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Influence of a multicomponent exercise intervention on fear of falling and gait parameters in community-dwelling older adults: a prospective study

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Abstract

Backgrounds The effects of exercise interventions on gait parameters and fear of falling (FOF) have been under-explored and the influence of FOF on exercise-induced adaptations of gait parameters is unclear. This interventional and comparative pilot study aimed to explore the influence of FOF status on gait parameters changes following a multicomponent exercise intervention in community-dwelling older adults at risk of mobility disability and implemented in routine care.

Methods One-hundred five older adults (80.63 ± 5.80 years) completed a supervised group-based exercise (6–8 participants) intervention (10 weeks, 2x/week, 1 h). Participants of this open cohort and prospective study were divided a-posteriori in 2 subgroups: with FOF subgroup (Falls Efficacy Scale-International (FES-I) > 23; $n = 64$) or without FOF subgroup (FES-I ≤ 23; $n = 41$). A two-way repeated measure ANOVA was performed to measure time, group and group*time interactions effects. Paired t-test were performed to measure changes within the subgroups. Correlations were performed between FOF delta's changes and gait parameters changes. Spatiotemporal gait parameters (i.e. gait speed; stride variability, symmetry, length; swing, stance and double support phases; lift and strike angles; number of cycles at the turn; turning angle), perceived gait quality (i.e. the "Locomotion" domain of the "SarQoL®" questionnaire), functional parameters (i.e. Short Physical Performance Battery and its subtests; Timed Up and Go) and FOF were assessed.

Results A time effect was observed for all spatial gait parameters ($p < .05$), all functional parameters ($p < .001$), perceived gait quality ($p < .001$) and FOF ($p < .01$) assessed after the intervention for the total cohort. A group effect was observed for FOF ($p < .001$), spatiotemporal gait parameters ($p < .05$) and perceived gait quality ($p < .001$). A group*time interaction was only observed for FOF ($p < .001$). Stride length, lift off angle, strike angle and turning angle ($p < .05$) improved in both subgroups. Stride variability ($p < .05$) and FOF ($p < .001$) improved only in the FOF subgroup. Correlations between gait parameters changes and FOF changes were only observed in FOF subgroup for double

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support phase ($r = .25$, $p < .05$), swing phase ($r = -.25$, $p < .05$) and stance phase ($r = .25$, $p < .05$). A moderate correlation was observed between FOF changes and perceived gait quality changes ($r = -.49$, $p < .01$) in no-FOF subgroup. This correlation became weak for the total cohort ($r = -.25$, $p < .05$).

Conclusions Our results demonstrate that a multicomponent exercise intervention lead to significant changes in FOF, spatial gait parameters and perceived gait quality in older adults and more in those with FOF. Thus, this routine care intervention could be widely proposed to older adults at risk of falls, and particularly to those with a FOF. Finally, although FOF and gait parameters are related, their changes over time do not seem to be as related. This study confirmed that managing the FOF is complex, multifactorial and might be orientated to a holistic approach.

Trial registration number NCT03667664 (registration date: 12/09/2018) and NCT06659484 (registration date: 26/10/2024).

Keywords Gait, Fear of falling, Prevention, Mobility, Exercise, Real-life care setting

Introduction

Around 30% of older adults over 65 years old fall every year [1]. Falls may lead to serious injuries (such as fractures) but also to psychological issues notably fear of falling (FOF) [1, 2]. FOF or concern about falling, defined as « a persistent feeling related to the risk of falling during one or more activities of daily living » [3], is a widespread and a complex syndrome in older adults [4]. FOF can be considered as protective response in order to avoid at-risk activities (walking on slippery or uneven surfaces, etc.) [5]. Nevertheless, FOF may lead to physical activity restriction and/or sedentary behavior that, in turn, cause a deconditioning vicious circle and consequently a decline in physical and postural function, social network, mental health and quality of life [4–6]. Moreover, FOF and physical inactivity are closely related to the development of geriatric syndromes such as frailty and sarcopenia, which ultimately lead to an increased risk of falling [3–6]. Thus, FOF should therefore be considered as a risk factor of fall and disabilities [5, 7].

FOF may also interfere with gait parameters and lead to gait disorders [8–12]. The decline of gait parameters, especially slowing of gait speed, could correspond to protective mechanisms in response to declining functional reserve and altered balance [8–10, 12, 13]. Functional reserve is defined as “the overall ability to compensate for the adverse effects of impairments, or recover from acute challenges to prevent functional loss in normal life” [14]. The functional reserve decline is associated with an alteration of various physiological system from whom the central nervous system which negatively impact the motor control system and could subsequently induce a decrease of dynamic balance control and thus gait parameters [15]. A decrease in gait speed is generally observed in physiological aging [16, 17], but gait speed and associated spatiotemporal parameters (i.e. reduced stride length, increased double support time, increased stride variability, etc.) are even more affected in fallers and those with FOF [7, 9, 10, 18, 19]. As the increase of falls, fear and physical function (i.e. strength, gait parameters, balance etc.) decline are all predictors of each other it is of the utmost importance to grasp this spiraling effect in the context of falls prevention [20]. Therefore, improving older adults’ functional reserve in order to enhance mobility by better gait parameters and to reduce FOF should be targeted through specific fall prevention programs [1, 20–22].

It is now well established that multicomponent exercise interventions are highly effective to improve several parameters such as gait and balance, and notably gait speed [19, 23]. Nevertheless, changes in spatiotemporal gait parameters have been poorly explored and require specific analysis [19]. Furthermore, the effectiveness of exercise on FOF remains unclear, with a small-to-moderate level of evidence [24–26]. Optimizing exercise adaptations on gait parameters, FOF and physical function and thus reduce fall risk is crucial. Therefore, it appears necessary to explore changes in gait parameters following exercise interventions, and to highlight influence of FOF status.

The main goal of this study was to explore the influence of FOF status on gait parameters changes following the intervention in community-dwelling older adults at risk of mobility disability. We also aimed to provide new data on specific gait parameters changes during an exercise program and thereby contribute to filling the knowledge gap in this field. While we expected to observe a moderate effect of the intervention on FOF, we hypothesized that older adults with a FOF at baseline may improve their gait parameters to a greater extent than those without FOF at baseline. Finally, we hypothesized that an improvement in gait parameters would be associated with a decrease in FOF.

