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Feasibility of Pilates for Late-Stage Frail Older Adults to Minimize Falls and Enhance Cognitive Functions

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Abstract: Globally, we are facing the tendency of aging, and demands for health enhancement among the older population have been steadily increasing. Among various exercise interventions, Pilates has been popularly utilized in rehabilitation; therefore, it is considered suitable for vulnerable populations. In this study, frail late-stage older adults (>75 years) participated in a modified Pilates program (30 min per session, once a week for eight weeks). Age- and condition-matched Controls were also involved as the benchmark to reveal the effect of Pilates. While only the Pilates group participated in the exercise intervention, both groups undertook the health assessments twice (before and after the intervention period). Assessments included: (i) falling risk based on 3D motion capture systems and (ii) overall cognitive functions utilizing Mini-Mental State Examination and executive function with the use of Trail Making Test-A (TMT-A). Two-dimensional mood state was also used to measure changes in mood due to Pilates intervention. An 8-week Pilates intervention was effective in achieving higher and symmetrical swing foot control. Dynamic balance at heel contact was also improved by extending the spatial margin in case of slipping. Despite the trend of positive Pilates effects on executive functions (29% improvement) confirmed by TMT-A, no significant effects were observed for cognitive functions. Positive mood changes were achieved by Pilates intervention, which may be the key for late-stage seniors to continue their participation in exercise programs. While further studies with a larger sample size are essential, Pilates appears to provide adequate exercise for the frail late-stage older population to minimize frailty.

Keywords: Pilates; falls prevention; motion capture; cognitive function; frailty; executive function; MMSE

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1. Introduction

Aging is commonly seen in many mature nations, while developing countries are also tracing the same path. This tendency is most profound in Japan, where almost one in three are over 65 years old, and the population of late-stage older adults (>75 years old) is predicted to exceed 20 million by 2025 [1]. Due to the increased proportion of seniors and the concurrent decrease in the working population, medical and nursing costs alone already exceed the national annual revenue [1]. In addition to conventional medical treatments, prevention and fundamental cure of healthcare issues are, therefore, urgently demanded, particularly for the senior population. While individuals above 65 years have been conventionally considered to be 'old', further sub-divisions (i.e., early-stage seniors

65–74 years and late-stage seniors > 75 years) can clarify at which age seniors generally start losing their healthy, independent lifestyles [2–5].

Once the health statuses of seniors decline below a certain level, engagement in regular activities becomes increasingly challenging [6]. Preventive or rehabilitation approaches are, therefore, somewhat underutilized for late-stage older adults due to various special considerations required for safety precautions [7,8]. It is, however, still necessary to devise feasible strategies for vulnerable populations with limited mobility to combat deterioration [9] because indefinite reliance on nursing care without the intention for recovery can only result in the gradual progression of fundamental health declines [10]. For the older population, the two major factors causing constant nursing care are falls-related injuries during locomotion and declined cognitive functions. In other words, health enhancement for seniors should focus on these two aspects, but, first of all, reliable assessment methods are essential to evaluate individuals' locomotion and cognitive functions.

Gait biomechanics utilizing 3D motion capture systems can accurately record human movements and quantify fall risks by looking at foot motion and dynamic balance [11]. While simple locomotion tests (e.g., 6 min walking and timed up and go test) are practical, no detailed examinations are possible to understand how their walking patterns can increase fall risks [12]. Despite rather complicated settings, gait testing based on 3D motion capture systems can biomechanically explain falling risks by characterizing swing foot motion and dynamic balance [11]. For assessments of cognitive functions, overall impairments can be checked by Mini-Mental State Examination (MMSE), while Trail Making Test-A (TMT-A) is a specific examination for executive functions that are highly linked with motor behaviors [13].

By undertaking these tests before and after an intervention, changes in the health functions of the frail senior population can be monitored, reflecting the 'effectiveness' of intervention strategies to prevent falls and cognitive impairments. Among various intervention strategies available for this purpose, 'exercise' should be prioritized due to the benefits for falls prevention, mental health and cognitive functions; suitability for rehabilitation; and cost advantages and relatively less adverse side effects, if executed appropriately [14–17]. Nevertheless, the frail late-stage senior population tends to avoid continuous engagement into exercise due to critical physical limitations and motivation issues. It is obvious that the safe prescription of adequate exercise is often challenging for late-stage older adults, but lack of motivation can also discourage physically and cognitively impaired populations from continuously engaging in exercise programs [18].

Pilates exercise was originally developed by Joseph Pilates to pursue 'natural human health', and its structural operation played an important role during World War I for wounded soldiers' rehabilitation. Many training sequences included the use of special equipment such as Cadillac, Reformer, and Wundachair. Mat-based Pilates is often conducted in the lying and sitting postures to avoid overloading of the foot and cardiovascular systems [19]. Unlike general exercise programs involving dynamic movements in strength and cardio training, Pilates focuses on fine-movement control to enhance 'core' stability and skeletal alignment [20], requiring less gross physical motions and is therefore more suitable for the frail population. A breathing technique called chestic lateral breathing is another essential practice to enhance overall circulation. Pilates requires constant concentration due to its multi-tasking nature, such as when breathing, maintaining posture, and performing finely coordinated movements, and thus may stimulate cognitive functions [21]. It is also noteworthy that previous Pilates intervention strategies revealed fewer dropout rates compared with other exercise interventions [22,23]. Thus, Pilates may be feasible for frail late-stage seniors. The current research assessed whether eight Pilates sessions would reduce fall risks and benefit cognitive functions with their motivation maintained for long-term participation.

