer monitor). For example, by drawing participants' attention away from pain, a VR environment was shown to induce a greater reduction in perceived pain level during wound care, compared to a video game control condition (Hoffman, Doctor, Patterson, Carrougher, & Furness, 2000). Similarly, adolescents who received cognitive training in a virtual classroom showed a greater improvement in attentional performance than those who received equivalent desktop training (Cho et al., 2002; Parsons, Rizzo, Rogers, & York, 2009). Here, the primary results support that a VR environment is inherently attention demanding, and this characteristic seems to be independent of the task (e.g., cognitive tasks in Cho et al., 2002 and reaching task here).

Researchers have suggested that VR can capture individuals' attention due to its motivating and engaging features (Cho et al., 2002; Proffitt et al., 2015). Most of our participants reported a higher engagement level during the virtual than the real target condition, a finding that is consistent with the presumption that the more engaged the participant is, the greater attention they would place on the task. The regression model analysis provided new insight into the engagement-target condition effect on attention. Participants who were highly engaged in the task demonstrated high attentional demand that was independent of target condition. The engaged participant allocated a similar amount of attentional resources to the task regardless of whether they were reaching for a virtual or real target. However, for participants who were less engaged (i.e., neutral and low self-reported engagement), the target condition for the reaching task differentially influenced attention. In other words, participants who perceived the task as being less engaging, required more attention under a VR environment than a non-VR environment. Therefore, this novel interaction suggests that the overall higher attentional demand for the VR-based task compared with the non-VR-based task is in part dependent on engagement level.

One may argue that the differing challenge associated with the two target conditions, such as the additional visual processing in the virtual condition (Singh et al., 2012), is more likely to require distinct attentional resources. However, the post-task interview data provide support instead for the notion that engagement level is a critical mediator of attentional demand. Approximately half the participants ($n = 10/22$), across the engagement groups, reported that the virtual target condition was challenging to them (high: neutral: low engagement group, $n = 3: 4: 3$, respectively); they experienced difficulties in determining the target depth, and felt that the order of target presentations was more random. In contrast, only one participant (neutral engagement group) reported that the real target condition was challenging. If the challenge level were the key factor in determining attentional demand, we would expect consistently longer VRTs during the virtual compared with the real target condition, independent of engagement level. Nevertheless, we found comparable attentional demands for the two target conditions, but only when self-reported engagement was high. Although the real-target reaching task was perceived as simple and easy, participants' attentional demand was intensified when they were engaged in the task. Further, the one participant who perceived challenge while reaching to the real target (noted above) did not show a lengthened VRT in the real target condition. Instead, his VRT was longer while he reported high engagement during the virtual target condition (virtual vs. real: 794.68 ms – high engagement vs. 473.96 ms – neutral engagement). Hence, we believe that the engagement level has an essential modulating effect on attentional demand. High engagement during VR-based exercise may therefore enhance individuals' motivation level and drive them to concentrate more on the task as well as adhere to a VR-based exercise program. This interpretation is consistent with previous work showing that motivational factors can modulate the allocation and sustainment of attentional resources during cognitive tasks (Robinson et al., 2012; Tomporowski & Tinsley, 1996). Our finding suggests that the attention modulating effect of motivational factors may not be limited to cognitive activities, but also include physical exercise.

There is a growing body of evidence suggesting that attentional and motivational factors associated with various practice conditions (e.g., training environment) have important influences on motor learning (Guadagnoli & Lee, 2004; Lee, Swinnen, & Serrien, 1994; Lewthwaite & Wulf, 2012). Since motor learning is a fundamental process in exercise training and rehabilitation (Krakauer, 2006), understanding the attentional demand of a VR environment is essential for the application of VR-based exercise in optimizing the effectiveness of exercise training. Previous work in young adults has demonstrated that when practice conditions are more demanding or require intense use of processing resources, motor learning is enhanced (Goh et al., 2012; Hemond et al., 2010; Lee et al., 1994). Alternatively, the increased attentional demand induced by the task could instead degrade older adults' performance (e.g., poor mobility judgment while talking on the phone) (Nagamatsu et al., 2011). Previous studies only investigated the temporary impact on performance in older adults; the influence on long-term change (i.e., motor learning) has not been studied. Our study was a single-session exposure, not a longitudinal learning study. The durability and long-term impact of these findings cannot be confirmed until further research is done using an appropriate motor learning design. Moreover, it is not clear from our results whether the increased attentional demand of VR-based exercise had an impact on

participants' task performance. Although most of our participants perceived challenge, all of them successfully accomplished the relatively simple reaching task. Further, the expected challenge of the stepping condition relative to the standing condition was not supported by the data. The relatively easy task in our study compared to other tasks that simulated daily activities (e.g., Nagamatsu et al., 2011; Ojha et al., 2009), cannot be ignored.

