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Examining the role of attention focus walking training on conscious motor processing during rehabilitation by older adults at risk of falling: A randomized controlled trial

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HIGHLIGHTS

- Conscious motor processing might disrupt automatic motor control and hamper gait.
- External focus training during gait reduces real-time conscious motor processing.
- Instruction-specific gait training shortly improves functional balance and gait.

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ABSTRACT

This study examined the impact of walking training with different attention focus instructions on real-time conscious motor processing and fall-related rehabilitation outcomes in older adults at risk of falling. A total of 102 community-dwelling older adults (mean age = 75.2 years, SD = 6.8 years) were randomly assigned to three groups: no attention focus walking group (NAFWG), external attention focus walking group (EAFWG), or internal attention focus walking group (IAFWG). All groups underwent 12 training sessions. Assessments were conducted at baseline, post-training, and six months later, measuring real-time conscious motor processing, functional balance and gait, balance ability, functional mobility, walking ability, trait conscious motor processing propensity, fear of falling, and recurrent falls. The EAFWG showed significant reduction on real-time conscious motor processing immediately after training ($p = 0.015$). No changes were observed for the IAFWG and NAFWG. All groups showed significant improvements in functional balance and gait ($p < 0.001$) and balance ability ($p < 0.001$) post-training. Implementing external focus instructions during walking training could be a feasible and beneficial strategy for reducing real-time conscious motor processing, which may improve walking performance and prevent falls in older adults. Further research is needed to examine the sustained benefits of these interventions and determine optimal training dosage for older adults with different risks of falling in fall prevention.

1. Introduction

Walking is an essential motor skill that plays a vital role in facilitating daily activities. However, as individuals age, it is common to experience a reduction in bone density (osteopenia/osteoporosis) and muscle mass (sarcopenia) (Iolascon et al., 2020). Sarcopenia, characterized by a lack of muscle strength and power, may have significant implications on physical performance (Iolascon et al., 2020). The loss of muscle mass may reduce force generation which could compromise step length, stride length, and double-limb support time during walking (Ambrose et al., 2013; Herssens et al., 2018), reducing balance and gait stability. These physical impairments, combined with other risk factors such as polypharmacy and history of falls (Iolascon et al., 2020), substantially increase the risk of falling, particularly in situations involving unexpected trips or slips (Jensen et al., 2001). Importantly, diminished gait and balance functions consistently emerge as one of the strongest risk factors for falls (Ambrose et al., 2013), which can result in severe consequences such as hip fractures, hospitalization, fear of falling, and even mortality (Kannus et al., 1999; Tinetti & Williams, 1997), especially when osteoporosis or sarcopenia is present. Given that walking is

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closely associated with falls (Li et al., 2006) and the potential severe consequences of falls, it is crucial to investigate and implement specific walking training interventions for older adults as part of falls prevention strategies in gait rehabilitation. These interventions should aim to improve gait patterns and stability, ultimately reducing the risk of falls during walking and enhancing the overall well-being of older adults.

In healthy older adults, walking typically occurs with minimal conscious thought regarding the movement process (Malone & Bastian, 2010). However, under stressful conditions such as increased fear of falling or movement difficulties, some older adults may rely on conscious motor processing to enhance movement efficiency. Conscious motor processing involves the use of explicit knowledge and strategies to control movement mechanism (Masters, 1992). This shift from automaticity to conscious control of movements is referred to as "reinvestment" (Masters & Maxwell, 2008; Masters, 1992). Previous studies have indicated that older adults with a history of falls tend to reinvest more than age-matched non-fallers (Wong et al., 2008), with fallers allocating attention to both internal and external information during walking, while non-fallers primarily focus externally (Wong et al., 2009). However, the internal focus of attention during conscious motor processing, which involves heightened awareness of limb movements, can overload working memory resources (Baddeley, 1999) and interfere with automatic motor control mechanisms (Deikman, 1966). This interference can potentially alter the normal walking pattern, leading to deteriorated gait stability and performance (Uiga et al., 2020).

To optimize gait patterns and stability in older adults at risk of falls, it is crucial to prioritize effective gait rehabilitation that addresses reinvestment (conscious motor processing) tendencies. Prior studies on implicit motor learning have explored the influence of attention focus instructions on various motor tasks related to gait, including balance, muscle efficiency, postural stability, and gait patterns. These studies consistently demonstrate that individuals instructed with an external attention focus or engaged in concurrent tasks exhibit superior balance (McNevin et al., 2003; Wulf et al., 1998, 2001; Wulf & McNevin, 2003), improved muscle efficiency (Vance et al., 2004; Wulf et al., 2010; Zachry et al., 2005), enhanced postural control (Huxhold et al., 2006), and more favorable gait patterns and variability (Lövdén et al., 2008; Verrel et al., 2009) compared to those instructed with an internal attention focus or without a concurrent task. These positive outcomes imply a reduction in conscious motor processing through the use of external focus instructions. These findings align with the theory of "constrained action hypothesis," proposing an external focus of attention allows the motor system to naturally self-organize, independent of conscious control (Wulf et al., 2001). Investigating the direct effects of attention focus instructions on real-time conscious motor control during walking tasks, Mak et al. (2021) observed a significant reduction in T3-Fz coherence (a measure of real-time conscious motor processing) in older adults instructed with an external focus compared to an internal focus. However, the effects of using external focus instructions as a training strategy on real-time conscious motor processing in the context of gait rehabilitation for older adults remain unclear.