We hypothesized that Pilates sessions would effectively reduce fall risks and improve cognitive functions among frail late-stage older adults. In addition, low dropout rates would be expected if Pilates intervention brought positive mood changes. The current research project is unique and important as it is one of the few studies that tested the possibility of Pilates as an exercise intervention for vulnerable late-stage and frail older adults to maintain their health and wellbeing.

2. Materials and Methods

2.1. Participants

Participants were frail late-stage older adults (>75 years old) who lost their independence in travelling alone, performing household tasks, and managing their own finances. Frailty was confirmed by the Kihon checklist, the official questionnaire used by health practitioners in Japan to assess eligibility for social support required for senior citizens [24]. Participants were randomly assigned to either the Pilates group (n = 10) or the Control group (n = 9). Group characteristics were statistically identical (Table 1).

Table 1. Group characteristics.

	Biological			
	Pilates		Control	
Age (years)	83.4 ± 5.0		84.8 ± 4.3	
Height (cm)	144.4 ± 4.3		148.6 ± 11.1	
Body mass (kg)	48.3 ± 7.5		51.0 ± 9.9	
Systolic blood pressure (mmHg)	145.8 ± 17.6		153.4 ± 22.9	
Diastolic blood pressure (mmHg)	78.7 ± 11.3		84.0 ± 12.2	
Pulse (beats/min)	85.8 ± 12.4		81.6 ± 9.1	
	Physical			
	Pilates		**Control**	
	Right	**Left**	**Right**	**Left**
Grip strength (kg)	15.8 ± 2.8	15.3 ± 3.1	18.3 ± 4.0	16.1 ± 3.3
Single leg standing (s)	8.8 ± 11.3	8.2 ± 11.5	3.4 ± 2.7	3.0 ± 1.8
Step length (cm)	8.1 ± 2.4	7.4 ± 3.0	9.3 ± 2.7	8.0 ± 2.6
Step width (cm)	10.6 ± 1.3	10.5 ± 1.3	9.3 ± 1.5	9.1 ± 1.9
Double support time (s)	0.23 ± 0.11	0.23 ± 0.13	0.26 ± 0.08	0.30 ± 0.17
Sit and reach (cm)	31.0 ± 10.4		23.9 ± 8.5	

Only the Pilates group undertook Pilates exercise (30 min once a week for 8 weeks). Prior to participation in the research, informed consent, approved and mandated by the University of Tsukuba Research Ethics Committee (Tai 27-4), was voluntarily signed by prospective participants and their guardians (i.e., physical therapists and family members). Exclusion criteria included the lack of ability to understand the aim of the research, difficulty in following the instructions, and any other severe health issues identified by clinicians, such as physical limitations in walking due to, for example, severe osteoarthritis, rheumatoid, Parkinsonism, and certain types of medications.

2.2. Pilates Intervention

Pilates is a conditioning method that pursues the complete harmony of ‘body, mind and spirit’, with essential principles including ‘whole body movement, breathing, balanced muscle development, concentration, control, centering, precision and rhythm’ [19,20]. Starting with simpler movements, the intensity and complexity of exercise gradually increases within a single session and over a prolonged period [25]. The Pilates program used in the current study followed the above principles but was modified to accommodate physical limitations due to frailty and is therefore better categorized as ‘pre-Pilates’ introductory exercise to prepare for full Pilates. All exercise repertories were conducted in a sitting position on a chair, starting with lower-body warm-up, particularly focusing on ankle dorsiflexion, plantarflexion, and the movement of each toe (5 min), followed by upper-body warm-up emphasizing the separate movement of the cervical, thoracic and lumbar regions

(5 min), pelvic rocking and activation of pelvic floor and transverse abdominus (5 min), chestic lateral breathing at various postures (5 min), modified basic exercises including single-leg stretch, side-reach, thoracic extension (5 min), and cool-down (5 min). Further details are described in Appendix A and the Supplementary Material.

2.3. Assessments

Both groups undertook a range of assessments before and after the 8-week intervention period. Gait testing was conducted on the motor-driven treadmill utilizing a 3D motion capture system (Optitrack, Naturalpoint, Corvallis, OR, USA). Due to severely impaired motor functions, participants walked at the slowest treadmill speed (0.3 km/h). In addition to the usual safety protocols (e.g., handrails and harnessing systems), it was necessary for the two experimenters to constantly stand aside to ensure safety while another assistant was fully in charge of treadmill operation in the likelihood of a potential emergency stop.

Reflective markers were attached to the following anatomical landmarks: toes (i.e., the superior anterior surface of the toe), heels (the proximal end of the foot), anterior superior iliac spine (ASIS), and posterior superior iliac spines (PSISs). Pelvis center of mass (COM) was defined by the average 3D position of two ASIS and two PSISs marker locations. Participants were asked to walk on the motor-driven treadmill until the minimum of 20 complete stride cycles were captured at 100 Hz, then lowpass-filtered at 6 Hz prior to analysis. Physiological data were collected as part of baseline assessment for both groups: height, body mass, blood pressure (systolic and diastolic), pulse, grip strength, single-leg standing and sit and reach, in addition to fundamental gait parameters, including step length, step width, and double support time [26]. During the assessment, a medical doctor was on site in case of any emergency situations.

2.3.1. Falling Risks

Biomechanical data included the parameter of minimum foot clearance (MFC), which indicates the tripping risk, defined as the local minimum vertical swing toe height during the mid-swing phase (Figure 1, left). Maintaining sufficient MFC height is the fundamental gait adaptation to prevent tripping falls [27].