Methods

Study design, participants and setting

A monocentric prospective and comparative pilot study (phase 2 ORBIT) was conducted on a cohort of adults aged 70 years or older to participate to the “well on my legs” exercise intervention [27]. Participants

were recruited between July 2020 and July 2023 and were included when they were diagnosed with a mobility disability risk. A mobility disability risk was defined as the presence of, at least, one of these criteria: short physical performance battery [SPPB] score < 10, presence of a dynapenia or a sarcopenia, reduced gait speed (≤ 0,8 m/s), reduced physical activity (reported by the Rapid Assessment of Physical Activity questionnaire [28] with a score < 6), exhaustion, FOF and at least one fall within the last 12 months [1, 14, 23, 27, 29, 30]. This risk was assessed during a multidimensional consultation (medical, physical, and nutritional) with 3 professionals (geriatrician, dietician, and kinesiologist) in accordance with international recommendations for dynapenia, sarcopenia, physical activity, exhaustion, FOF and fall risk [1, 23, 29, 30]. Participants with severe disability were not included in this current-care intervention and re-oriented to other specialized professionals. We considered as severe disability: SPPB score < 5; high cardiovascular risk (non-stabilized coronary illness, decompensated heart failure, non-stabilized arrhythmia, severe and symptomatic aortic stenosis, uncontrolled arterial hypertension, aortic dissection, acute myocarditis, pericarditis or endocarditis, acute thromboembolic disease, severe pulmonary hypertension, Marfan syndrome, non-stabilized type 2 diabetes mellitus, non-stabilized orthostatic hypotension); heavy locomotive handicap (needs a wheelchair); high cognitive impairment, or dementia (previously diagnosed in specialized consultation or inability to follow a small-group session) [31]. Due to the nature of this study, neurological conditions, vestibular or orthopedic disorders were not considered as exclusion criteria as long as they were able to follow the program. To be included in these analyses, participants had to complete at least 15 collective exercise sessions (out of 20 sessions).

This study was approved by the scientific and ethical committee of the Hospices Civils de Lyon (France) (NCT03667664, registration date: 12/09/2018 and NCT06659484, registration date: 26/10/2024). This study complies with the Helsinki Declaration as after receiving detailed information, all study participants signed on their informed consent form.

Exercise intervention

As described previously [27] the multicomponent exercise intervention is implemented as a current-care intervention in real-life settings in the area of Lyon, France. This intervention is in line with the current recommendations for older adults presenting frailty, mobility disability and falls [1, 23, 31]. Briefly, during the intervention, the participants followed one hour of supervised group-based sessions (6 to 8 participants) twice a week during 10 weeks (total of 20 sessions). Trained kinesiologists supervised the exercise sessions which included three progressive phases to optimize physiological adaptations. Each session included a warm-up, a combined resistance (i.e. using elastic band, dumbbells or at bodyweight) and balance exercises (i.e. unipodal or tandem balance), adapted physical activities (i.e. individual or in teams, dribbling with a ball, passing between participants, shooting into a basket; passing over a net with a racket and a balloon, etc.), gait retraining (i.e. walking with change pace, tandem walking, heel-to-toe walking, obstacle-clearing exercises) and a cool-down phase with stretching. Resistance exercises were mainly focused on quadriceps, hamstrings, iliopsoas, gluteal, plantar and dorsi flexors muscles for lower limbs. The main muscle groups of the upper body were mobilized, including the biceps and triceps brachii, pectoralis major, deltoids, rotator cuff muscles, trapezius, rhomboid, dorsalis major, erector spinae and abdominal muscles. Each exercise was performed over a range of 2 to 3 sets of 6 to 15 repetitions with a perceived effort (using the Borg CR10 scale) ranging from light to moderate and moderate to vigorous depending on the participant's physical capacities and medical conditions. To monitor perception of effort, kinesiologists asked participants "how hard, heavy and strenuous the previous exercise was to perform" [32]. At first, the targeted intensity was light to moderate. According to planned progress, any potentials relative medical contraindications and when participants were performing correctly exercise without pain (during and after sessions), the intensity was increase [31]. The Borg CR10 scale was used to assess difficulties to perform the exercises in order to, adjust the number of repetitions, the range of motion, the task complexity (i.e. adding or removing a weight and/or movement) and the rest time [27].

Data collection

Geriatricians and trained kinesiologists performed assessments and collected data during baseline and reassessment visits as previously described [27]. They were not blinded as it was performed in current care setting.

General characteristics

In addition to age, weight and height, a self-reporting of falls in the last 12 months was collected at baseline.

Gait parameters

Gait parameters were measured using two validated shoe-worn inertial sensors "PhysiLog®5"[a] during a fifty meters walking test [33]. The test was performed at usual speed over a twenty-five meters round trip. The sensors were set on each shoe, under the malleolus. All cycles, except the two initiation and termination cycles to rule out the acceleration and deceleration phases,

were included and analyzed [34]. Gait parameters were obtained using the *MindMaze©* analysis package[b] and characterized through validated *spatiotemporal (gait speed, m/sec)*, *temporal* and *spatial gait parameters.*

More specifically the analyzed t*emporal gait parameters* include : *(1) Stride variability* (coefficient of variation of cycle duration; in percent), *(2) Stride symmetry* (ratio of swing times which compared the time in the air between both feet; in percent), *(3) Swing phase* (portion of the cycle during which the foot was in the air and did not touch the ground; in percent), *(4) Stance phase* (portion of the cycle during which a part of the foot touched the ground; in percent), *(5) Double support phase* was calculated as the portion of the cycle where both feet touched the ground, in percent. The *spatial gait parameters* include: (1) *Stride length* (distance, in meters, between two successive steps on the ground, from the heel of a foot to the heel of the same foot, one cycle after), (2) *Lift off angle* (angle between the foot and the ground at the end of the push phase, just before the start of swing phase), (3) *Strike angle* (angle between the foot and the ground at heel strike on a vertical plane), (4) *Turning angle* (angle between two consecutive foot-flat phases of the same foot on a horizontal plane, we selected the maximum value), and (5) *Number of cycles at the turn* (sum of cycles to complete the turn). To facilitate analyses, the mean value of the two feet was used for these variables: swing phase, stance phase, stride length, strike angle, lift off angle and turning angle. Lift off and strike angle were used to assess plantar roll.