To address this research gap, our study aims to examine the effects of external, internal, and no attention focus instructions during gait rehabilitation training on real-time conscious motor processing (reinvestment) and fall-related rehabilitation outcomes among community-dwelling older adults. This research endeavor is crucial to advance future rehabilitative psychomotor training in gait and fall rehabilitation to reduce the risk of falls among older adults. We hypothesize that older adults at risk of falling who undergo external attention focus walking training during gait rehabilitation will exhibit reduced real-time conscious motor processing and improve fall-related rehabilitation outcomes compared to those who undergo internal and no attention focus walking training.

2. Materials and methods

2.1. Design

The study followed a multi-site, single-blinded (assessor), randomized controlled trial with three parallel groups. Participants were randomly assigned to one of the following groups: the “No Attention Focus Walking Group” (NAFWG; active control group), “External Attention Focus Walking Group” (EAFWG), or the “Internal Attention Focus Walking Group” (IAFWG). The training protocols implemented were previously validated for their feasibility, effectiveness, and safety in a pilot study.

2.2. Participants

Participants were recruited from the local community centers in Hong Kong based on the following inclusion criteria: (1) aged 65 or above; (2) no history of cerebral vascular disease, Parkinson’s disease, or any other neurological deficit; (3) a minimum total score of 24/30 on the Chinese version of the Mini-Mental State Examination (MMSE-C) (Chiu et al., 1994; Folstein et al., 1975); (4) independent indoor ambulation with comfortable pace of at least 40 m continuously; (5) a total score of less than 24/28 on the Tinetti Performance Oriented Mobility Assessment Tool (POMA) (Tinetti, 1986). Participants unable to meet the above inclusion criteria were excluded. The study was approved by the Institutional Review Board of the Hong Kong Polytechnic University (PolyU IRB) (reference number: HSEARS20200617001–02). The randomized controlled trial was conducted and reported as per the international standards of Consolidated Standards of Reporting Trials (CONSORT) (Schulz et al., 2010). The trial was pre-registered in the ClinicalTrials.gov (ID: NCT04419753) prior to data collection. Informed consent was obtained from all participants prior to any experimental procedures.

2.3. Sampling and randomization

An effect size = 0.32 was calculated from a prior pilot study for the primary outcome of real-time conscious motor processing, which suggested that a sample size of 30 participants per group would provide sufficient power for the study to detect groups’ differences. Accounting for an anticipated 20 % dropout rate for a similar type of randomized controlled trial, a total of 108 participants (36 per group) were estimated. Among the 221 participants screened, 108 met eligibility criteria, but six participants were unable to participate due to time constraints. A total of 102 eligible participants were randomly assigned to three groups by an independent person: NAFWG (n = 34), EAFWG (n = 34), or IAFWG (n = 34). Randomization utilized concealed block randomization with opaque and sealed envelopes, generated by a computerized random-number generator.

2.4. Intervention

Participants attended a total of 12 training sessions (three times per week for four weeks), with each session lasting 45 min. The training sessions took place at local community centers. During the sessions, all three groups performed identical balance exercises. However, they received distinct walking instructions developed by expert geriatric rehabilitation physiotherapists while walking under the same condition (i.e., along the same walkway at a comfortable pace). In the NAFWG, participants were instructed to walk with a simple command: "Please walk until the end of this walkway and return to the starting point at a comfortable pace." In the EAFWG, external attention focus instruction was utilized: "Please walk until the end of this walkway and return to the starting point at a comfortable pace. While walking along the walkway, please look at the screen in front of you and concentrate on a random series of numbers ranging from 0 to 9 displayed on the screen." In the

IAFWG, participants walked with an internal attention focus instruction: "Please walk until the end of this walkway and return to the starting point at a comfortable pace. While walking along the walkway, please focus on your footsteps and lower limb movements." Apart from the differences in the above walking instructions, there were no other treatment differences among the three groups.

2.5. Procedures

Before the training sessions, participants attended a pre-training session to receive a thorough explanation of their group-specific walking instructions.

Training sessions were conducted in small groups of up to six participants and included a (i) 5-min warm-up (e.g., joint mobility, stepping exercises), (ii) 5-min balance training (e.g., static and dynamic balance), (iii) 5-min body transport training (e.g., transfer from sitting to standing), (iv) 5-min body transport training with hand manipulation (e.g., transfer from sitting to standing with object in hands), (v) 20-min walking training with varying difficulty levels along a 40-m, 25 m^2 walking field, adhering to group-specific instructions, and (vi) 5-minute cool-down. These sessions constituted the sole treatment provided and were all led by registered physiotherapists with extensive geriatric rehabilitation experience.

At the beginning of the 12 training sessions, a structured questionnaire collected demographic, medical, fall history, social, and socioeconomic information. Outcome assessments were conducted at three time points: baseline (T0), immediately after training (T1), and six months post-training (T2) to evaluate cognitive and physical abilities. The strategies of telephone reminder and monetary incentives were adopted to improve adherence and retention of participants.