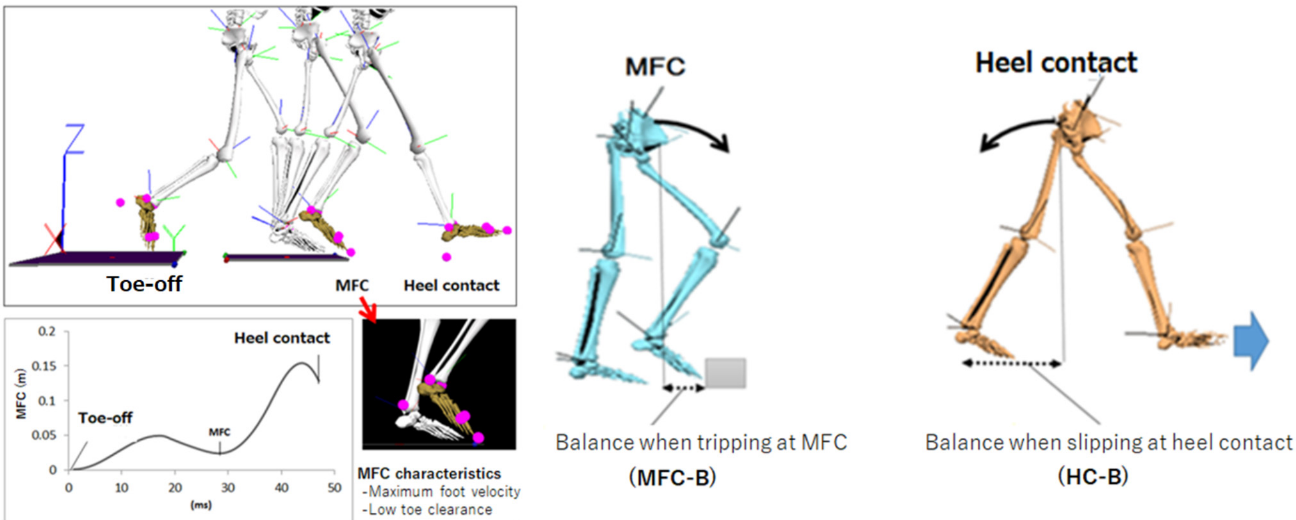

Figure 1. (**left**) Definition of minimum foot clearance (MFC); (**middle**) MFC-B: spatial margin to balance loss at MFC; (**right**) HC-B: spatial margin to balance at heel contact.

Balance was assessed at MFC and heel contact, reflecting the likelihood of balance recovery in case of tripping and slipping. As shown in Figure 1 (right), anterior distance from *CoM* to swinging of the toe indicated the spatial threshold for forward balance loss when tripping at the MFC (MFC-B) [28,29]. In contrast, backward balance loss is more likely due to slipping following heel contact; therefore, the posterior distance from

CoM to the trailing foot's heel indicates dynamic balance at heel contact (HC-B) [28,30]. Dynamic balance usually considers *CoM* velocity factors based on extrapolated center of mass (*XCoM*),

$$XCoM = x + {}^{CoMvel}/_{\sqrt{g/l}} \tag{1}$$

where x, g, and l, respectively, indicate *CoM* position, gravitational acceleration, and limb length. In the current study, however, the late-stage frail older participants (mean = 84.1 years) walked at a very slow speed (0.3 km/h). Therefore, velocity factors (i.e., $CoMvel/\sqrt{g/l}$) were neglected, justifying the use of MFC-B and HC-B (Figure 1, right).

2.3.2. Cognitive Functions

Overall cognitive functions were assessed by Mini-Mental Scale Examination (MMSE), conducted as a verbal test by an examiner [31]. MMSE is a questionnaire considered valid to test for dementia. Of the total scores (i.e., 30), 23 or lower can be classified as suffering from dementia, and 24–25 indicates 'mild cognitive impairment' (MCI). The Trail-Making Test-A (TMT-A) evaluates executive function. A set of numbers (1–25) was arranged randomly on a sheet of paper, and the participant was asked to connect lines from 1 to 25 in numerical order as quickly as possible. The time taken to complete the task was recorded [32]. The normative data showed 50–60 s as the standard for the healthy age-matched population [33].

2.3.3. Two-Dimensional Mood Scale (TDMS)

For frail populations, exercise intervention can often be overwhelming, and motivation issues discourage their continuous engagement, while Pilates can be relatively feasible [34,35]. Instant mood changes after Pilates intervention were, therefore, examined by the Two-Dimensional Mood State (TDMS), measuring the four fundamental mood components, including 'Vitality', 'Stability', 'Pleasure', and 'Arousal' [36]. Each component was evaluated based on 8 questions. TDMS was used immediately before and after each session, and the average scores for both pre- and post-intervention were analyzed.

2.4. Statistical Analysis

Multiple measurements were conducted, requiring different statistical approaches. Computed p-values less than 0.05 determined significant effects.

(i) Falling risks (MFC, MFC-B and HC-B): motion capture data distinguished the right and left side separately; therefore, a (2 × 2 × 2 = group × limb × intervention) repeated measure of analysis of variance (ANOVA) was employed. Any interaction effects were further examined by Tukey's post hoc analysis.
(ii) Cognitive functions (MMSE and TMT-A): a (2 × 2 = group × intervention) design was applied to obtain Pilates effects.
(iii) Mood (TMTS): averaged pre- and post-intervention TDMS scores were compared by independent t-tests in the Pilates group.