As there are no minimal detectable changes for gait parameters in this population (except for gait speed: +0.1 m/s [35]), we cannot use reliable changes values. However, reference values were presented in a recent study of Dapp et al. (2022) [15].

Fear of falling (FOF)

The FOF was assessed using the Falls Efficacy Scale International (FES-I) questionnaire, which is the recommended tool to assess the "concern about falling" on community-dwelling older adults [1, 3, 36]. The FES-I is a self-report questionnaire with 16 items. Each item is graduated from 1 (not at all concerned) to 4 (very concerned) with sub scores of 2 (somewhat concerned) and 3 (fairly concerned). The sum of all the items provides a score ranging from a minimum of 16 to a maximum of 64 [3, 36]. Among the participants who completed the intervention and based on the validated FES cut point [3], participants with a FES score >23 were included in the FOF subgroup ($n=64$) whereas those with a FES score ≤ 23 were included in the no-FOF subgroup ($n=41$).

There are no minimal detectable changes for FES-I score in this population, we cannot use reliable changes values. However, we could use the effect size by referring a recent meta-analysis of Feng et al. (2022) (i.e. effect size of −0.34) [26].

Physical performances and functional capacities

We assessed objectively physical performance and functional capacities through the following validated tests: (1) *Short Physical Performance Battery (SPPB*) [37], (2) normal 6-meters gait speed test [29], (3) 5 times sit-to-stand test (5-STS) [29], and 3) normal 3-meters Timed Up and Go (TUG) [29]. We also assessed participant's perceived gait quality through the "Locomotion" domain of the "SarQoL®" questionnaire [38]. This domain assesses the limitation in waking time, walking speed, number of outings outdoor, steps length, the feeling of fatigue when walking, difficulties to cross a road fast enough and difficulties to walk on uneven grounds [38].

Statistical analysis

Participants were analyzed on a per protocol analysis. Variables were expressed as mean plus or less standard deviation (SD) or count (percentage). Normality was checked with Kolmogorov-Smirnov test or Shapiro-Wilk test for sample higher than 50 and lower than 50 respectively. Statistical difference was considered, for all variables, when $p<.05$. A two-way repeated measures analysis of variance (ANOVA) was conducted to evaluate the time effect (pre and post intervention, for the total cohort), the group effect (FOF vs. no-FOF subgroup) and the effect of time*group interaction. As the participant subgroups were different at baseline, we needed to perform paired t-tests to study the pre/post differences for the two FOF subgroups of participants. For variables that did not respect the ANOVA requirements (Mauchly or Greenhouse-Geisser sphericity and Levene's homogeneity), we conducted non-parametric tests (Mann-Whitney and Wilcoxon tests for inter and intra group differences respectively). For these non-parametric variables, we assessed the group*time interaction by comparing the delta change (post-pre values) between FOF subgroups. To measure the effect size, we used the Cohen's D (values of $d=0.20$, $d=0.50$, and $d=0.80$ indicate small, medium, and large effect sizes) [39]. Finally, Spearman and Pearson correlations, according to normality, between FES-I score delta changes and gait parameters delta changes were conducted to explore potential inter-relationship. A correlation was weak when $r\leq.30$, moderate when $0.30<r<.50$ and strong when $r\geq.50$ [40]. All data were analyzed using IBM SPSS Statistics version 21 (IBM Corp., Armonk, NY, USA)[c].

Results

Baseline characteristics

As shown in Fig. 1, among the 480 participants who completed an initial assessment, 42.1% were included

