

Supplemental Material

Exercise Program

The exercise program was based on the scientifically validated exercise protocol developed by the European Union funded “Vivifrail” project (9). This program aims to prevent frailty and falls and to increase PA among people ≥ 70 years of age. The “Vivifrail” exercise program offers four different intensity levels, which are selected based on the participants’ individual functional capacity. Allocation to the training program is based on the Short Physical Performance Battery (SPPB) and other functional tests (9). Each training program consists of 7-9 exercises targeting strength, balance, flexibility, and cardiorespiratory fitness. The home-based exercises are designed to be performed daily over a 12-week period, with each session lasting about 30–60 minutes. Participants were encouraged to adjust the intensity of each exercise using heavier weights, such as water bottles, or other training equipment, such as balls or ankle weights. At the beginning, participants received personal instruction on how to perform each exercise. In addition, all participants in the intervention group (IG) were provided with a manual containing written and illustrated instructions, information on exercise frequency, and guidance on how to increase intensity.

Telephone Coaching

In addition to the exercise program, participants received weekly telephone coaching from trained study staff throughout the 12-week intervention. The coaching was guided by principles of motivational interviewing and incorporated behavior change techniques (BCTs) (6). BCTs are clearly defined, observable, and replicable components of an intervention that are designed to change behavior. Telephone coaching focused on BCTs that have previously been shown to be effective in promoting PA and supporting cognitive and emotional functioning in older adults (4,5). Based on participants’ demographic characteristics, personal goals, and previous experiences, which were assessed at the start of the intervention, coaches selected and tailored the most appropriate BCTs to individual needs. The BCTs most frequently applied during the coaching sessions included: goal setting (behavior and outcomes), action planning, self-monitoring of behavior and behavioral outcomes, problem solving, feedback on behavior, information about health consequences, instruction on how to perform a behavior, behavioral practice, restructuring the physical/ social environment, graded tasks, and social support.

Coaching calls lasted approximately 20 minutes and followed a structured discussion guide. The aim of the motivational coaching was to help participants develop the ability to carry out the exercise program independently and to support long-term behavior change. Each participant was assigned the same coach for the duration of the intervention to ensure continuity and facilitate the development of a supportive coaching relationship. The structured coaching sessions included the following components:

- Monitoring adherence to and acceptance of the exercise program;
- Assessing current health status (physical function, pain);
- Tailoring the exercise program to individual needs;
- Providing education on the benefits of exercise training; and
- Delivering motivational support to encourage continued participation and long-term exercise behavior.

Physical Activity Assessments and Raw Data Processing

As part of the data processing, auto-calibration using local gravity as a reference and the sleep detection function were applied. The Euclidean Norm Minus One (ENMO, in milli-gravitational units [mg]) was calculated by taking the vector magnitude of the acceleration values on the x, y, and z axes and averaging them over 5-second epochs. This was then corrected for gravity by subtracting 1 g, with any negative values set to zero. Recordings with calibration error >0.06 g, less than 14 hours of valid wear time on at least 4 valid days, and without wear data present for each 15-minute period of the 24-h cycle present were excluded (7,8).

The average acceleration (AvAcc) is defined as the arithmetic mean of ENMO over the 24-hour period, expressed in milligravity units (mg). AvAcc serves as a reliable proxy for overall PA volume, integrating both intensity and duration (7).

The intensity gradient characterizes the distribution of PA intensity over a 24-hour period (7). It is derived as the slope of a regression line fitted to the natural logarithm of time spent in 25-mg acceleration bins against the natural logarithm of the midpoints of these bins (7). Intensity gradient quantifies the rate at which accumulated times decreases with increasing activity intensity and consistently yields negative values. Therefore, it provides a robust metric for assessing the intensity profile of daily PA (7,8).

Step count measures were derived using the OxWearables ‘stepcount’ algorithm version 3.12.0 (1). ‘stepcount’ applies PA behavior was classified using a validated machine learning framework developed for the UK Biobank, based on the approach described by Willetts et al., which applies balanced random forests and Hidden Markov models to wrist-worn accelerometer data (2,11). PA intensity was derived using the OxWearables ‘biobankAccelerometerAnalysis’ accelerometer processing pipeline version 7.5.0 applying further intensity categories described by Walmsley et al. (3,10).

Sample Size Calculation

An a priori sample size calculation was challenging because no previous study has investigated the effects of a comparable combined intervention (individualized exercise program and motivational interviewing) in older individuals (aged ≥ 70 years). Therefore, based on Fischer et al. (4), we assumed a small to medium effect size of 0.18 for our intervention, which would result in higher physical activity levels following the intervention compared with the control condition. A total of 28 participants were required for the final analysis to achieve 80% statistical power at a two-sided significance level of 0.05.

Supplementary Table S1

Descriptive statistics of baseline accelerometer measured physical activity variables in the overall sample. AvAcc=average acceleration; SD=standard deviation; Min=Minimum; Max=Maximum.