3. Results

3.1. Pilates Effects on Falling Risks

As shown in Figure 2, post-intervention showed a higher MFC for both groups ($F_{1,18}$ = 24.3, p < 0.01). Pilates intervention resulted in more symmetrical MFC control, qualified by the group × limb × intervention interaction ($F_{1,18}$ = 16.6, p < 0.01).

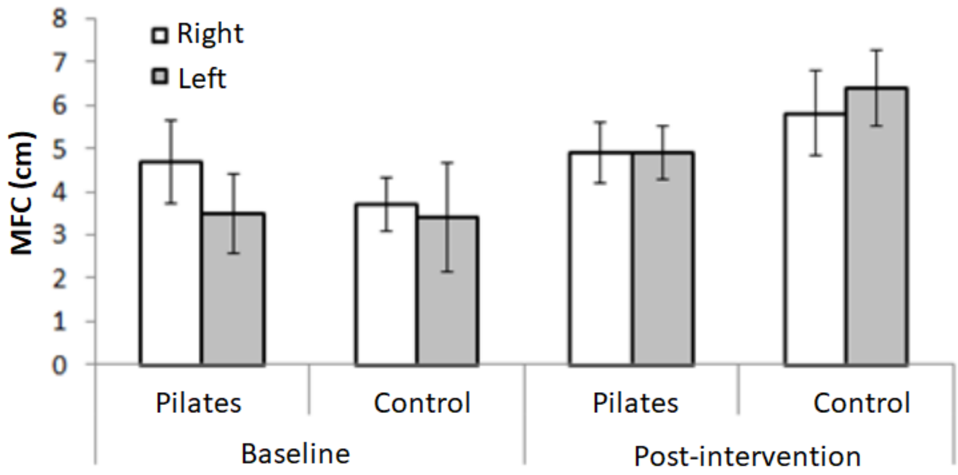

Figure 2. Minimum foot clearance (MFC).

Although both Pilates and Control groups showed a higher MFC post-intervention, further analysis revealed that one participant in the Control group demonstrated abnormally high values (>9 cm). This participant showed 'stomping and marching-like' walking patterns with exaggerated hip flexion motions to increase MFC in post-intervention but not in baseline assessment.

Table 2 describes dynamic balance at MFC and heel contact. Pilates intervention significantly increased HC-B, confirmed by both intervention effects ($F_{1,18}$ = 4.84, p = 0.041) and the intervention × group interaction ($F_{1,18}$ = 4.58, p = 0.046). No other significant effects were observed. I = intervention effect, I × G = intervention × group interaction effect.

Table 2. Dynamic balance at MFC (MFC-B) and heel contact (HC-B); significant effects indicated by bold letter, I = intervention effects, G = Group effects, NS standing for not significant.

Dynamic Balance	Pre-Intervention		Post-Intervention		Effects
	Pilates	Control	Pilates	Control	
MFC-B Right	6.7 ± 3.0	7.8 ± 2.7	4.7 ± 2.3	5.7 ± 2.6	NS
MFC-B Left	4.8 ± 2.5	5.9 ± 3.1	8.5 ± 2.0	5.8 ± 2.1	
HC-B Right	5.8 ± 2.6	5.5 ± 2.5	**9.9**$^{\mathbf{I \times G}}$ ± 2.7	5.5 ± 2.0	I, I × G
HC–B Left	5.5 ± 2.7	4.6 ± 2.5	**10.5**$^{\mathbf{I \times G}}$ ± 2.9	4.7 ± 2.0	

3.2. *Pilates Effects on Cognitive Functions*

An 8-week Pilates intervention did not show significant effects on cognitive functions, indicated by both MMSE and TMT-A (Table 3). However, there was a 67.5 s reduction in TMT-A in the Pilates group, while a 14.7 s increase was observed in the Control group. Despite the remarkable trend, this interaction was not statistically qualified.

Table 3. Cognitive functions: MMSE and TMT-A.

	Baseline		Post-Intervention	
	Pilates	Control	Pilates	Control
MMSE (points)	23.4 ± 4.1	23.4 ± 4.6	24.1 ± 4.9	23.1 ± 6.4
TMT-A (s)	297.0 ± 240.4	191.2 ± 106.1	229.6 ± 124.7	239.6 ± 113.9

3.3. Pilates Effects on Mood

Except for Arousal, the Pilates session significantly increased the scores of all the other mood components (3.2 points for Vitality ($p < 0.01$), 4.0 points for Stability, and 7.3 points for Pleasure ($p < 0.01$) (Figure 3)).

