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Effect of Augmented Reality-Based Dual-Task Training on Postural Control in Critical Situations: Analysis by Gender

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Abstract

Purpose: This study investigates the impact of dual-task training on postural sway, particularly focusing on how cognitive tasks influence postural stability in healthy adults.

Methods: A total of 30 asymptomatic adults participated in a series of assessments measuring postural sway during dual-task conditions. Participants performed a cognitive task while maintaining postural stability on a force platform. The sway metrics were analyzed pre- and post-intervention to assess the effects of dual-task training.

Results: The findings revealed that dual-task training significantly reduced the impact of cognitive tasks on postural sway. Participants demonstrated improved postural stability and reduced sway amplitude when engaged in simultaneous cognitive tasks. Furthermore, measures of lumbar lordosis and pelvic inclination were assessed, showing relevant correlations with postural control.

Conclusions: This study highlights the importance of incorporating dual-task training in rehabilitation protocols aimed at improving postural control. The results suggest that cognitive engagement can be effectively managed through training interventions, which may enhance functional mobility and reduce fall risk in both clinical and healthy populations.

Keywords: Augmented reality, Dual task, postural control, critical situation

Introduction

Dual-tasking, which involves performing a primary physical task like walking while engaging in a secondary cognitive activity such as using a smartphone, often leads to what is known as dual-task interference [1]. This phenomenon divides attention, reduces balance, and hinders one's responsiveness to unexpected situations, particularly in contexts where quick reactions are essential for safety [2]. Consequently, dual-task interference has been linked to impaired cognitive performance and a higher risk of falls and injuries while walking [1,2]. A prevalent example is smartphone use while walking, a behavior that has been implicated in 5-30% of falls and walking-related accidents, with incidence rates continuing to rise [3].

However, not all dual-tasking activities carry the same risk. For instance, studies indicate that some tasks, like listening to music while driving, can reduce stress and tension without significantly impairing brake response times [4]. Comparatively, listening to music while driving is less distracting than engaging in a phone conversation [5]. Still, Schwebel et al. [5] caution that, in high-attention environments like crosswalks, activities such as talking on the phone, texting, or even listening to music while walking can pose safety risks. In healthy adults, dual-tasking while walking raises the risk of accidents, particularly in new or unfamiliar environments where rapid postural adjustments may be necessary [6,7]. This highlights the nature of dual-tasking. whether it hinders or enhances postural control, affects daily mobility and safety.

Central to safe and efficient movement is postural control, a fundamental aspect of functional mobility that relies on the integration of somatosensory, visual, and vestibular inputs to maintain stability within a defined base of support [8]. Advances in augmented reality (AR) technology are generating interest in AR-assisted rehabilitation methods, especially for enhancing postural control. While AR and virtual reality (VR) technologies have traditionally been applied in fields such as manufacturing, defense, and education, their role in healthcare is expanding, offering promising applications for therapeutic practices and social health challenges [9,10].

One such promising application is the use of wearable devices, like AR glasses, in rehabilitation settings. AR glasses provide real-time visual feedback during exercises by overlaying virtual images onto real-world environments, thereby enhancing engagement and adherence to rehabilitation routines [11]. The immersive experience these devices offer encourages active participation, allowing therapists to adapt and adjust exercise intensity based on patient progress [12,13,14]. AR-based systems facilitate sensory feedback, making them especially valuable for postural control exercises, which often require continuous, responsive adjustments from the patient.

The use of AR in rehabilitation also intersects with studies examining dual-task performance and postural control. For instance, previous research using multiscale entropy analysis demonstrated that dual-tasking—such as performing cognitive tasks while standing—reduces the complexity of postural control in older adults [15]. Young adults, by contrast, have shown higher sample entropy values under similar conditions, suggesting enhanced efficiency in their postural control systems [16]. Additionally, it has been reported that AR-based dual-task training can improve muscle strength and balance, enhancing postural stability [17, 18]. Further supporting this, B. Wollesen et al. [19] highlight the potential for dual-task training to improve gait performance and overall mobility in both fall-prone and non-fall-prone populations [20].

Nevertheless, the impact of AR on postural control is not universally positive. For example, Sven Blomqvist et al. [21] found no significant improvements in balance performance following AR training among elderly participants, while other authors reported that AR-based postural control training either had no effect or, in some cases, worsened stair-climbing performance among children with cerebral palsy [22]. Similarly, unsupervised home-based AR training showed limited improvement in standing balance among children with migraines or bilateral paralysis who were able to walk [23].