2.6. Outcome assessments

2.6.1. Primary outcome

Real-time conscious motor processing was assessed using Alpha 2 Electroencephalography (EEG) coherence between T3 (verbal-analytical region) and Fz (motor planning region) (i.e. T3-Fz EEG coherence) during three walking trials on a 6-meter level-ground walkway. Previous research has demonstrated that Alpha 2 T3-Fz EEG coherence is sensitive to within-subject changes in real-time conscious motor processing during motor tasks (Ellmers et al., 2016; Zhu et al., 2011). These findings support the use of Alpha 2 T3-Fz EEG coherence as a key variable of interest for assessing the primary outcome.

The real-time EEG activity was measured using a wireless EEG device with a sampling frequency of 200 Hz (Brainquiry PET 4.0, Brainquiry, The Netherlands), and was recorded by a biophysical data acquisition software (BioExplorer 1.5, CyberEvolution, US). Using the standard international ten-twenty electrode system (Jasper, 1958), T3, T4 (visuospatial region) and Fz electrodes were placed on the left and right temporal region and frontal midline, respectively. Additional electrodes were placed on right (reference electrode) and left mastoid (ground electrode), and left zygomatic bone (eye blink) (Zhu et al., 2011). The average Alpha 2 T3-Fz EEG coherence was calculated based on the three walking trials per participant. Coherence values were calculated using custom scripts in a biophysical data processing and analysis software (BioReviewer 1.5, CyberEvolution, US) (Zhu et al., 2011).

2.6.2. Secondary outcomes

Functional balance and gait were assessed using the POMA (Tinetti, 1986), comprising balance (16 points) and gait (12 points) components, with a total score of 28 points. A higher score indicates a lower risk of falling ($\leq$18 = high risk; 19–24 = moderate risk; $\geq$25 = low risk). Balance ability was evaluated using the Berg Balance Scale (BBS) with 14 performance items (Berg et al., 1989). A higher BBS score indicates better balance ability. Functional mobility was measured using the Time "Up and Go" Test (TUG) (Podsiadlo & Richardson, 1991), with completion time greater than 14 s indicating a higher risk of falling (Shumway-Cook et al., 2000). Walking ability was assessed via 10-meter comfortable and fast walking speed (Bohannon, 1997).

Trait conscious motor processing propensity was examined using the Chinese version of the Movement Specific Reinvestment Scale (MSRS-C), a 10-item scale with two subscales (five items each): (i) conscious motor processing and (ii) movement self-consciousness. It has demonstrated reliability and validity in measuring the propensity for reinvestment in the older Chinese population (Masters et al., 2005), with higher scores indicating a higher trait movement-specific reinvestment propensity. Fear of falling was assessed using the Chinese version of the Falls Efficacy Scale International (FES-I (Ch)) (Kwan et al., 2013). Participants recorded the number of falls experienced during the 6-month follow-up period (T2) using a structural calendar. T4-Fz EEG coherence was assessed to ensure the differences in the T3-Fz EEG coherence is not due to global cortical activation (Zhu et al., 2011).

2.7. Data processing

Statistical analysis employed IBM SPSS Statistics version 28.0 (IBM Corp, Armonk, NY, USA). Descriptive statistics summarized both continuous (mean and standard deviations) and categorical (numbers with percentages) variables. Between-group differences at baseline (T0) were analyzed using one-way analysis of variance (ANOVA) and chi-square tests. The effects of walking training on primary and secondary outcomes were analyzed using 3 (Group: NAFWG, EAFWG, and IAFWG) x 2 (Time: T0, T1 and T0, T2) mixed-model ANOVA with Bonferroni adjusted post hoc tests. Recurrent falls were compared among groups at T2 using one-way ANOVA. Significance level was set at $p < 0.05$. We performed per-protocol analysis, in which data were only analyzed for participants who completely adhered to the treatment protocol. This did not consider participants who violated the protocol, did not show good treatment adherence, or did not undergo or complete scheduled assessments over time. An available-case analysis was then adopted for handling missing data as the observed missing data were considered as missing completely at random.

3. Results

The study flow (Fig. 1) involved a final sample of 102 participants at baseline. Among them, 98 completed the T1 assessment immediately after the 12 training sessions. However, only 41 participants successfully completed the T2 (due to the COVID-19 pandemic) as per the study protocol.

3.1. Participants' characteristics at baseline

Table 1 displays the baseline characteristics of participants at T0. The mean age was 75.15 years (SD = 6.79). The majority were females (n = 91, 89.22 %), and around one-third had a history of falls (n = 34, 33.33 %).

At T0, significant differences were observed among the groups in age, BBS, TUG, MMSE, and 10-meter comfortable and fast walking speeds, as the NAFWG group generally demonstrated lower scores and slower speeds than the other two groups.

3.2. Intervention effects on the primary and secondary outcomes

Table 2 shows the summary of intervention effects on both primary and secondary outcomes at T1 and T2, respectively.

3.2.1. Primary outcome

3.2.1.1. T0 to T1. There was a significant Group x Time interaction effect on T3-Fz EEG coherence (F[2, 95] = 4.60, $p = 0.01$, $\eta_p^2 = 0.09$).