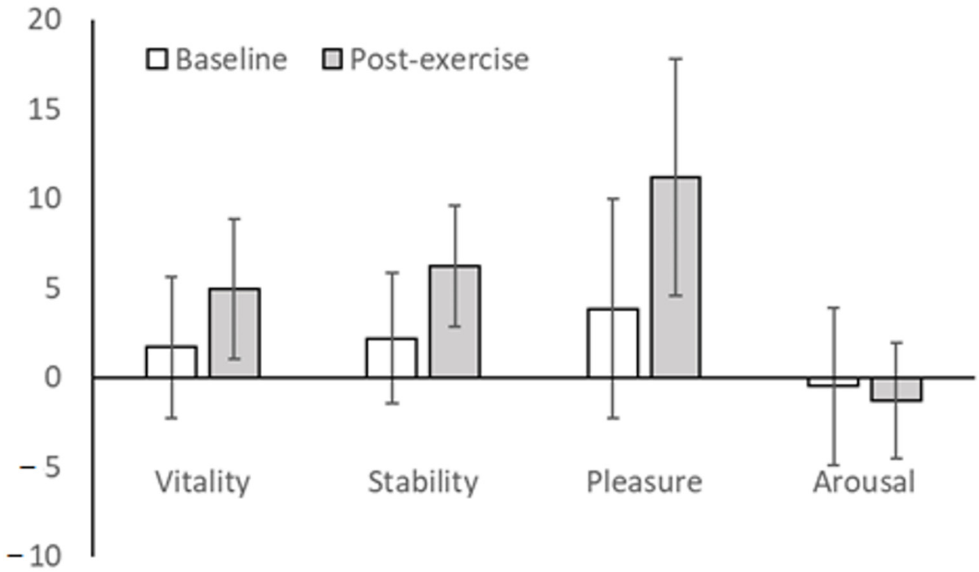

Figure 3. Two-dimensional mood scale (TDMS).

4. Discussion

The participants in the current research were confirmed to be frail late-stage older adults (>75 years) due to limited locomotive functions (e.g., 0.3 km/h on the treadmill and short and wide steps with long double support time) and signs of cognitive decline (e.g., average MMSE scores of 23.4). In addition, single-leg standing scores, sit and reach performance, and grip strength were below the healthy benchmark [33,37]. Continuous engagement in physical exercise programs for frail late-stage older adults is usually challenging, but the current study tested whether they would benefit from an 8-week Pilates program.

A total of eight sessions (30 min, once a week) increased MFC and attained more symmetrical swing foot clearance control, indicating a lower tripping risk [27]. Increased MFC can be attributed to more active dorsiflexion and fine-toe control, emphasized in the warm-up part of the program. Moosabhoy and Gard [38] reported that dorsiflexion was the most effective lower limb joint motion to increase MFC. Chronic plantarflexor contracture can be another cause of reduced MFC, which is prevalent in the inactive aged population [39]. The warm-up exercise attempted to increase ankle joint range of motion and help loosen undesirable contracture of muscles and soft tissues. Furthermore, the tactility of each toe part was stimulated by the specific warm-up repertoire, and the participants practiced fine-toe movement control for optimum swing foot clearance. Each component of every exercise was conducted for both sides, resulting in symmetrical MFC and associated reduction in the tripping risk [40].

Increased HC-B indicates greater resistance against backward balance loss when a foot slips forward [30], possibly attributable to improvements of age-associated posterior pelvic tilt known as 'backward disequilibrium' [41]. Pelvic rocking in the Pilates program emphasized correcting undesirable pelvic tilt to help align the lumbar-thoracic region to be more upright and to ensure a more anterior location of the *CoM*. In addition, activation of the pelvic floor, followed by transversus abdominis, helped strengthen the link between the pelvic region and the upper body. Although backward disequilibrium (posterior *CoM* position) can be caused by various physical factors, co-working of the muscle groups connecting the upper and lower body enhanced overall body coordination and stabilized

CoM. In contrast, dynamic balance at MFC (MFC-B) did not increase, but it was attainable if backward disequilibrium was corrected. In other words, postural adjustments may not assist with increasing MFC-B. Overall, the Pilates sessions seemed to help reduce the tripping risk and increase the likelihood of balance recovery in case of slipping.

The cognitive functions of late-stage frail seniors did not reveal significant improvements after 8 weeks of Pilates sessions, but there was a strong trend of potential enhancement in executive functions due to a remarkable reduction in the TMT-A (67.5 s). It has recently been reported that the dual-tasking component of Pilates (e.g., breathing and movement) can enhance executive functions [21,42]. High correlations between executive function and flexibility were previously reported [26], suggesting that further flexibility training may improve executive functions. Similarly, flexibility performance increasing MFC may prevent tripping falls [26]. Corti et al. [42] reported a potential link between executive functions and fine motor control for quick and effective pre-planning skills for motor behaviors.

Although studies of exercise intervention for older adults generally report high dropout rates [22], an excellent outcome was that there were no dropouts from the Pilates intervention group. Based on TDMS (Figure 3), Pilates positively changed the mood of late-stage seniors, possibly due to ease of engagement, conditioning of the mind (i.e., breathing, control and concentration), and a sense of participation in a group activity [19,20]. While effectiveness is essentially required for intervention strategies to enhance the health of senior late-stage adults, it is arguably more important that they continue as a routine activity. For safety, the current study limited intervention to 30 min per session and eight sessions over eight weeks in total. As no dropouts were observed, increased volume (frequency and duration) of Pilates exercise is recommended for future studies. Executive functions measured by TMT-A, for example, showed remarkable improvements but did not reach statistical significance. With the extended Pilates program, cognitive functions may possibly be enhanced.

The current study was unique and important in investigating late-stage frail adults (>75 years) with locomotive and cognitive impairments, but there are some fundamental limitations to acknowledge. First, the sample size was small due to difficulty in recruiting frail late-stage adults. For conclusive evidence in every aspect of the current study, a larger sample size needed to be tested. Biomechanical assessment also required special adaptations for the frail participants to minimize the time taken in testing. More comprehensive marker setups, however, particularly whole-body modeling, allowed for a better understanding of their movement functions. Gait testing was conducted on the treadmill at a constant 0.3 km/h across all participants. In the pilot stage of experimental design, frail late-stage adults struggled with maintaining consistent walking patterns. Treadmill walking was, therefore, selected to provide a constant belt speed as the external pacemaker. Controversy, however, still exists in treadmill gait testing, especially for older adults [40].