The effectiveness of AR-based dual-tasking on postural control is particularly underexplored in healthy young adults. Previous studies indicated that more complex dual tasks tend to impair postural control more than simpler tasks, resulting in decreased adaptability in the dynamic postural system and increased sway in the center of pressure [24, 25]. Given the variability in findings across populations, further research is warranted to clarify AR's specific effects on dual-task performance, particularly in young adults, who may experience different postural responses compared to older adults.

Finally, gender differences in physical capabilities and recovery have implications for AR-based postural control training. Studies reveal that male and female athletes differ in lower limb muscle function and anaerobic performance, with males generally demonstrating greater physical strength and resilience [26]. Similarly, gender-based disparities are observed in post-injury recovery rates, with men often recovering more rapidly from hip fractures than women, who experience higher instability in certain joints [27]. These findings suggest that AR-based dual-task training might not only enhance postural control but also help mitigate gender disparities in physical performance. Based on this context, the present study aimed to investigate the effects of AR-based dual-task training on postural control, with an emphasis on identifying potential gender-based differences in performance outcomes during emergency scenarios.

Materials and methods

Participants

A total of 30 healthy adult students from Sun Moon University (13 males and 17 females) participated in the study. Inclusion criteria required participants to be adults (aged 18–30), currently enrolled students, and able to walk unaided without any assistive devices. Participants also needed to be free of any cognitive, vestibular, neurological, or musculoskeletal conditions that could impact their performance on the dual-task exercises. Exclusion criteria included any history of severe musculoskeletal or neurological injury, current medication affecting balance or cognitive function, or any condition that would prevent safe participation in physical or cognitive tasks. Four male participants withdrew from the study, resulting in a final cohort of 13 males and 17 females. The study adhered to the Declaration of Helsinki and all participants providing written consent after receiving a full explanation of the study's purpose and procedures. Participant demographics are detailed in Table 1.

Table 1. General characteristics of subjects (n= 30)

Variable	Mean± SD
Age (year)	21.30±1.34
Height (cm)	168.10±9.93
Weight (kg)	66.67±12.74

Measurements and equipment

A 3D optical motion capture system (EDDO Biomechanics, STT Systems, 2022.1, Spain) was employed to track anterior-posterior postural disturbances. Key anatomical markers were placed on the right shoulder (acromion of the right scapula), spine (L1 vertebra), left hip (left greater trochanter), back hip (coccyx), right hip (right greater trochanter), left knee (lateral epicondyle of the left femur), and right knee (lateral epicondyle of the right femur), resulting in seven marked points to analyze body movement. Muscle activity in relevant areas, such as hip extensors (gluteus maximus), lumbar stabilizers (quadratus lumborum), knee flexors (biceps femoris), and the gastrocnemius lateral, was assessed. The motion analysis was performed with participants holding a box, eyes and ears covered by an eye patch and earplugs, as they attempted to catch a ball released by the researcher into the box [Table 2].

Table 2. Motion analyzer maker location

Electromyography (EMG) measurements were conducted using FreeEMG 1000 (BTS G-sensor, AP1180, USA) to analyze muscle activation in the right quadratus lumborum, right gluteus maximus, right biceps femoris, and right gastrocnemius lateral muscles [Figure 2].

Maker	Attachment point
Right shoulder	Acromion of the right scapular
Spine down	L1 vertebra body
Left hip	Left greater trochanter
Back hip	Coccyx; first coccygeal vertebra
Right hip	Right greater trochanter
Left knee	Lateral epicondyle of the left femur
Right knee	Lateral epicondyle of the right femur

Before electrode placement, the skin was shaved and cleaned with alcohol swabs to reduce resistance and ensure signal quality. Surface electrodes were aligned parallel to muscle fibers, spaced 2 cm apart. EMG signals from these four muscle sites were collected for analysis [Table 3].