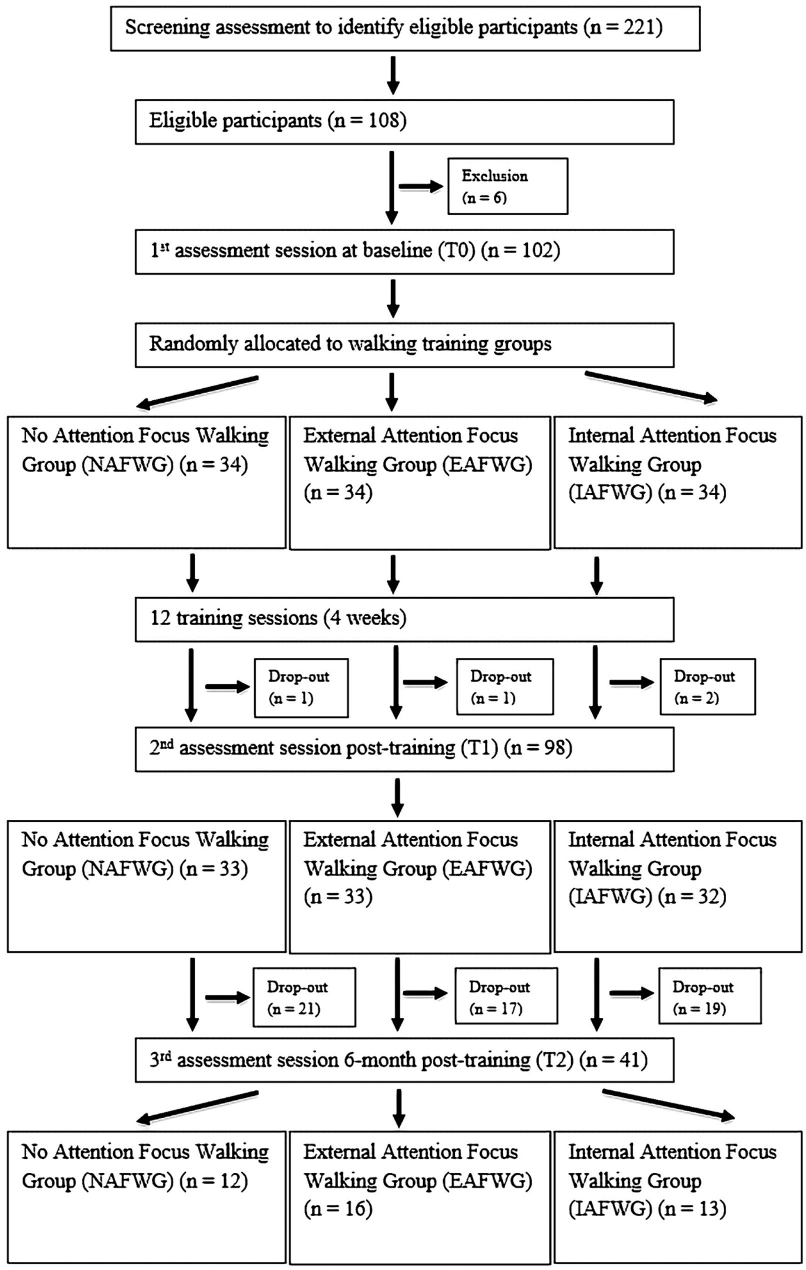

Fig. 1. Schematic diagram of the study flow.

Post hoc comparisons revealed that only EAFWG showed significant reduction in T3-Fz coherence at T1 compared to T0 ($t[32] = 2.58$, $p = 0.02$). There were no significant between-group differences at T0 and T1 among the three groups for the T3-Fz coherence (all $p > 0.05$). Fig. 2 illustrates the significant interaction effect from T0 to T1 in the primary outcome.

3.2.1.2. T0 to T2. There was no significant Group x Time interaction ($F[2, 38] = 0.77, p = 0.47, \eta_p^2 = 0.04$;), group ($F[2, 38] = 0.17, p = 0.85, \eta_p^2 = 0.01$) or time ($F[1, 38] = 1.54$, $p = 0.22$, $\eta_p^2 = 0.04$) effect on T3-Fz EEG coherence. The T3-Fz did not differ across groups and time.

3.2.2. Secondary outcomes

3.2.2.1. T0 to T1. No significant Group x Time interaction effects were found for all physical measures including functional balance and gait, balance ability, functional mobility, and walking ability (comfortable and fast speeds) (POMA: $F[2, 95] = 1.07, p = 0.35, \eta_p^2 = 0.02$; BBS: $F[2, 95] = 0.50$, $p = 0.61$, $\eta_p^2 = 0.01$; TUG: $F[2, 95] = 2.34$, $p = 0.10$, $\eta_p^2 = 0.05$; Comfortable: $F[2, 95] = 1.31, p = 0.28, \eta_p^2 = 0.023$; Fast: $F[2, 95] = 1.74, p = 0.18, \eta_p^2 = 0.035$). Significant main effects of time were only observed for POMA and BBS, as the scores significantly improved among all groups at T1 compared to T0 (POMA: $F[1, 95] = 184.47$, $p < 0.001$, $\eta_p^2 = 0.66$; BBS: $F[1, 95] = 26.96$, $p < 0.001$, $\eta_p^2 = 0.22$) (Figs. 3 and 4).

For other secondary measures, only MSRS-C showed significant Group x Time interaction effect ($F[2, 95] = 4.80$, $p = 0.01$, $\eta_p^2 = 0.09$). Post hoc comparisons revealed that only IAFWG showed significant increase in MSRS-C score at T1 compared to T0 ($t[31] = -2.31, p = 0.03$). There were no significant between-group differences at T0 ($p = 0.85$) but EAFWG demonstrated significant lower MSRS-C score at T1 compared to NAFWG and IAFWG ($p < 0.001$). There was no significant group (FES-I (Ch): $F[1, 95] = 0.10$, $p = 0.76$, $\eta_p^2 = 0.001$; T4-Fz EEG coherence: $F[2, 95] = 0.59, p = 0.56, \eta_p^2 = 0.01$) or time (FES-I (Ch): $F[2, 95] = 0.12, p = 0.89, \eta_p^2 = 0.003$; T4-Fz EEG coherence: $F[1, 95] = 1.13$,

Table 1
Participants' characteristics at baseline (T0).