For a sustainable aging society, reversibility of frailty among senior adults is an important topic in addition to prevention and conventional medical practice [9,10]. In the case of Japan, locomotive and cognitive functions are considered the main determinants to maintain independent lifestyles [24]. Healthcare science is, therefore, expected to quantify these abilities and systematically evaluate seniors' health, which, in turn, helps to select effective intervention strategies. While Pilates can be applied in seniors and other vulnerable populations, there are a few fundamental challenges to mass utilization. First of all, it is necessary to establish a method that can be operated by practitioners after the systematic learning process. It cannot be a complete approach if Pilates effects excessively depend on each practitioner's skills. This issue can be overcome by establishing legitimate training programs and qualifications [43], but, currently, there are many random and unofficial certificates that can be obtained by attending seminars for a few days. There might be certain benefits with such short and intensive courses, but it may take years of practice before Pilates exercise can be prescribed for vulnerable populations, including late-stage adults.

Further research efforts are thus essential, but the current study revealed the potential benefit of Pilates intervention for late-stage frail adults. Previous studies [35,44] supported Pilates intervention for falls prevention among older adults based on simple assessments (e.g., timed up and go). This study employed biomechanical research methods, and found a reduced risk of tripping due to improved swing foot clearance at MFC and greater dynamic balance against slipping-related balance loss. In the future, Pilates programs should focus on fine-movement control and core training for fall-prevention purposes. Furthermore, Pilates sessions enhanced the participants' mood, probably due to engagement in the exercise program. It is expected that future studies be undertaken to investigate the benefits in various population groups.

5. Conclusions

A modified Pilates program (30 min × 8 sessions over 8 weeks) showed positive effects on fall risks among the frail late-stage adults (mean = 84.1 years) due to increased swing foot clearance to avoid tripping and improved ability for balance recovery against slipping. Cognitive functions were not significantly improved, but further studies with a larger sample size may be likely to reveal contrary findings. Pilates may be considered a potential intervention program to enhance the health of late-stage seniors because positive mood changes were observed after each session, which encouraged continuous participation.

Supplementary Materials: The following supporting information can be downloaded at: https://app.box.com/s/fnbvme5xfcknsuef4kjm79gw6ohj92b5, Video about the Pilates program used in the current study.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed was obtained from the patient(s) to publish this paper if applicable.

Data Availability Statement: The data presented in this study are available on reasonable request. The data are not publicly available due to privacy policies.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

No	Contents	Detail		Reps
1. Warm-up: Lower Body (3 min)				Position: Seated
A	Toe mobility	toe loosen (flex/extension/close-open)		3 each
B	Ankle joint mobility	dorsi flexion/planter flexion/rotation		3 each
C	Calf massage	from ankle joint to knee		3
D	Hip mobility	flex/extension/rotation		3
E	Knee mobility	flex/extension	※with towel	3

No	Contents	Detail	Reps
2. Warm-up: Upper Body (2 min)			Position: Seated
A	Spine mobility	flex/extension/rotation/lateral flexion	2 each
B	Shoulder stretch	retraction/protraction/elevation/depression/ upward rotation/downward rotation	2 each
C	Face stretch	clasp and unclasp face/tongue out	3 each
3. Core activation (5 min): ⌈Modified Pilates⌋			Position: Seated
A	Pelvic rocking	Front-back/left-right/rotation	3 each
B	Core activation	(1) confirming correct alignment of ischium/pubis/coccyx (2) set up ischium and extend spine toward ceiling (3) activating pelvic floor muscles (4) raise center of gravity (5–10 s)	2
4. Breathing (5 min): ⌈Modified Pilates⌋			Position: Seated/Child pose
A	Diaphragmatic breathing	Seated: inflate stomach when breathing	3
B	Breathing on the back	Child pose: breathing towards back	3
C	Lateral breathing	Seated: set pelvis to neutral position, continue applying abdominal pressure, spread rib cage	2
5. Walking Exercise (3 min): ⌈Pitago⌋ tm			Position: Standing
A	Standing on toe/heel	stand against wall and activate core shift weight back and forth	5
B	Standing one leg	stand against wall and activate core raise one leg and hold for 5 s	3 each
C	Tandem stretch	line up right and left foot on line shift weight slowly back and forth	2 each
6. Warm-down (2 min)			Position: Seated
A	Tapping	awaken sensory nerves	1
B	Deep breath	breath deeply with movement of arms	3