(A) **(B)**

Figure 1. (A) Electromyography; (B) Non-motorized treadmill

Table 3. Electromyography maker location

Maker	Attachment point
Lumbar	Rt. Quadratus Lumborum; slightly oblique point between the iliac crest and the 12th rib on the 4cm side of the erector spinae muscle
Hip Extensor	Rt. Gluteus Maximus; 1/2 the distance b/t the greater trochanter & and the sacral vertebra at the level of the trochanter, on an oblique angle parallel to muscle fiber direction
Knee Flexor	Rt. Biceps Femoris; in the lateral of the back of the thigh, approx. 1/5-1/4 the distance from the gluteal fold to the back of the leg
	Rt. Gastrocnemius Lateral; just distal from the knee, 1-2cm medial or lateral to the midline

The iRunner Jubatus non-motorized treadmill was used, featuring a curved design that mimics natural terrain and a highly elastic belt to absorb impact, reducing the risk of joint damage and knee injuries. Participants performed dual-task walking exercises on this treadmill, which was calibrated to match their regular stride and walking speed. Researchers closely monitored participants to ensure safety, providing support in cases of dizziness or potential falls. All participants received training on equipment usage and fall prevention.

The UINCARE Pro AR platform, a smart rehabilitation tool for real-time 3D motion analysis and interactive exercises, was utilized to assess postural control during dual-tasking. The program "Racing," which requires participants to avoid high obstacles in real time, served

as the AR-based dual-tasking exercise. The AR system was set to a high difficulty and speed level, and all participants received training on device protocol prior to the tasks [Figure 2].

Figure 2. (A) Augmented reality-based devices;
(B) Participants performing a dual task using an augmented reality-based devices

Intervention methods

Participants in the dual task, non-motorized treadmill began the tasks by standing on the non-motorized treadmill while holding a smartphone. At the researcher's signal, participants walked for six minutes while performing various phone-related tasks. The researcher engaged participants by messaging, giving verbal instructions, and taking and sending photos, aiming to replicate daily smartphone use without explicitly instructing participants on their walking posture.

For the AR-based dual-task, participants engaged in a three-minute obstacle-avoidance game, with the challenge of evading virtual obstacles while maintaining a phone conversation. The difficulty and speed were set to high and fast, respectively, to challenge participants' postural control and responsiveness. This task required participants to coordinate their movements dynamically while avoiding obstacles and staying engaged in the conversation.

Statistical analysis

Descriptive statistics, including mean and standard deviation, were calculated for participants' demographic data (age, gender, height, weight). Paired t-tests were used to assess differences in postural control before and after the intervention, while independent-sample t-tests examined pre- and post-study outcomes by gender. All analyses were conducted using IBM-SPSS 22.0 software, with statistical significance set at $p < 0.05$. Descriptive statistics are presented as mean ± standard deviation for clarity in data interpretation.

Results

Postural control

This study assessed changes in posture control by restricting participants' vision and hearing and measuring their postural adjustments when catching a ball using a motion analyzer. Participants were divided into male and female groups, with posture measurements recorded both pre- and post-training to allow for within-group and between-group comparisons. A paired t-test was conducted to analyze the pre- and post-training changes within each group. Both male and female groups showed statistically significant improvements in posture control after training, indicating effective adaptation to the sensory restrictions and the training program [Table 4].

To examine potential gender-based differences in posture control, an independent t-test was performed for each measured location. The analysis showed no significant differences between male and female groups, suggesting that both groups responded similarly to the training in terms of posture adjustments under sensory restrictions [Table 5].

Table 4. Comparison of postural control within groups pre and post test differences

	Axis	Gender	Pre-test	Post-test	t	*p*
Rt.S	X	M	7.20±7.38	1.01±4.30	3.780	0.00
		F	4.18±8.13	-1.66±7.56	4.763	0.00
	Y	M	7.31±5.05	2.34±3.39	3.710	0.00
		F	3.86±4.85	-0.64±4.60	5.016	0.00
	Z	M	0.75±9.11	-4.78±9.79	4.485	0.00
		F	8.03±11.29	2.75±11.68	3.011	0.01
SD	X	M	4.67±5.70	-0.93±3.69	2.986	0.01
		F	0.98±9.09	-4.03±8.00	3.965	0.00
	Y	M	5.16±4.82	1.54±4.02	5.367	0.00