Variables	Mean (SD)								p Value
	Total ($n = 102$)		NAFWG ($n = 34$)		EAFWG ($n = 34$)		IAFWG ($n = 34$)		
Age	75.15	(6.79)	76.53	(7.57)	76.12	(6.68)	72.79	(5.53)	0.044*
Sex, female, n (%)	91	(89.22 %)	30	(88.24 %)	29	(85.29 %)	32	(94.12 %)	0.49
With a history of falls, n (%)	34	(33.33 %)	12	(35.29 %)	12	(35.29 %)	10	(29.41 %)	0.84
MSRS-C	37.83	(10.12)	38.38	(9.83)	37.03	(9.50)	38.09	(11.23)	0.85
POMA	22.41	(1.14)	22.32	(1.00)	22.53	(0.96)	22.38	(1.42)	0.75
BBS	49.82	(3.64)	48.18	(4.63)	50.68	(2.72)	50.62	(2.76)	0.005*
TUG (seconds)	12.85	(3.64)	15.01	(4.51)	11.85	(2.58)	11.69	(2.53)	<0.001*
FES-I (Ch)	40.9	(11.78)	40.65	(11.57)	40.38	(12.43)	41.68	(11.61)	0.89
MMSE-C	28.45	(1.51)	27.82	(1.77)	28.94	(0.92)	28.59	(1.54)	0.007*
T3-Fz Coherence	0.40	(0.18)	0.38	(0.16)	0.45	(0.21)	0.36	(0.15)	0.09
T4-Fz Coherence	0.32	(0.17)	0.31	(0.15)	0.36	(0.20)	0.29	(0.15)	0.22
10-meter Walk									
Comfortable speed (m/s)	12.89	(3.89)	14.47	(5.27)	11.31	(2.42)	12.88	(2.76)	0.003*
Fast speed (m/s)	10.42	(3.33)	11.89	(4.65)	9.11	(1.90)	10.25	(2.15)	0.002*

Note. MSRS-C = Movement-Specific Reinvestment Scale (Chinese version); POMA = Tinetti Performance Oriented Mobility Assessment Tool; BBS = Berg Balance Scale; TUG = Timed Up and Go Test; FES-I (Ch) = Falls Efficacy Scale – International (Chinese version); MMSE-C = Mini-Mental State Examination (Chinese version); NAFWG = No Attention Focus Walking Group; EAFWG = External Attention Focus Walking Group; IAFWG = Internal Attention Focus Walking Group. *$p < 0.05$.

Table 2
Summary of intervention effects (T1 & T2).

Variables		Mean (SD)					
		NAFWG		EAFWG		IAFWG	
Primary Outcome							
T3-Fz Coherence	T1	0.35	(0.18)[a]	0.36	(0.18)[a,b]	0.41	(0.19)[a]
	T2	0.33	(0.13)	0.35	(0.21)	0.39	(0.09)
Secondary Outcomes							
POMA	T1	24.70	(1.74)	25.12	(1.41)[b]	25.38	(1.79)
	T2	22.08	(2.54)[a]	24.94	(1.77)[a,c]	22.77	(2.49)[a]
BBS	T1	50.03	(3.44)	51.97	(2.77)[c]	51.75	(2.31)
	T2	46.42	(3.50)	49.88	(2.94)	49.54	(3.53)
TUG (seconds)	T1	14.27	(4.56)	11.30	(2.57)	12.12	(1.88)
	T2	18.20	(6.67)	12.80	(3.40)	12.79	(3.58)
10-m walk (Comfortable speed) (m/s)	T1	15.11	(6.77)	12.01	(2.80)	12.61	(2.20)
	T2	18.96	(8.06)	13.10	(4.62)	15.34	(4.20)
10-m walk (Fast speed) (m/s)	T1	11.73	(4.63)	12.15	(13.98)	10.21	(1.82)
	T2	15.85	(5.67)	11.02	(3.83)	12.73	(3.68)
MSRS-C	T1	42.09	(10.68)[a]	33.70	(7.61)[a]	41.63	(10.56)[a,c]
	T2	41.17	(11.18)	33.88	(7.43)	38.62	(10.70)
FES-I (Ch)	T1	39.97	(12.74)	41.52	(12.33)	42.06	(9.32)
	T2	41.33	(12.29)	38.81	(12.48)	40.54	(11.13)
T4-Fz Coherence	T1	0.27	(0.18)	0.30	(0.18)	0.34	(0.18)
	T2	0.25	(0.12)	0.31	(0.21)	0.31	(0.11)

[a] Significant Group x Time interaction effect ($p < 0.05$).
[b] Significant difference at T1 compared to T0 ($p < 0.05$).
[c] Significant difference at T2 compared to T0 ($p < 0.05$)
Note. MSRS-C = Movement-Specific Reinvestment Scale (Chinese version); POMA = Tinetti Performance Oriented Mobility Assessment Tool; BBS = Berg Balance Scale; TUG = Timed Up and Go Test; FES-I (Ch) = Falls Efficacy Scale – International (Chinese version); NAFWG = No Attention Focus Walking Group; EAFWG = External Attention Focus Walking Group; IAFWG = Internal Attention Focus Walking Group.