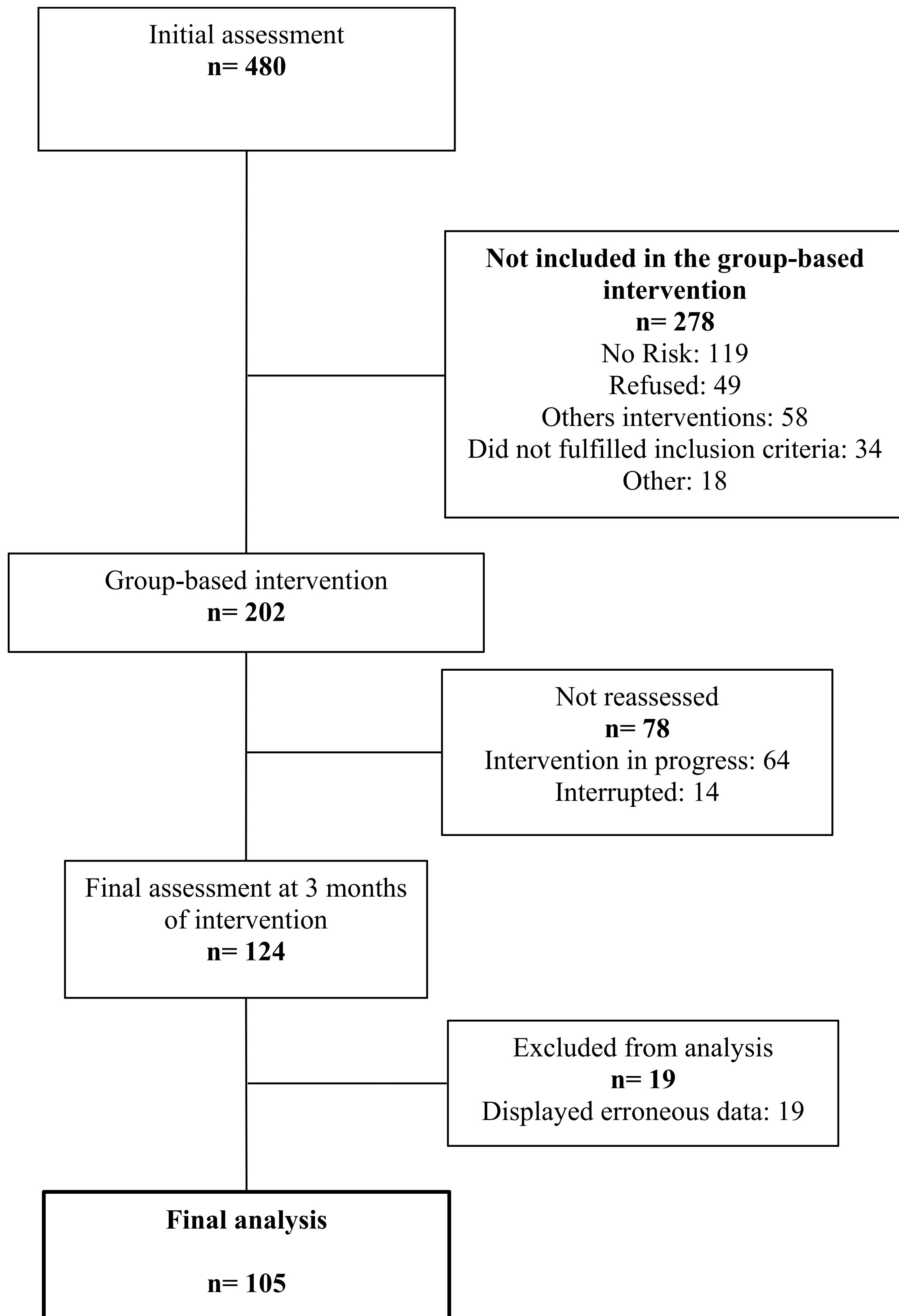

Fig. 1 Flow chart

Table 1 Baseline characteristics of all participants and subgroups

	Participants (*n* = 105)	Fear of Falling subgroup (*n* = 64)	No-Fear of Falling subgroup (*n* = 41)
Age (y)	80.63 ± 5.8	80.67 ± 5.77	80.56 ± 5.94
Sex (n. %)	♀: 79 (75.24%) ♂: 26 (24.76%)	♀: 52 (81.25%) ♂: 12 (18.75%)	♀: 27 (65.85%) ♂: 14 (34.15%)
Weight (kg)	69.03 ± 16.3	69.05 ± 15.55	68.99 ± 14.35
Height (cm)	160.21 ± 9.14	159.23 ± 8.63	161.74 ± 9.81
BMI (kg/m²)[a]	26.82 ± 5.42	27.10 ± 5.84	26.34 ± 4.76
Falls/pers (n)[b]	1.02 ± 2.63	1.29 ± 3.23	0.63 ± 1.22
Non-fallers (n, %)	62 (59.05%)	35 (54.69%)	27 (65.85%)
Single fallers (n, %)	20 (19.05%)	11 (17.19%)	9 (21.95%)
Multiple Fallers (n, %)	23 (21.90%)	18 (28.12%)	5 (12.20%)
FES-I (/64)[c]	27.55 ± 8.17	31.98 ± 7.49	20.63 ± 2.15

[a] *BMI* Body mass index

[b] Number of self-reported falls during the last 12 months per person. When participants reported only one fall, they were considered as "single fallers". When they reported two or more falls, they were considered as "multiple fallers"

[c] FES-I : Falls Efficacy Scale International questionnaire. "Fear of Falling subgroup": participants with FES-I baseline score >23/64. "No-Fear of Falling subgroup": Participants with FES-I baseline score ≤ 23/64. Quantitative variables are expressed as mean ± standard deviation, qualitative variables are expressed as count (percentage)

Table 2 Time effect for all participants after the multicomponent exercise intervention (*n* = 105)

Variable	Pre (Mean ± SD)	Post (Mean ± SD)	*p**	d
Questionnaires				
FES-I (/64)[a]	27.55 ± 8.17	26.25 ± 8.04	**< 0.01**	−0.22
Locomotion SarQoL score (/100)	48.79 ± 14.59	53.35 ± 15.59	**< 0.001**	0.41
Physical function				
SPPB (/12)[b]	9.38 ± 1.85	10.56 ± 1.59	**< 0.001**	0.83
5-STS (s)[c]	14.78 ± 5.89	11.73 ± 3.96	**< 0.001**	−0.71
6-meters gait speed (m/s)	0.83 ± 0.19	0.92 ± 0.21	**< 0.001**	0.63
Static balance (SPPB item/4)	3.40 ± 0.80	3.74 ± 0.50	**< 0.001**	0.46
50-meters gait speed (m/s)	0.99 ± 0.20	1.04 ± 0.22	**< 0.001**	0.47
TUG (s)[d]	12.65 ± 3.21	11.48 ± 3.10	**< 0.001**	−0.47
Temporal gait parameters				
Stride variability (%)	4.54 ± 2.13	4.25 ± 1.45	0.065	−0.16
Stride symmetry (%)	5.50 ± 5.86	5.07 ± 4.77	0.566	−0.07
Double support phase (%)	21.28 ± 5.58	20.65 ± 5.86	0.264	−0.12
Swing phase (%)	39.53 ± 2.79	39.67 ± 2.93	0.266	0.12
Stance phase (%)	60.65 ± 2.79	60.33 ± 2.93	0.264	−0.12
Spatial gait parameters				
Stride length (m)	1.06 ± 0.17	1.09 ± 0.18	**< 0.001**	0.41
Lift off angle (°)	54.74 ± 7.79	56.31 ± 8.02	**< 0.01**	0.29
Strike angle (°)	21.39 ± 5.06	22.33 ± 5.36	**< 0.05**	0.27
Turning angle (°)	87.92 ± 16.27	92.85 ± 16.29	**< 0.01**	0.36
The number of cycles at the turn (n)	3.37 ± 0.65	3.17 ± 0.58	**< 0.01**	−0.26

[a] *FES-I* Falls Efficacy Scale International questionnaire.

[b] *SPPB* Short Physical Performance Battery

[c] *5-STS* 5 times sit-to-stand test.

[d] *TUG* Timed Up and Go test. *p* Values are significant at values < 0.05. Significant values are highlighted in bold. d: d of Cohen's effect size

in the group sessions, 24.8% had no risk factors, 12.1% were redirected to another intervention and only 10.2% refused to take part in the group sessions despite the medical indication to participate. When the study was carried out, among the 202 participants included in the collective sessions, 61.4% were reassessed, 31.7% were still participating in the collective sessions and have not completed all 20 sessions in the collective sessions (as data were obtain through a current-care program), and only 6.9% stopped attending before the end (mainly for health reasons, unrelated to the intervention). No significant difference was observed between participants who dropped out of the study and the subgroup with FOF. All these results are detailed in the additional table in the appendix.

Among the total cohort analyzed, 105 participants (79 women and 26 men, 80.63 ± 5.80 years old) met the inclusion criteria. The sample included 59.05% of non-fallers, 19.05% of single fallers and 21.90% of multiple fallers and reported an average FES-I score of 27.55 (± 8.17).