Study Limitations

As with any research that forges new ground, there are limitations. First, although the reaching task under two conditions was controlled (i.e., same reach extent), the manner of target presentation and the viewers' perspective were not. In the virtual target condition, eight targets were projected on the screen all at once with the goal target highlighted, while in the real target condition, only one target was presented at a time. In the real target condition, the moving trajectory of the tennis ball, as it was being moved into position by the experimenter, was observable to the participants. It is unknown whether the participants' attentional demand was systematically affected by these two different modes of target presentation. In addition, the avatar may introduce a third person-perspective on the reaching task in the virtual target condition, in contrast to a first person-perspective in the real target condition. Previous research showed that when people learn tasks that require them to move virtual avatars, they often shift over time from an egocentric reference frame (a reference frame coincident with their body) to a viewer centric or an end-point centric reference frame (a reference frame coincident with the avatar) (Carrozzo, McIntyre, Zago, & Lacquaniti, 1999). Although participants in this study were not instructed to focus on the avatar in the virtual target condition, we do not know whether the difference of viewer's perspective would have an impact on attentional demand. Furthermore, the virtual target condition, which required reaching to virtual targets with movements represented by an avatar, was a relatively novel task compared to the real target condition. Although we (1) removed the first set of targets from data analysis to minimize the possible impact of novelty in our results, and (2) did not observe a gradual decrease of VRT across trials in either virtual or real target conditions as would be evidence of decreased novelty, the possible influence of task novelty on attentional demand of VR-based exercise cannot be completely ruled out.

Additionally, the generalization of our attentional demand findings may be limited. All the participants had a relatively active lifestyle and did not report any balance impairments (Table 1); half of the participants were recruited from exercise programs at the Center for Successful Aging at California State University, Fullerton, which may explain the finding that participants' attentional demand was not significantly affected by the balance demand induced by stepping. To extend and optimize the application of VR-based exercise to a more generic older population, young adults or even to special populations who are in need of rehabilitation (e.g., individuals with balance impairments), additional research is required. Moreover, to extend our attentional demand findings to other VR-based exercises requires caution. The attentional demand inherent to VR-based tasks may differ depending on the amount of sensory stimuli, feedback as well as physical or cognitive demand of the tasks. To understand the generalizability of our finding to various VR-based exercises, future studies are needed.

Finally, the results of the exploratory analysis to better understand the relationship between engagement and attention is limited by the particular classification of engagement group used in this study and the small sample that distributed across each of the engagement categories. This novel finding needs to be confirmed and extended with a larger sample and a between-group design.

Conclusions

To our knowledge, this is the first feasibility study to directly compare the attentional demand of a standing VR-based reaching exercise to a standing non-VR-based reaching exercise. The greater attentional demand required for VR-based exercise compared to that for a non-VR-based counterpart is a novel finding that adds new basic knowledge about VR-based activities. The heightened attentional demand appears to be associated with enhanced task engagement—a potential modulating factor that is important for the allocation of attentional resources. VR-based exercises could be more than just fun. Our findings suggest that VR-based exercises require older adults to allocate more attentional resources to the task than do non-VR-based exercises; more importantly, this greater attentional demand appears to depend on the level of task engagement. These findings add to the growing body of evidence supporting the beneficial effects of VR-based applications by highlighting a potential social-cognitive mechanism mediating this effect.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Study design and experimental set-up

Figure 2.

Response time is a valid measure of attentional demand. (a) Response time during the baseline single-task and dual-task conditions. (b) Reaching movement time of the probe and non-probe trials during each condition. Error bars are standard errors.

Figure 3.

Response times for each target condition. The asterisk (*) indicates a significant difference between target conditions for both standing and stepping states in *post hoc* comparisons ($p < 0.05$). Error bars are standard errors.

Figure 4.

Number of participants in each engagement category for each target condition. The number above each bar represents the frequency (# of participants) for that category.

Figure 5. Response time across each engagement category for virtual and real target conditions. Error bars are standard errors.

Table 1
Participant characteristics (n=22)

Characteristics	Value
Age (yr) ^a	73.89 ± 8.38
Gender (male: female, n)	9:13
Berg balance scale ^{a,b}	53.32 ± 2.93
Activity level (n)	
<i>In a typical week, how often do you leave your house for errands, work or social activities?</i>	
less than once	0
1-2 times	0
3-4 times	3
most every day	19

^aValue is reported as Mean ± SD.

^bThe maximal score of Berg balance scale = 56.

Table 2
Selected themes (attentional demand-related) from post interview

Real Target Condition	Virtual Target Condition
Is just a task, not a game	Required more concentration
Simplistic	More challenging
Depth is easier to understand	Less patterned/more random

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