References

1. Cabinet Office, Government of Japan (Japanese). Available online: https://www8.cao.go.jp/kourei/whitepaper/w-2021/zenbun/pdf/1s1s_01.pdf (accessed on 14 June 2022).
2. Kropf, N.P. Life span: Older adultshood/seniors (from 60 to 75). *Enclypedia Soc. Work* **2020**. [CrossRef]
3. Portland University. Late Adulthood. Available online: https://pdx.pressbooks.pub/humandevelopment/chapter/late-adulthood/ (accessed on 8 June 2022).
4. Arai, H. Definition of older people: Time to reconsider the definition? *Jpn. Geriatr. Soc.* **2019**, *56*, 1–5. (In Japanese)
5. Orimo, H.; Ito, H.; Suzuki, T.; Atsushi, A.; Hosoi, T.; Sawabe, M. Reviewing the definition of "elderly". *Geriatr. Gerontol. Int.* **2006**, *6*, 149–158. [CrossRef]
6. McPhee, J.S.; French, D.P.; Jackson, D.; Nazroo, J.; Pendleton, N.; Degens, H. Physical activity in older age: Perspectives for healthy ageing and frailty. *Biogerontology* **2016**, *17*, 567–580. [CrossRef]
7. Cowley, A.; Goldberg, S.E.; Gordon, A.L.; Kerr, M.; Logan, P. Exploring rehabilitation potential in older people living with frailty: A qualitative focus group study. *BMC Geriatr.* **2021**, *21*, 165. [CrossRef]
8. Tijsen, L.M.; Derksen, E.W.; Achterberg, W.P.; Buijck, B.I. Challenging rehabilitation environment for older patients. *Clin. Interv. Aging* **2019**, *12*, 1451–1460. [CrossRef]
9. De Labra, C.; Guimaraes-Pinheiro, C.; Maseda, A.; Lorenzo, T.; Millán-Calenti, J.C. Effects of physical exercise interventions in frail older adults: A systematic review of randomized controlled trials. *BMC Geriatr.* **2015**, *2*, 154. [CrossRef]
10. Vigelso, A.; Gram, M.; Wiuff, C.; Andersen, J.L.; Hilge, J.W.; Dela, F. Six weeks aerobic retraining after two weeks immobilization restores leg lean mass and aerobic capacity but does not fully rehabilitate leg strength in young and older men. *J. Rehabil. Med.* **2015**, *47*, 552–560. [CrossRef]

11. Shanahan, C.J.; Boonstra, F.M.C.; Cofré Lizama, L.E.; Strik, M.; Moffat, B.A.; Khan, F.; Kilpatrick, T.J.; van der Walt, A.; Galea, M.P.; Kolbe, S.C. Technologies for advanced gait and balance assessments in people with multiple sclerosis. *Front. Neurol.* **2018**, *2*, 708. [CrossRef]
12. Buisseret, F.; Catinus, L.; Grenard, R.; Jojczyk, L.; Fievez, D.; Barvaux, V.; Dierick, F. Timed Up and Go and Six-Minute Walking Tests with Wearable Inertial Sensor: One Step Further for the Prediction of the Risk of Fall in Elderly Nursing Home People. *Sensors* **2020**, *20*, 3207. [CrossRef]
13. Beauchet, O.; Annweiler, C.; Montero-Odasso, M.; Fantino, B.; Herrmann, F.R.; Allali, G. Gait control: A specific subdomain of executive function? *J. Neuroeng. Rehabil.* **2012**, *9*, 12. [CrossRef] [PubMed]
14. Dismore, L.; Hurst, C.; Sayer, A.A.; Aspray, T.; Granic, A. Study of the older adults' motivators and barriers engaging in a nutrition and resistance exercise intervention for sarcopenia: An embedded qualitative project in the MilkMAN pilot study. *Gerontol. Geriatr. Med.* **2020**, *6*, 1–9. [CrossRef] [PubMed]
15. Boyle, P.A.; Buchman, A.S.; Wilson, R.S.; Leurgans, S.E.; Bennett, D.A. Association of muscle strength with the risk of Alzheimer disease and the rate of cognitive decline in community-dwelling older persons. *Arch. Neurol.* **2009**, *66*, 1339–1344. [CrossRef] [PubMed]
16. Kitayuguchi, J.; Kamada, M.; Inoue, S.; Kamioka, H.; Abe, T.; Okada, S.; Mutoh, Y. Association of low back and knee pain with falls in Japanese community-dwelling older adults: A 3-year prospective cohort study. *Geriatr. Gerontol. Int.* **2017**, *17*, 875–884. [CrossRef]
17. Gillespie, L.D.; Robertson, M.C.; Gillespie, W.J.; Sherrington, C.; Gates, S.; Clemson, L.M.; Lamb, S.E. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst. Rev.* **2012**, *9*, CD007146.
18. Bennett, J.A.; Winters-Stone, K. Motivating older adults to exercise: What works? *Age Ageing* **2011**, *40*, 148–149. [CrossRef]
19. Pilates, J.H. *Return to Life through Contrology*; Pilates Method Alliance Inc.: Miami, FL, USA, 2010.
20. Rogers, F.R.; Pilates, J.H. *The Pilates Pamphlet: Return to Life through Contrology*; American Foundation for Physical Fitness: Reston, VA, USA, 1957.
21. Falbo, S.; Condello, G.; Capranica, L.; Forte, R.; Pesce, C. Effects of physical-cognitive dual task training on executive function and gait performance in older adults: A randomized controlled trial. *BioMed Res. Int.* **2016**, *2016*, 5812092. [CrossRef]
22. Schmidt, J.A.; Gruman, C.; King, M.B.; Wolfson, L.I. Attrition in an exercise intervention: A comparison of early and later dropouts. *J. Am. Geriatr. Soc.* **2000**, *48*, 952–960. [CrossRef]
23. Culligan, P.L.; Scherer, J.; Dyer, K.; Priestley, J.L.; Guingon-White, G.; Delvecchio, D.; Vangeli, M. A randomized clinical trial comparing pelvic floor muscle training to a Pilates exercise program for improving pelvic strength. *Int. Urogynecol. J.* **2010**, *21*, 401–408. [CrossRef]
24. Watanabe, D.; Yoshida, T.; Watanabe, Y.; Yamada, Y.; Miyachi, M.; Kimura, M. Validation of the Kihon Checklist and the frailty screening index for frailty defined by the phenotype model in older Japanese adults. *BMC Geriatr.* **2022**, *22*, 478. [CrossRef]
25. Pilates Method Alliance. *The PMA Pilates Certification Exam Study Guide*; Pilates Method Alliance, Inc.: Miami, FL, USA, 2007.
26. Sarashina, E.; Mizukami, K.; Nagano, H.; Begg, R.K. Validity of Simple Health Assessments to Evaluate Locomotive and Cognitive Functions of Late-Stage Older Adults in Japan. *Int. J. Sports Exerc.* **2017**, *3*, 068. [CrossRef]
27. Begg, R.; Best, R.; Dell'Oro, L.; Taylor, S. Minimum foot clearance during walking: Strategies for the minimisation of trip-related falls. *Gait Posture* **2007**, *25*, 191–198. [CrossRef] [PubMed]
28. Smeesters, C.; Hayes, W.C.; McMahon, T.A. Disturbance type and gait speed affect fall direction and impact location. *J. Biomech.* **2001**, *34*, 309–317. [CrossRef]
29. Nagano, H.; Levinger, P.; Downie, C.; Hayes, A.; Begg, R. Contribution of lower limb eccentric work and different step responses to balance recovery among older adults. *Gait Posture* **2015**, *42*, 257–262. [CrossRef]
30. Bhatt, T.; Pai, Y.C. Prevention of slip-related backward balance loss: The effect of session intensity and frequency on long-term retention. *Arch. Phys. Med. Rehabil.* **2009**, *90*, 34–42. [CrossRef]
31. Crevin, S.T.; Wisniewski, S.; Noel-Storr, A.H.; Trevelyan, C.M.; Hampton, T.; Rayment, D.; Thom, V.M.; Nash, K.J.E.; Elhamoui, H.; Milligan, R.; et al. Mini-mental state examination (MMSE) for the detection of dementia in clinically unevaluated people aged 65 and over in community and primary care populations. *Cochrane Database Syst. Rev.* **2016**, *13*, CD011145. [CrossRef]
32. Kodama, A.; Suzuki, Y.; Sakuraba, K.; Kume, Y.; Ota, H. The effect of deep micro vibrotactile stimulation on cognitive function of mild cognitive impairment and mild dementia. *Int. J. Environ. Res. Public Health* **2022**, *19*, 3803. [CrossRef]
33. Tombaugh, T.N. Trail Making Test A and B: Normative data stratified by age and education. *Arch. Clin. Neuropsychol.* **2004**, *19*, 203–214. [CrossRef]
34. García-Garro, P.A.; Hita-Contreras, F.; Martínez-Amat, A.; Achalandabaso-Ochoa, A.; Jiménez-García, J.D.; Cruz-Díaz, D.; Aibar-Almazán, A. Effectiveness of a Pilates training program on cognitive and functional abilities in postmenopausal women. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3580. [CrossRef]
35. Moreno-Segura, N.; Igual-Camacho, C.; Ballester-Gil, Y.; Blasco-Igual, M.C.; Blasco, J.M. The effects of the Pilates training method on balance and falls of older adults: A systematic review and meta-analysis of randomized controlled trials. *J. Aging Phys. Act.* **2018**, *26*, 327–344. [CrossRef]
36. Sakairi, Y.; Nakatsuka, K.; Shimizu, T. Development of the two-dimensional mood scale for self-monitoring and self-regulation of momentary mood states. *Jpn. Psychol. Res.* **2013**, *55*, 338–349. [CrossRef]