The subgroup of participants with FOF included 64 older adults (52 women and 12 men, 80.67 ± 5.77 years old). Among the FOF subgroup, 54.69% were defined as non-fallers, 17.19% as single fallers and 28.12% as multiple fallers. The average FES-I score in the FOF subgroup was 31.98 (± 7.49).

The subgroup of participants without FOF (41 older adults: 27 women and 14 men, 80.56 ± 5.94 years old) included 65.85% of non-fallers, 21.95% of single fallers and 12.20% of multiple fallers. The average FES-I score in the no-FOF subgroup was 20.63 (± 2.15). More details on Table 1.

Changes after the intervention for the total cohort

Changes in gait parameters and gait quality perception

First, we observed a time effect for the locomotion SarQoL score (p <.001) and for all spatial parameters that improved significantly after the multicomponent exercise intervention (p <.05). No time effect was observed for the temporal gait parameters. Nevertheless, we observed a tendency towards improved stride variability (p =.065) (Table 2). Moreover, the locomotion SarQol score exceed the smallest detectable change for group of 0.85 point (+ 4.56 points) [41].

Changes in FES-I score and physical function

As shown in Table 2, a time effect was observed for the FES-I score that significantly decrease (p<.01) after the multicomponent exercise intervention. There is no minimal detectable change or minimal important change for FES-I score, however we found an effect size of −0.22 that is lower to the one found in a recent meta-analysis (effect size of −0.34) [26]. A time effect was also observed for all physical and functional parameters (SPPB score, 5-STS time, 6-m gait speed, TUG time, and 50-m gait speed) that improved significantly (p<.001). Moreover, SPPB score and 5-STS time reached a clinical meaningful difference (+1.18 points and −3.05 s respectively) [35, 37]. Finally, 6-meters gait speed was close to reach the clinical threshold of +0.1 m/s (+0.09 m/s) [35].

Changes after the intervention per subgroups of FOF

Changes in gait parameters and gait quality perception

A group effect was observed for the locomotion SarQoL score (p<.001), all spatial and temporal gait parameters (p<.05) except for the stride symmetry (p=.297). Gait quality perception (p<.01), all spatial gait parameters (p<.05) and stride variability (p<.05) were significantly improved in the FOF subgroup. Gait quality perception (p<.05) and all spatial gait parameters (p<.05), except for the number of cycles at the turn (p=.144), were significantly improved for the no-FOF subgroup. Nevertheless, no time*group interaction was observed for gait parameters and gait quality perception (Table 3). Moreover, the locomotion SarQol score exceed the smallest detectable change for group of 0.85 point for the FOF and the no-FOF subgroup (+5.45 and +3.12 points respectively) [41].

Changes in FES-I score and physical function

A group and a time*group interaction effects were only observed for the FES-I score (p<.001). The FES-I score was only decreased for the FOF subgroup (p<.001; Table 3). SPPB score, 5-STS and TUG were improved in both FOF subgroups (p<.05; Table 3). In FOF subgroups, SPPB score and 5-STS time reached a clinical meaningful difference (+1.32 points and −3.3 s respectively) [35]. The FES-I effect size was −0.39 for the FOF subgroup that is higher to the one found in a recent meta-analysis (effect size of −0.34) [26]. In no-FOF subgroup, 5-STS time reached a clinical meaningful difference (−2.28 s) and SPPB score was close to reach the clinical threshold of +1 (+0.95 points) [35, 37].

Correlation between FES-I score deltas and gait parameters deltas

Significant correlation, albeit weak, were observed between the FES-I score delta change and the double support phase delta (r=.25, p<.05), the swing phase delta change (r=-.25, p<.05) and the stance phase delta (r=.25, p<.05) in FOF subgroup only. No other significant correlation was observed in objectives gait parameters. Nevertheless, a moderate and significant correlation was observed between the FES-I score delta and the locomotion SarQol score delta (r=-.49, p<.01) in no-FOF subgroup. This correlation became weak for the total cohort (r=-.25, p<.05) (Table 4).

Discussion

The main goal of this study was to explore the influence of FOF status on gait parameters changes following the intervention in community-dwelling older adults at risk of mobility disability. We also aim to provide new data on specific gait parameters changes during an exercise program and thereby contribute to filling the knowledge gap in this field. The main result of this study is the absence of robust associations between spatiotemporal gait parameters changes and FES-I changes following the exercise intervention. In addition, this study shows that, while perceived gait quality, spatial gait parameters and functional capacity were improved for all participants after the exercise intervention, FES-I score was only reduced in the FOF subgroup.

Changes of gait parameters after the exercise intervention

First, it is interesting to notice that spatial parameters, gait speed and gait quality perception increased significantly after the intervention for the total cohort. This suggests that spatial gait parameters and gait speed may exert a greater influence on older adults' perception of their gait quality than temporal gait parameters. Perception of improvement in gait quality could be a good lever to support involvement to this type of intervention [42].

Considering the association between quadriceps strength (i.e. 5-STS) [43] and some gait parameters, such as speed and stride length [44], it is therefore consistent to observe an improvement in these parameters after the intervention [45]. The effectiveness of exercise interventions in improving gait speed is now widely established and our results are in line to those observed in other studies [19, 35]. In a recent systematic review, only one study investigated the effect of resistance training on specific spatiotemporal gait parameters and observed a greater positive difference on stride length than in our study [19, 46]. This study proposed a 16-weeks exercise intervention with three exercises sessions (one supervised collective session and two home sessions per weeks). Participants had to complete thirteen exercises during a session. They used elastic band with a progressive increase of intensity and volume as we did. The difference in results with our study observed could be explained by a higher duration and volume of training. Another recent study, also observed a positive effect on several gait parameters including stride length on hospitalized

Table 3 Group and group*time interaction effects for subgroups of participants after the multicomponent exercise intervention