		F	7.31±4.91	3.03±11.00	5.521	0.00
	Z	M	0.55±11.23	-8.64±9.99	3.988	0.00
		F	3.03±11.00	-2.31±7.57	2.470	0.03
Lt.H	X	M	5.09±3.59	-0.61±2.93	4.017	0.00
		F	2.71±5.58	-2.04±4.78	5.374	0.00
	Y	M	2.76±1.08	0.20±0.99	6.660	0.00
		F	2.45±2.02	-0.24±2.05	4.537	0.00
	Z	M	-2.96±11.62	-9.77±10.71	3.484	0.01
		F	-1.48±11.17	-9.94±8.01	4.495	0.00
BH	X	M	4.38±4.53	-0.60±3.31	2.969	0.01
		F	2.05±7.98	-3.44±7.21	4.996	0.00
	Y	M	6.01±2.30	1.22±2.62	5.032	0.00
		F	4.73±4.50	1.29±3.86	3.253	0.01
	Z	M	-1.37±11.22	-9.90±10.08	4.242	0.00
		F	2.45±9.29	-5.22±7.53	3.080	0.01
Rt.H	X	M	5.85±3.44	-0.93±3.16	4.598	0.00
		F	2.71±5.45	-2.15±5.51	5.412	0.00
	Y	M	4.749±1.60	0.80±1.45	9.862	0.00
		F	3.86±2.44	0.05±2.03	6.591	0.00
	Z	M	-5.21±14.91	-11.58±1.97	3.420	0.01
		F	-1.87±8.70	-8.15±8.09	2.510	0.02
Lt.K	X	M	4.78±1.97	-0.14±1.57	6.989	0.00
		F	3.41±2.77	0.33±2.59	3.221	0.01
	Y	M	3.38±3.50	0.62±0.83	2.761	0.01
		F	3.97±2.34	0.15±1.13	6.603	0.00
	Z	M	-1.6±5.43	-7.03±5.82	4.055	0.00
		F	4.74±10.31	-2.62±5.69	3.075	0.01
RK	X	M	4.59±1.98	-0.66±1.84	6.209	0.00
		F	4.07±4.07	0.31±2.31	3.371	0.00
	Y	M	4.51±1.06	0.35±0.94	12.957	0.00
		F	4.18±2.15	0.55±1.52	5.405	0.00
	Z	M	-0.11±7.00	-5.97±7.77	3.328	0.01
		F	3.42±10.44	-4.41±7.62	2.547	0.02

* p<0.005; Mean(sec) ± Standard Deviation(sec); Rt.S, Right Shoulder; SD, Spine Down; Lt.H, Left Hip; BH, Back Hip; Rt.H, Right Hip; Lt.K, Left Knee; Rt.K, Right Knee.

Table 5. Comparison of postural control pre and post test differences between groups

Pre	**Axis**	**Male**	**Female**	**t**	***p***	**Post**	**Axis**	**Male**	**Female**	**t**	***p***
Rt.S	X	7.20±7.38	4.18±8.13	1.050	0.30	Rt.S	X	1.01±4.30	-1.66±7.56	1.136	0.27

	Y	7.31±5.05	3.85±4.85	1.903	0.07		Y	2.34±3.40	-0.64±4.60	1.961	0.06
	Z	0.75±9.11	8.03±11.29	-1.900	0.07		Z	-4.78±9.80	2.75±11.68	-1.873	0.07
SD	X	4.67±5.70	0.98±9.09	1.282	0.21	SD	X	-0.93±3.69	-4.03±8.00	1.291	0.21
	Y	5.16±4.82	7.31±4.91	-1.196	0.24		Y	1.54±4.02	3.99±3.99	-1.665	0.11
	Z	-0.22±11.23	3.03±11.00	-0.876	0.39		Z	-8.64±9.99	-2.31±7.57	-1.976	0.06
Lt.H	X	5.09±3.59	2.71±5.58	1.338	0.19	Lt.H	X	-0.61±2.93	-2.04±4.78	0.945	0.35
	Y	2.76±1.08	2.45±2.02	0.490	0.63		Y	0.20±0.99	-0.24±2.05	0.720	0.48
	Z	-2.96±11.62	-1.48±11.17	-0.355	0.73		Z	-9.79±10.71	-9.94±8.01	0.045	0.96
BH	X	4.38±4.53	2.05±7.98	0.939	0.36	BH	X	-0.60±3.31	-3.44±7.21	1.314	0.20
	Y	6.01±2.30	4.73±4.50	0.929	0.36		Y	1.22±2.62	1.29±3.86	-0.053	0.96
	Z	-1.37±11.22	2.44±9.28	-1.021	0.32		Z	-9.90±10.08	-5.22±7.53	-1.455	0.16
Rt.H	X	5.85±3.45	2.71±5.45	1.811	0.08	Rt.H	X	-0.93±3.16	-2.15±5.51	0.711	0.48
	Y	4.79±1.60	3.86±2.44	1.185	0.25		Y	0.80±1.45	0.05±2.03	1.129	0.27
	Z	-5.21±14.91	-1.87±8.70	-0.769	0.45		Z	-11.58±13.84	-8.15±8.09	-0.851	0.40
Lt.K	X	4.78±1.97	3.41±2.77	1.510	0.14	Lt.K	X	-0.14±1.57	0.33±2.59	-0.577	0.57
	Y	3.38±3.50	3.97±2.34	-0.553	0.59		Y	0.62±0.83	0.15±1.13	1.275	0.21
	Z	-1.36±5.43	4.74±10.31	-1.932	0.06		Z	-7.03±5.82	-2.62±5.69	-2.085	0.05
Rt.K	X	4.59±1.98	4.07±4.07	0.420	0.68	Rt.K	X	-0.66±1.84	0.31±2.31	-1.241	0.23
	Y	4.51±1.06	4.18±2.15	0.503	0.62		Y	0.35±0.94	0.55±1.52	-0.407	0.69
	Z	-0.11±7.00	3.42±10.44	-1.050	0.30		Z	-5.97±7.77	-4.41±7.62	-0.553	0.58