$p = 0.29$, $\eta_p^2 = 0.01$) effect on other measures including FES-I (Ch) and T4-Fz EEG coherence. The FES-I (Ch) and T4-Fz EEG coherence did not differ across groups and time.

3.2.2.2. T0 to T2. Significant Group x Time interaction was only found for physical measure of POMA ($F[2, 38] = 4.04$, $p = 0.03$, $\eta_p^2 = 0.18$). Post hoc comparisons revealed that only EAFWG showed significant improvement in POMA score at T2 compared to T0 ($t[15] = -6.28$, $p < 0.001$). Group differences were significant at T2 for POMA score, with EAFWG differing from NAFWG ($p = 0.006$) and IAFWG ($p = 0.04$). There was no time effect (BBS: $F[1, 38] = 0.31$, $p = 0.56$, $\eta_p^2 = 0.008$; TUG: $F[1, 38] = 0.23$, $p = 0.64$, $\eta_p^2 = 0.006$; Comfortable: $F[1, 38] = 1.75$, $p = 0.19$, $\eta_p^2 = 0.04$; Fast: $F[1, 95] = 3.88$, $p = 0.06$, $\eta_p^2 = 0.09$) on the other physical measures. The BBS, TUG and walking ability (comfortable and fast speeds) did not differ across time. The main effect of group was significant on BBS, TUG and 10-meter comfortable walking speed (BBS: $F[2, 38] = 6.06$, $p = 0.005$, ηp2 = 0.2423; TUG: $F[2, 38] = 14.04$, $p < 0.001$, ηp2 = 0.43; Comfortable: $F[2, 38] = 10.12$, $p < 0.001$, ηp2 = 0.35), as the NAFWG demonstrated significantly lower score and slower speed than EAFWG (BBS: $p = 0.01$; TUG: $p < 0.001$; Comfortable: $p < 0.001$) and IAFWG (BBS: $p = 0.01$; TUG: $p < 0.001$; Comfortable: $p = 0.01$) respectively at T0 and T2.

There was no significant Group x Time interaction (MSRS-C: $F[2, 38] = 2.04$, $p = 0.14$, $\eta_p^2 = 0.10$; FES-I (Ch): $F[2, 38] = 0.32$, $p = 0.73$, $\eta_p^2 = 0.02$; T4-Fz EEG coherence: $F[2, 38] = 0.48$, $p = 0.62$, $\eta_p^2 = 0.02$), group (MSRS-C: $F[2, 38] = 0.78$, $p = 0.47$, $\eta_p^2 = 0.04$; FES-I (Ch): $F[2, 38] = 0.02$, $p = 0.98$, $\eta_p^2 = 0.001$; T4-Fz EEG coherence: $F[2, 38] = 0.36$, $p = 0.70$, $\eta_p^2 = 0.02$) or time (MSRS-C: $F[1, 38] = 0.003$, $p = 0.96$, $\eta_p^2 = 0.00$; FES-I (Ch): $F[1, 38] = 1.38$, $p = 0.25$, $\eta_p^2 = 0.04$; T4-Fz EEG coherence: $F[1, 38] = 0.83$, $p = 0.37$, $\eta_p^2 = 0.02$) effect on MSRS-C, FES-I (Ch), or T4-

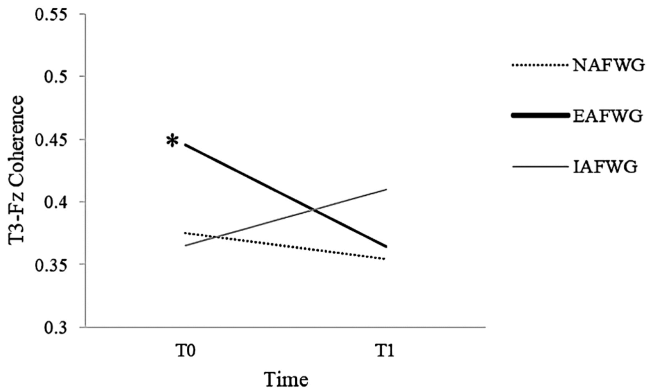

Fig. 2. Comparison of real-time conscious motor processing (T3-Fz EEG Coherence) from T0 to T1 for all training groups. *Note.* NAFWG, no attention focus walking group; EAFWG, external attention focus walking group; IAFWG, internal attention focus walking group. * $p < 0.05$.

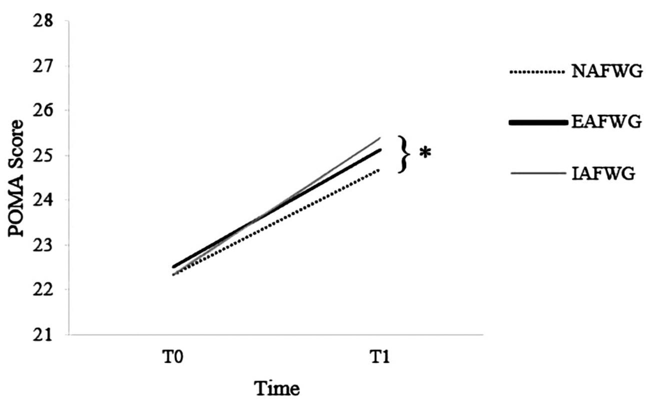

Fig. 3. Comparison of functional balance and gait ability (POMA score) from T0 to T1 for all training groups. *Note.* POMA, Tinetti Performance Oriented Mobility Assessment Tool; NAFWG, no attention focus walking group; EAFWG, external attention focus walking group; IAFWG, internal attention focus walking group. * $p < 0.05$.