		Fear of Falling Subgroup (*n*=64)			No-Fear of Falling Subgroup (*n*=41)			Fear of Falling Subgroup vs No-Fear of Falling Subgroup	
Variables	**Group (G)*p* G * Time (T)*p***	**Pre (Mean ± SD)**	**Post (Mean ± SD)**	***p* (*d*)**	**Pre (Mean ± SD)**	**Post (Mean ± SD)**	***p* (*d*)**	**Pre *p* (*d*)**	**Post *p* (*d*)**
FES-I (/64)[a]	**G = <.001 G * T = <.001**	31.98 ± 7.49	29.34 ± 8.40	**<.001** (-.39)	20.68 ± 2.07	21.37 ± 4.16	0.543 (.16)	**<.001 (1.87)**	**<.001 (1.13)**
Locomotion SarQoL score (/100)	**G = <.001** G * T = 0.727	43.84 ± 13.34	49.29 ± 15.50	**<.01 (.42)**	56.60 ± 13.10	59.72 ± 13.62	**<.05 (.38)**	**<.001 (-.96)**	**<.001 (-.70)**
6-meters gait speed (m/s)	**G = <.01** G * T = 0.556	0.79 ± 0.19	0.88 ± 0.22	**<.001 (.62)**	0.90 ± 0.16	0.98 ± 0.17	**<.001 (.66)**	**<.01 (-.61)**	**<.05 (-.49)**
50-meters gait speed (m/s)	**G = <.001** G * T = 0.560	0.93 ± 0.21	0.98 ± 0.23	**<.001 (.43)**	1.07 ± 0.14	1.14 ± 0.17	**<.01 (.53)**	**<.001 (-.75)**	**<.001 (-.77)**
SPPB (/12)[b]	**G = <.001** G * T =.146	8.77 ± 1.88	10.09 ± 1.74	**<.001 (.90)**	10.34 ± 1.33	11.29 ± 0.96	**<.001 (.72)**	**<.001 (-.93)**	**<.001 (-.81)**
5-STS (s)[c]	**G = <.01** G * T = 0.434	15.62 ± 6.70	12.32 ± 4.59	**<.001 (-.71)**	13.11 ± 4.49	10.83 ± 2.53	**<.05 (-.74)**	**<.05 (.42)**	0.093 (.38)
TUG (s)[d]	**G = <.001** G * T = <.425	13.51 ± 3.57	12.18 ± 3.56	**<.001 (.61)**	11.31 ± 19.2	10.39 ± 1.78	**<.001 (-.51)**	**<.001 (.72)**	**<.05 (.60)**
Temporal gait parameters									
Stride variability (%)	**G = <.05** G * T = 0.108	4.96 ± 2.52	4.42 ± 1.57	**<.05** (-.31)	3.88 ± 1.00	3.99 ± 1.21	0.856 (.07)	**<.05 (.52)**	0.199 (.30)
Stride symmetry (%)	G = 0.297 G * T = 0.669	6.30 ± 6.88	5.66 ± 5.59	0.532 (-.10)	4.25 ± 3.48	4.14 ± 2.97	0.989 (-.03)	0.315 (.35)	0.657 (.26)
Double support phase (%)	**G = <.05** G * T = 0.800	22.21 ± 6.09	21.46 ± 5.92	0.327 (-.12)	19.85 ± 4.37	19.38 ± 5.59	0.297 (-.11)	**<.05 (.43)**	0.075 (.36)
Swing phase (%)	**G = <.05** G * T = 0.804	38.89 ± 3.04	39.26 ± 2.96	0.331 (.12)	40.07 ± 2.18	40.31 ± 2.80	0.297 (.11)	**<.05 (-.43)**	0.075 (-.36)
Stance phase (%)	**G = <.05** G * T = 0.800	61.10 ± 3.04	60.73 ± 2.96	0.327 (-.12)	59.93 ± 2.18	59.69 ± 2.79	0.297 (-.11)	**<.05 (.43)**	0.075 (.36)
Spatial gait parameters									
Stride length (m)	**G = <.001** G * T = 0.926	1.01 ± 0.17	1.04 ± 0.18	**<.01 (.41)**	1.14 ± 0.14	1.17 ± 0.16	**<.05 (.40)**	**<.001 (-.82)**	**<.001 (-.75)**
Lift off angle (°)	**G = <.01** G * T = 0.701	52.88 ± 8.17	54.61 ± 8.22	**<.05 (.33)**	57.63 ± 6.21	58.95 ± 7.02	**<.05 (.24)**	**<.01 (-.64)**	**<.01 (-.56)**>
Strike angle (°)	**G = <.05** G * T = 0.445	20.31 ± 5.07	21.46 ± 5.38	**<.05 (.32)**	23.06 ± 4.61	23.68 ± 5.12	**<.05 (.20)**	**<.01 (-.56)**	**<.05 (-.42)**
Turning angle (°)	**G = <.05** G * T = 0.521	84.62 ± 16.40	90.50 ± 16.24	**<.05 (.39)**	93.08 ± 14.83	96.41 ± 15.90	**<.05 (.30)**	**<.01 (-.54)**	0.071 (-.37)
The number of cycles at the turn (n)	**G = <.01** G * T = 0.714	3.5 ± 0.71	3.26 ± 0.63	**<.05 (.28)**	3.17 ± 0.50	3.02 ± 0.47	0.144 (.24)	**<.05 (.52)**	**<.05 (.42)**

[a]FES-I: Falls Efficacy Scale International questionnaire

[b]SPPB : Short Physical Performance Battery

[c]5-STS : 5 times sit-to-stand test

[d]TUG: Timed Up and Go test. "Fear of Falling subgroup": participants with FES-I baseline score >23/64. "No-Fear of Falling subgroup": Participants with FES-I baseline score ≤ 23/64. p Values are significant at values <.05. Significant values are highlighted in bold. d: d of Cohen's effect size

older adults with a "Square-Stepping Exercise" protocol [47]. The intervention was performed five times a week (30-minutes) during 3-weeks with three specific session of square-stepping at body weight. Participants of this study performed a higher volume of training per week but in a shorter duration. Moreover, participants were hospitalized. Nevertheless, these studies showed that gait improvement could be achieved using different protocols and provided that the exercise was progressive, adapted and of sufficient volume. However, it is noteworthy that devices used (i.e. GAITRite) and the test condition were different (i.e. straight walking) that could change the results [48]. Using a 50-m distance with a half-turn could induce more tiredness than a 10-m distance in a straight-line for older adults at risk of mobility disability.