* $p<0.005$; Mean(sec) ± Standard Deviation(sec); Rt.S, Right Shoulder; SD, Spine Down; Lt.H, Left Hip; BH, Back Hip; Rt.H, Right Hip; Lt.K, Left Knee; Rt.K, Right Knee.

Muscle Activity

Muscle activity onset time was analyzed through electromyography (EMG) measurements to observe changes in muscle activation patterns while participants caught a ball under restricted sensory conditions. The data were separated into pre- and post-training measurements to enable within-group and between-group comparisons. A paired t-test revealed significant differences within each group, demonstrating that training impacted the timing of muscle activation in both males and females [Table 6].

To evaluate gender-based variations in muscle activity onset time, an independent t-test was conducted across different measurement locations. The results indicated no statistically significant differences between males and females, implying that muscle activation patterns were similarly influenced by the training for both groups [Table 7].

Table 6. Comparison of muscle activity onset times within groups pre and post test differences

	Gender	Pre	Post	t	*p*		Gender	Pre	Post	t	*p*
QL	M	0.68±0.13	0.58±0.13	3.155	0.01	BF	M	0.76±0.20	0.60±0.12	3.140	0.01
	F	0.81±0.29	0.66±0.21	4.096	0.00		F	0.91±0.39	0.67±0.18	3.402	0.00
GM	M	0.88±0.29	0.61±0.13	3.700	0.00	GL	M	0.78±0.30	0.56±0.14	2.852	0.02
	F	0.89±0.31	0.67±0.17	4.989	0.00		F	0.81±0.27	0.65±0.20	4.736	0.00

* p<0.005; Mean(mm) ± Standard Deviation(mm); QL, Quadratus Lumborum; GM, Gluteus Maximus; BF, Biceps Femoris; GL, Gastrocnemius Lateral.

Table 7. Comparison of muscle activity pre and post test differences between groups

	Gender	Pre-test	Post-test		Ggender	Pre-test	Post-test
QL	M	0.68±0.13	0.58±0.14	BF	M	0.76±0.21	0.60±0.12
	F	0.81±0.29	0.66±0.21		F	0.91±0.39	0.67±0.18
	T	-1.669	-1.221		T	-1.269	-1.181
	P	0.11	0.23		P	0.22	0.25
GM	M	0.88±0.29	0.61±0.13	GL	M	0.78±0.30	0.56±0.14
	F	0.89±0.31	0.67±0.17		F	0.81±0.27	0.65±0.20
	T	-0.119	-1.029		T	-0.308	-1.272
	P	0.91	0.31		P	0.78±0.30	0.21

* p<0.005; Mean(mm) ± Standard Deviation(mm); QL, Quadratus Lumborum; GM, Gluteus Maximus; BF, Biceps Femoris; GL, Gastrocnemius Lateral

Discussion

This study aimed to investigate gender differences in postural control under sudden, dual-task conditions using AR-based training. The dual task simulated everyday life by requiring participants to walk while using a smartphone, engaging in auditory, visual, and proprioceptive senses. Effective execution of this task relies on minimal postural sway and rapid muscle reaction times. However, dual tasks can be distracting, potentially reducing balance and reaction capabilities. By integrating AR with smartphone-based walking, we sought to create a realistic training environment that mirrored real-life scenarios. Our primary goal was to enhance postural control and muscle reactivity in sudden situations, ultimately contributing to improved stability and reduced injury risk.