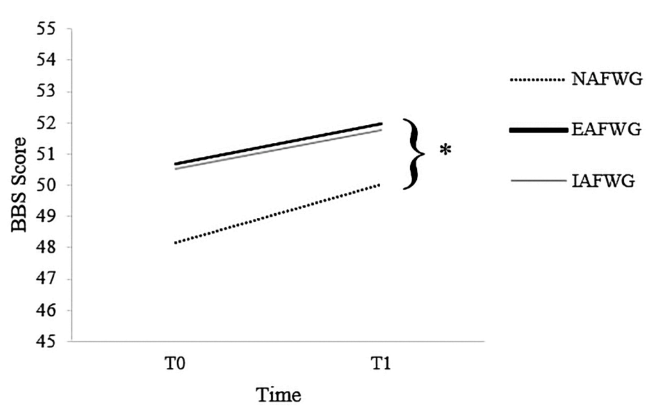

Fig. 4. Comparison of balance ability (BBS score) from T0 to T1 for all training groups. *Note.* BBS, Berg Balance Scale; NAFWG, no attention focus walking group; EAFWG, external attention focus walking group; IAFWG, internal attention focus walking group. * $p < 0.05$.

Fz EEG coherence. The MSRS-C, FES-I (Ch) and T4-Fz did not differ across groups and time. There was also no significant difference in the number of recurrent falls at T2 across groups ($F[2,38] = 0.81$, $p = 0.45$, $\eta_p^2 = 0.04$).

4. Discussion

This study aimed to investigate the immediate and long-term effects of three training strategies (no attention focus, external attention focus, and internal attention focus walking training) on real-time conscious motor processing and fall-related rehabilitation outcomes in older adults at risk of falling. We hypothesized that external attention focus walking training would reduce real-time conscious motor processing and yield greater improvements in rehabilitation compared to no attention focus (active control) and internal attention focus. Our hypothesis was based on the assumption that emphasizing external attention focus would promote motor system automaticity (Wulf et al., 2001), therefore potentially minimizing real-time conscious control of limb movements and improving other rehabilitation outcomes.

The study findings strongly support our hypothesis on real-time conscious motor processing measured by T3-Fz EEG coherence. The EAFWG showed a significant reduction in T3-Fz EEG coherence after training, while no changes were observed in the NAFWG and IAFWG. Importantly, the insignificant changes in T4-Fz EEG coherence indicate the decrease in T3-Fz coherence in the EAFWG was not a global brain activation effect (Zhu et al., 2011). This localized reduction of T3-Fz coherence suggests diminished engagement of verbal-analytical processes in motor performance (T3) and movement planning (Fz) (Haufler et al., 2000; Kerick et al., 2001), which could potentially preserve working memory and enable individuals to focus more externally on environmental hazards (Baddeley, 1999; Uiga et al., 2015) for improving walking fluency (Wulf et al., 2001). The results demonstrate the effectiveness of a 4-week, 12-session walking training program using external attention focus in reducing real-time conscious motor processing in older adults at risk of falling.

However, our findings only partially support our hypothesis regarding the secondary outcomes. Consistent with a previous study by Mak et al. (2022), we did not observe any significant changes in trait conscious motor processing propensity (as measured by MSRS-C scores) in EAFWG, despite a significant reduction in T3-Fz coherence was shown in our study. This lack of significant association between MSRS-C scores and T3-Fz EEG coherence is consistent with recent evidence (Mak et al., 2020; Mak & Wong, 2022), where self-reported trait reinvestment propensity may not adequately capture real-time conscious processing of movements especially when the motor tasks lack sufficient challenge (Mak et al., 2022.; Mak & Wong, 2022). Additionally, there may be potential score discrepancies among older adults due to the vague definition of movements in the MSRS-C questionnaire, leading to variations in how individuals interpret and relate to the movements when providing their responses (Wong et al., 2015). This result further supports the effectiveness of walking training with external attention focus in mitigating real-time conscious motor processing while leaving trait conscious motor processing unaffected.

Our results indicate overall improvements in functional balance and gait across all three groups, as evidenced by significant enhancements in POMA and BBS scores following 12 sessions of walking training. Provided all groups received balance training as part of the intervention protocol, it is reasonable to observe balance improvements among all groups. This suggests that EAFWG might offer similar functional benefits in balance and gait to NAFWG and IAFWG in older adults at risk of falling. Regarding walking ability, no significant training effects were found on walking speeds (comfortable and fast) in any of the three groups. While improvements in walking speed are typically expected after walking training, our interventions mainly focused on restoring normal gait pattern and enhancing overall stability during walking instead of walking speed as the primary outcome. Considering that walking speed is influenced by multiple factors, such as muscle strength, balance, and coordination (Van Abbema et al., 2015), future studies could focus on interventions that explicitly aim to improve walking speed (Hortobágyi et al., 2015; Van Abbema et al., 2015) in addition to gait pattern and stability that were targeted in our interventions.