The observed improvements of the plantar roll after the intervention seem consistent with the increase in stride length [49]. It is assumed that this change may be

Table 4 Correlation between changes of FES-I score and gait parameters for the total cohort and subgroups

	Correlations with gait speedr (*p)**		**Correlations with temporal gait parametersr (*p**)**					**Correlations with spatial gait parametersr (*p**)**					**Correlations with perceived gait qualityr (*p**)**
Variables	**Δ 6-m gait speed**	**Δ 50-m gait speed**	**Δ Stride variability**	**Δ Stride symmetry**	**Δ Double support phase**	**Δ Swing phase**	**Δ Stance phase**	**Δ Stride length**	**Δ Lift off angle**	**Δ Strike angle**	**Δ Turning angle**	**Δ The number of cycles at the turn**	**Δ Locomotion SarQoL score**
Δ FES-I[a] **Total Cohort**	−0.15(0.136)	−0.03 (0.728)	0.10 (0.306)	−0.1 (0.335)	0.17 (0.076)	0.17 (0.077)	0.17 (0.077)	−0.80 (0.416)	−0.06 (0.530)	−0.05 (0.613)	0.05 (0.650)	0.004 (0.970)	**−0.252 (< 0.05)**
Δ FES-I Fear of Falling Subgroup	0.09 (0.465)	−0.11 (0.393)	0.05 (0.072)	−0.14 (0.269)	**0.25 (< 0.05)**	**−0.25 (< 0.05)**	**0.25 (< 0.05)**	−0.07 (0.570)	−0.03 (0.845)	−0.08 (0.549)	0.56 (0.668)	0.01 (0.930)	−0.154 (0.233)
Δ FES-I No-Fear of Falling Subgroup	−0.24 (0.125)	−0.18 (0.270)	0.03 (0.870)	−0.13 (0.429)	0.12 (0.474)	0.12 (0.474)	0.12 (0.474)	−0.20 (0.206)	−0.10 (0.527)	0.06 (0.715)	−0.001 (0.995)	−0.03 (0.862)	**−0.486 (< 0.01)**

[a]FES-I: Falls Efficacy Scale International questionnaire. "Fear of Falling subgroup": participants with FES-I baseline score > 23/64. "No-Fear of Falling subgroup": Participants with FES-I baseline score ≤ 23/64. r = Pearson or Spearman correlation results. Δ: Delta = post-pre values. *p* Values are significant at values < 0.05. Significant values are highlighted in bold

due to an increase in the strength of the plantar flexors and extensors [50] and/or an improvement in the distal proprioceptive capacity of the lower limbs [51]. The practice of exercises to stand on tiptoe, heel-to-toe walking, changing walking pace, tandem walking, obstacle-clearing exercises, might also have been useful. Half-turn quality (i.e. the number of cycles required to make a half-turn and half-turn angle) was also one of the spatial parameters that changed positively after the intervention. In our study, the improvement in half-turn quality may consequently results into better TUG performances following the exercise intervention together with the increase of gait speed and 5-STS.

Surprisingly, temporal gait parameters remained unchanged after the exercise intervention. Regarding stride variability, this result was unexpected, as stride variability is regularly used to characterize gait parameters in older adults [52]. Given that stride variability is associated with quadriceps power [53], we could expect to obtain improvements in stride variability as 5-STS increased in the total cohort and in both subgroups [54]. Yet, only a tendency was observed for this parameter. It seems that the effects of exercise on stride variability may differ from study to study, due to different training modalities (duration, intensity, volume) [45, 55–57]. It is also worth noting the difference in the populations studied, which are all younger and more robust than our own [45, 55–57]. Moreover, a supervised exercise intervention, conducted on autonomous older adults during 12-weeks with 3 sessions of 1 h per week and with progressive intensity, observed a significant improvement of stride variability; but failed to show an improvement, at an intermediate assessment at 8 weeks [45]. As our intervention lasted 10 weeks (with 2 weekly 1-hour sessions), the absence of improvement might be explained by an insufficient volume or duration of training to induce significant changes [45] for the overall cohort.

The other temporal parameters (double-support phase, support phase, swing phase and step asymmetry) did not change after the exercise intervention. Considering the association of double-support phase with gait speed and FOF [8], it is surprising to not observe changes of double-support phase after the intervention, while gait speed and FOF were improved. One study using the specific "Square-Stepping Exercise" protocol, observed significant improvement of double-support phase [47]. Thus, it might be possible that this protocol could be more effective to improve this parameter. With regards to stride symmetry, baseline data were relatively preserved, that mainly explain the absence of change after the intervention [58]. The positive changes after the intervention on spatial gait parameters observed did not seem to be followed by improvements in temporal gait parameters.

Overall, gait improvement could be achieved using different exercise protocols, if the exercise was progressive, adapted and of sufficient intensity (at least moderate) and volume (at least 2 sessions per week). Exercises should be performed using bodyweight or small equipment (such as elastic bands), in 2 to 3 sets of 6 to 12 repetitions. Exercises should be transposable to functional movements and target the muscles recruited during gait (hip, knee and ankle flexors and extensors muscles; postural upper body muscles and arms muscles).

Influence of FOF in exercise adaptations: comparison between FOF subgroups

First, FOF significantly decreased after the multicomponent exercise intervention but with a small effect in the overall cohort. These results are in agreement with previous studies [24–26]. More specifically, the population most likely to experience changes following an intervention are those with a higher level of FOF or with a higher level of frailty according to previous study of Delbaere et al. [3]. It is worth noting that FES-I scale has a floor effect, especially for older adults without FOF, but remains limited [59]. Thus, this could partly explain the absence of FOF decrease in the no-FOF subgroup. In the context of falls prevention, these results are encouraging. Nevertheless, although the FOF is a major factor in the risk of falling, management of fall prevention cannot be limited to this factor alone. It needs to be considered in a global approach with the history of falls, physical functions and activity restrictions [1, 20–22]. Indeed, there is a "spiraling effect of increasing falls, fear and functional decline", since they are all predictors of each other [20].