The first intervention involved walking on a non-motorized treadmill while using a smartphone. A prior study by Saraiva et al. [25] identified a lack of dynamic movement in similar dual-task settings as a limitation, which we addressed by incorporating walking. The non-motorized treadmill allowed participants to set their pace, simulating typical walking conditions. This dual-task training engaged auditory, visual, and proprioceptive senses, and by integrating smartphone-based activities such as social media browsing or photography, we attempted to replicate real-life scenarios. This approach may benefit participants' daily stability and potentially reduce postural sway.

The second intervention focused on AR-based dual-task training that included obstacle walking while using a smartphone. Walking while distracted by smartphone use is common and poses risks by diverting attention and impacting gait stability. Given the advances in AR and VR applications in medical training, we leveraged AR for its real-time feedback capabilities, which can enhance engagement and motivation in training. Moon et al. [18] found that AR-based exercises, such as sling exercises, positively impacted muscle strength and balance, potentially aiding in rapid postural adjustments. These findings align with the aims of this study, supporting AR's role in fostering improved balance and strength in sudden scenarios.

Our first set of motion analysis results showed significant improvements within both male and female groups, aligning with Ghai et al. [28] who reported improved postural stability through dual-tasking in young adults. Pellecchia et al. also observed that dual-task participants exhibited less postural sway than those performing single or no tasks, suggesting that dual-tasking contributes to postural stability. Our second result focused on gender differences, with mixed findings. While no significant pre-post gender differences were observed overall, prior research suggests that physical differences, such as lower muscle strength in women, may affect outcomes. Studies by Choi et al. [26] and Arinzon et al. [27] indicate that men typically exhibit better physical fitness and faster recovery post-injury. Additionally, Gartsman et al. [29] and Pellecchia et al. [30] report higher rates of ankle and shoulder instability in women. A study by Youdas et al. [31] also noted that women generally exhibit greater pelvic tilt when standing. Despite these differences, women in this study showed comparable outcomes to men, possibly due to the focused nature of AR training. Jeongsu et al. [32] found that women tend to concentrate more during media use, suggesting AR-based training could yield comparable postural improvements for women, benefiting their stability despite higher predispositions for certain instabilities.

The EMG results indicated that onset times were slightly faster in females than males. While differences in physical characteristics might suggest slower response times for women, our findings indicate that AR-based dual-task training effectively reduces muscle activation onset time, contributing to quicker neural responses in dynamic tasks. This outcome aligns with Dayanidhi et al. [33], who found that reduced muscle onset positively complements neural maturation in dynamic tasks, underscoring the efficacy of AR training in sudden, dual-task situations.

No significant inter-group differences were observed in preliminary outcomes. Based on existing research, we anticipated more pronounced gender differences in postural control and muscle activation times due to physical distinctions. However, the small sample size (13 males and 17 females) may have impacted these findings. Additionally, the study’s focus on young adults without medical conditions may have further limited detectable differences.

Several limitations should be considered. First, the study sample consisted of young adults, which may restrict generalizability across age groups. Nevertheless, the results demonstrated effective outcomes within this demographic, suggesting potential for gender-specific clinical interventions. Second, the AR device's difficulty level was designed for individuals with conditions like cerebral palsy, which may have limited its challenge level for young adults. However, the intervention's impact aligned with the study's purpose, and results may improve with higher-difficulty devices. Third, adding a postural sway measure alongside the COG measure would provide more accurate data. Finally, the intervention lasted only four weeks; a longer duration could potentially yield more significant results.

Conclusions

This study aimed to investigate gender differences in postural control during sudden situations through AR-based dual-task training. Our findings indicate that dual-task activities, such as walking while using a smartphone, can enhance postural stability and muscle reaction times in both men and women. Although no significant gender differences were observed, the comparable improvements suggest that AR training is effective across genders. This research supports the potential of AR technologies in rehabilitation and highlights the need for further investigation into their application in diverse populations to improve balance and reduce injury risk.

Conflicts of interest

The authors declare no conflict of interest

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