Our study found no significant changes in Falls Efficacy Scale-International (FES-I (Ch)) scores among the three groups. This result may due to our training sessions focusing primarily on participants' physical mobility. Although physical interventions such as tai chi, home-based exercise, and multifactorial interventions have demonstrated effectiveness in reducing fear of falling among community-dwelling older adults, these interventions typically incorporate psychological components such as motivation and education (Zijlstra et al., 2007). The absence of psychological components in our training program provides a rationale for the lack of support in reducing the FES-I (Ch) scores. Addressing fear of falling may therefore necessitate a comprehensive approach that integrates both physical and psychological components.

Overall, the observed significant effects in T3-Fz EEG coherence, functional balance, and gait and balance ability were immediate, but a high drop-out rate during the six-month reassessments caused by the COVID-19 pandemic may have hindered the retention effect at follow-up. Although not statistically significant, improvements in outcomes such as T3-Fz EEG coherence, functional balance and gait, trait conscious motor processing, and fear of falling were observed at T2 compared to T0, particularly in the external group. However, these gains declined compared to T1. The lack of practice during the 6-month period influenced by the COVID-19 pandemic, along with the reduced sample size, may explain the insignificant improvements at T2 compared to T0. Studies indicate that balance outcomes can decline significantly after just 4 weeks of no intervention (Modaberi et al., 2021), and skills decay with longer non-practice period (Arthur Jr et al., 1998). Considering our balance and gait training involve both cognitive and motor skill acquisition, repetitive practice throughout the 12-week training may enhance synaptic plasticity and cortical reorganization associated with those skills (Dayan & Cohen, 2011). However, without regular practice, these connections and cortical specialization can weaken (Dayan & Cohen, 2011), leading to insignificant improvements in both cognitive and physical outcomes. Further investigation is needed to explore the potential for retention effects with the interventional strategy and foster the retention of the acquired skills from the training.

Future research should investigate the long-term effects and optimal dosage (frequency, intensity, duration, and type) of the walking training protocol to maximize improvements in walking performance and falls prevention in at-risk older adults. While external attention focus training reduced real-time conscious motor processing, its correlation with fall risk reduction was not clearly demonstrated in this study, reflected by an insignificant difference among groups in recurrent falls at follow-up. The uniformly low incidence of falls across all groups can be attributed to reduced outdoor activities enforced by COVID regulations, limited challenges of a home environment that may not lead to falls, and loss of follow-up. This investigation would provide valuable insights into the potential benefits of the employed training regimen.

Several limitations in our study may have contributed to the insignificant findings. Firstly, the high dropout rate at T2 during the COVID-19 period in Hong Kong resulted in reduced sample size and statistical power, increasing the likelihood of type II errors and false negative results. Future studies should aim for larger sample sizes and more robust follow-up procedures. Another limitation was the sole reliance on gait speed as an indicator of walking ability, which did not fully capture the comprehensive assessment of gait pattern and stability. Incorporating additional parameters such as step length, double limb support time, and step accuracy in the motion capture laboratory could provide a more nuanced understanding of walking ability (de Melker Worms et al., 2017; Uiga et al., 2020). Furthermore, the absence of psychological components in our training protocol limited the potential for enhancing fear reduction and fall prevention. Integration of psychological interventions, like cognitive behavioral therapy, could potentially improve outcomes such as FES-I (Ch) scores (Liu et al., 2018). Additionally, the omission of dual-task assessment during walking reduced our understanding of the training strategies' impact on fall risk. Evaluating dual-task performance would have established a link between the strategies and fall prevention (Muir-Hunter & Wittwer, 2016). Future research should address these limitations to enhance our understanding of fall prevention interventions for at-risk older adults.

5. Conclusion

This present study represents the first attempt to provide valuable insights into the effectiveness of external focus strategy in walking training for older adults at risk of falling. Results indicate that this approach reduces real-time conscious motor processing and improves functional balance and gait immediately after training. However, these effects were not sustained in the six-month follow-up, likely due to high drop-out rates during the COVID-19 pandemic. The study highlights the potential of external focus instruction in gait training for immediate improvements in conscious motor processing, balance and gait outcomes. These findings have important clinical implications to the field of geriatric rehabilitation, particularly in physiotherapy interventions. This approach could be a feasible and effective intervention in geriatric rehabilitation settings, offering a promising strategy to prevent falls and promote overall well-being in older adults at risk of falling. Given the clinical significance of these findings, it is recommended that physiotherapists consider integrating external focus instructions into their walking training programs. This could enhance the effectiveness of their interventions in addition to the traditional balance and strengthening exercises and contribute to the prevention of falls among the vulnerable population. However, further research is needed to strengthen the evidence base and support the widespread implementation of these strategies in clinical practice. Further investigation into the long-term effects and optimal training dosage is essential to ensure the successful incorporation of external focus strategies into geriatric rehabilitation protocols.

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CRediT authorship contribution statement

Toby C.T. Mak: Software, Investigation, Data curation, Writing – review & editing. **Shamay S.M. Ng:** Validation, Supervision, Resources, Writing – review & editing. **Melody C.Y. Leung:** Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Thomson W.L. Wong:** Conceptualization, Methodology, Supervision, Formal analysis, Writing – review & editing, Funding acquisition, Project administration.

Declaration of competing interest

There are no conflicts of interest for any authors to report.

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