37. Massy-Westropp, N.M.; Gill, T.K.; Taylor, A.W.; Bohannon, R.W.; Hill, C.L. Hand Grip Strength: Age and gender stratified normative data in a population-based study. *BMC Res. Notes* **2011**, *14*, 127. [CrossRef] [PubMed]
38. Moosabhoy, M.A.; Gard, S.A. Methodology for determining the sensitivity of swing leg toe clearance and leg length to swing leg joint angles during gait. *Gait Posture* **2006**, *24*, 493–501. [CrossRef] [PubMed]
39. Case, L.E.; Coats, J. Commentary on "Progression of ankle plantarflexion contractures and functional decline in Duchenne muscular dystrophy: Implications for physical therapy management". *Pediatric Phys. Ther.* **2019**, *31*, 67. [CrossRef] [PubMed]
40. Nagano, H.; Begg, R.K.; Sparrow, W.A.; Taylor, S. Ageing and limb dominance effects on foot-ground clearance during treadmill and overground walking. *Clin. Biomech.* **2011**, *26*, 962–968. [CrossRef]
41. Manckoundia, P.; Mourey, F.; Pérennou, D.; Pfitzenmeyer, P. Backward disequilibrium in elderly subjects. *Clin. Interv. Aging* **2008**, *3*, 667–672. [CrossRef]
42. Corti, E.J.; Johnson, A.R.; Riddle, H.; Gasson, N.; Kane, R.; Loftus, A.M. The relationship between executive function and fine motor control in young and older adults. *Hum. Mov. Sci.* **2017**, *51*, 41–50. [CrossRef]
43. Lim, E.-J.; Hyun, E.-J. The Impacts of Pilates and Yoga on Health-Promoting Behaviors and Subjective Health Status. *Int. J. Environ. Res. Public Health* **2021**, *18*, 3802. [CrossRef]
44. De Silva, L.D.; Shiel, A.; McIntosh, C. Pilates reducing falls risk factors in healthy older adults: A systematic review and meta-analysis. *Front. Med.* **2021**, *8*, 708883. [CrossRef]