However, we did not observe a time*group interaction in gait parameters and in physical function (SPPB score, 5-STS and TUG), indicating that the presence of FOF may not be responsible of different spatial gait parameters and physical function changes. In addition, as stride variability and number of cycles at the turn were only improved in FOF-subgroup, there seems to be a ceiling effect for the no-FOF subgroup. Indeed, participants in the FOF-subgroup had lower gait parameters at baseline than those in the no-FOF subgroup. This was even more marked for temporal parameters, since the differences between the subgroups were no longer present after the multicomponent exercise intervention. Nevertheless, the spatial parameters of participants with FOF seemed to be too impaired at baseline to attain gait parameters comparable to those of participants without FOF. To our knowledge, this is the first study to compared differences in gait parameters adaptations according to FOF. However, considering the difference of physical function between the subgroup participants at baseline, this difference of exercise-induced adaptations could also be explained by the training load (volume and intensity) that may be insufficient for the more robust no-FOF group [45]. As no-FOF participants showed better fitness, the training load might not be sufficient for them to achieve a gain, as previously discussed [45]. In addition, analysis of the participants who dropped out of the study (for health reasons unrelated to the intervention) indicated that their profiles were similar to those of the subgroup with FOF.

Furthermore, although the intervention adaptation in gait parameters was slightly different between the subgroups of FOF, the improvements in perceived gait quality was equally marked in both subgroups. This finding is particularly interesting for mobility loss prevention, since it has been shown that the perception of difficulty in walking is strongly associated with social isolation and the risk of developing sarcopenia [60, 61]. Thus, decrease FOF and improve perceived gait quality can therefore help participants to be more involved to develop social activities and reduce sedentary time. Secondly, an improvement in perceived gait quality is encouraging, considering the predictive value of self-perception of mobility on occurrence of adverse events in older adults, especially when the FOF and its related consequences are added [3–6, 62, 63].

Correlations between FOF and gait parameters changes

Considering that literature showed significant associations between FOF and gait parameters [8–12], we should have expected a synergic changes between them after the intervention. Surprisingly, no robust correlation between delta changes were observed. We only found weak correlations in FOF subgroup for some temporal parameters. From a clinical point of view, participants who exhibit a decrease in FOF will reduce their stance time and logically increase their swing time. These results seem consistent with the literature, which indicates that stance time increases with FOF [8]. Moreover, as we observed a group effect on these parameters, these results suggest that it might be relevant to target older adults with prolonged stance phase and double support phase for this type of multicomponent exercise intervention. A recent observational study which was carried out on fallers and non-fallers older adults [7], reported that after 6 months without intervention, the gait speed of both groups remained stable but FOF remained stable only in the fallers' group [7]. Non-fallers, conversely, reduced their FOF. Thus, although FOF and gait parameters are related, their changes over time do not seem to be as related. Nevertheless, perceived gait quality changes were correlated with FOF changes, particularly in no-FOF subgroup. Surprisingly, no significant correlation was observed for the subgroup with the greatest changes in FOF. These results reinforce the idea that FOF is complex and multifactorial [1]. Thus, changes of FOF cannot easily be associated with changes of objective and subjective gait parameters.

Identifying factors that appear to be most related to FOF reduction would be a relevant approach to optimize the efficiency of the multicomponent exercise interventions. We assumed that the reduction of FOF might be induced by psychological factors changes such as a better stress management and self-efficacy. Focusing exercise interventions towards gait retraining (e.g. with gait paths) and psycho-affective factors for the most frail and fearful of falls older adults could be worth testing further. Finally, these results reinforce the importance of integrating older adults with a FOF into these types of interventions. For older adults without FOF, targeting exercise interventions on FOF might not be a priority on physical function improvement and social isolation decrease. In clinical setting, an assessment of FOF in the first multidimensional assessment could be used to allocate participants in specific exercise interventions.

Limitations

This study had some limitations. While this study provides clinical knowledge closer to real-life care interventions and a population representative of patient profiles encountered in usual care practice, the effect of the exercise intervention needs to be interpreted with caution. Based on the real-life care setting and for obvious ethical reasons, this study was not blinded and a control group could not be constituted in this context. Thus, the superiority effect of the intervention on the studied parameters cannot be affirmed. Despite we have not carried out an intention-to-treat analysis to assess all participants included in the intervention, we performed, to limit bias, a comparative analysis of participants at baseline that allow us to maintain our analysis design (per-protocol) and conclusion. As our study was an exploratory pilot study (phase II ORBIT framework) and a pragmatic feasibility intervention (usual care), we had not calculated a prior sample size. Several results are based on self-administrated questionnaires, however therapists involved with the study had to ensure that patients completed them in their entirety. Nevertheless, this study had also some strengths: it is the first to investigate the changes and the influence of FOF status on spatiotemporal gait parameters after a multimodal exercise intervention implemented in the community with older adults at risk of mobility disability. In addition, this study also contributes to fill the gap on specific gait parameters, such as half-turn and to promote the interest of current-care intervention in real-life settings in mobility disability prevention.

Conclusion

Our results demonstrate that a multicomponent exercise intervention lead to significant changes in FOF, spatial gait parameters and perceived gait quality in older adults and more especially in those with FOF. Although FOF and gait parameters are related, their changes over time do not seem to be as related. This study confirmed that managing the FOF is complex, multifactorial and might be orientated to a holistic approach. Further comparative studies are necessary to better determine which factors are most related to changes in gait parameters and FOF. Finally, this study shows that multicomponent exercise interventions appear to influence not only physical parameters, but also spatiotemporal gait parameters and FOF. Consequently, these interventions should be proposed more widely to older adults at risk of falls, and particularly to those with a FOF.

Abbreviations

5-STS 5 Times Sit-to-Stand test
FES-I Falls Efficacy Scale International
FOF Fear Of Falling
SPPB Short Physical Performance Battery
TUG Timed Up and Go test

Supplementary Information

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Additional file 1: Baseline comparison between participants drop-out and participants included in the analysis.

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Suppliers

[a]Physilog5, Gait Up, Switzerland.
[b]MindMaze© gait analysis package.
[c]IBM SPSS Statistics version 21 (IBM Corp., Armonk, NY, USA).

Authors' contributions

A.C.B, T.G, M.A.L and M.B designed and conceptualized the study. A.C wrote the manuscript and analyzed the data. T.G, M.A.L and M.B. supervised the research project. All authors had access to all of the data, contributed to the interpretation of findings, revised and approved the final manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the scientific and ethical committee of the Hospices Civils de Lyon (France) (NCT03667664, registration date: 12/09/2018 and NCT06659484, registration date: 26/10/2024). This study complies with the Helsinki Declaration as after receiving detailed information, all study participants gave their informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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