OVERALL SAMPLE (N=30)						
CHARACTERISTIC	MEAN	SD	MEDIAN	RANGE	MIN	MAX
OVERALL PHYSICAL ACTIVITY						
AvAcc (mg)	27.7	8.8	26.4	33.2	12.0	45.1
Intensity gradient	-2.813	0.186	-2.846	0.748	-3.152	-2.404
Walking time (min/day)	80.3	40.6	82.1	187.3	2.1	189.5
Daily steps (N)	5886	2908	6196	13483	121	13604
PHYSICAL ACTIVITY PHENOTYPES						
Sleep (%)	45.7	10.2	46.3	39.2	27.1	66.3
Sit/Stand (%)	34.3	6.7	35.4	26.0	20.9	46.9
Mixed-activity (%)	9.8	6.8	8.0	22.2	1.3	23.5
Walking (%)	6.9	3.8	7.1	11.6	1.2	12.9
Bicycling (%)	0.3	0.6	0.1	3.2	0.0	3.2
Vehicle (%)	2.9	2.7	2.2	14.6	0.2	14.8
PHYSICAL ACTIVITY INTENSITY						
Sedentary (%)	46.9	9.9	46.2	40.6	27.5	68.1
Light (%)	17.1	8.3	15.4	29.9	3.1	32.9
Moderate-vigorous (%)	1.1	0.9	1.0	3.4	0.0	3.4

Supplementary Table S2

Descriptive statistics of follow-up accelerometer measured physical activity variables in the overall sample. AvAcc=average acceleration; SD=standard deviation; Min=Minimum; Max=Maximum.

OVERALL SAMPLE (N=30)						
CHARACTERISTIC	MEAN	SD	MEDIAN	RANGE	MIN	MAX
OVERALL PHYSICAL ACTIVITY						
AvAcc (mg)	27.7	8.7	28.4	42.6	9.9	52.5
Intensity gradient	-2802	0180	-2812	0756	-3142	-2386
Walking time (min/day)	88.7	38.6	99.0	157.4	1.3	158.7
Daily steps (N)	6628	2978	7643	11294	76	11370
PHYSICAL ACTIVITY PHENOTYPES						
Sleep (%)	46.5	10.0	48.1	38.8	27.9	66.7
Sit/Stand (%)	33.0	7.3	33.5	36.1	11.5	47.6
Mixed-activity (%)	9.0	5.6	9.4	22.9	0.4	23.3
Walking (%)	7.6	3.9	7.5	15.2	0.4	15.6
Bicycling (%)	0.7	1.5	0.1	8.1	0.0	8.1
Vehicle (%)	3.2	2.5	2.9	9.8	0.0	9.8
PHYSICAL ACTIVITY INTENSITY						
Sedentary (%)	47.7	9.7	47.7	40.7	27.8	68.5
Light (%)	17.0	7.6	18.1	31.0	1.2	32.2
Moderate-vigorous (%)	1.9	2.2	1.5	10.0	0.0	10.0

Supplementary Table S3

Descriptive statistics of baseline accelerometer measured physical activity variables in the intervention group. AvAcc=average acceleration; SD=standard deviation; Min=Minimum; Max=Maximum.

OVERALL SAMPLE (N=30)						
CHARACTERISTIC	MEAN	SD	MEDIAN	RANGE	MIN	MAX
OVERALL PHYSICAL ACTIVITY						
AvAcc (mg)	26.9	8.0	24.0	25.8	13.7	39.5
Intensity gradient	-2833	180	-2862	598	-3135	-2537
Walking time (min/day)	91.6	37.3	83.5	139.1	50.4	189.5
Daily steps (N)	6719	2562	6534	9976	3627	13603
PHYSICAL ACTIVITY PHENOTYPES						
Sleep (%)	45.3	8.5	46.5	31.5	29.9	61.4
Sit/Stand (%)	33.8	6.7	34.5	26.0	20.9	46.9
Mixed-activity (%)	10.6	6.9	9.2	20.4	1.9	22.3
Walking (%)	6.8	3.0	6.6	10.6	1.6	12.2
Bicycling (%)	0.2	0.3	0.0	1.1	0.0	1.1
Vehicle (%)	3.4	3.6	2.2	14.6	0.2	14.8
PHYSICAL ACTIVITY INTENSITY						
Sedentary (%)	46.4	8.1	46.5	26.7	34.4	61.1
Light (%)	18.0	7.7	14.2	22.6	10.3	32.9
Moderate-vigorous (%)	1.2	0.7	1.2	2.5	0.2	2.7

Supplementary Table S4

Descriptive statistics of follow-up accelerometer measured physical activity variables in the intervention group. AvAcc=average acceleration; SD=standard deviation; Min=Minimum; Max=Maximum.

OVERALL SAMPLE (N=30)						
CHARACTERISTIC	MEAN	SD	MEDIAN	RANGE	MIN	MAX
OVERALL PHYSICAL ACTIVITY						
AvAcc (mg)	27.0	4.8	28.3	16.8	16.7	33.4
Intensity gradient	-2.812	0.151	-2.810	0.484	-3.036	-2.552
Walking time (min/day)	101.3	28.6	105.8	110.7	47.9	158.7
Daily steps (N)	7635	2164	7989	8068	3302	11370
PHYSICAL ACTIVITY PHENOTYPES						
Sleep (%)	45.8	7.0	48.2	26.1	31.8	57.9
Sit/Stand (%)	32.5	4.6	32.6	15.6	24.6	40.3
Mixed-activity (%)	8.4	4.2	10.1	13.1	2.1	15.2
Walking (%)	8.5	3.2	8.1	13.3	2.3	15.6
Bicycling (%)	0.9	2.1	0.2	8.1	0.0	8.1
Vehicle (%)	3.9	2.4	3.5	7.9	0.5	8.4
PHYSICAL ACTIVITY INTENSITY						
Sedentary (%)	47.1	6.5	47.9	26.9	32.4	59.3
Light (%)	17.4	5.1	18.6	14.0	10.4	24.4
Moderate-vigorous (%)	2.5	2.5	2.0	9.8	0.1	10.0

Supplementary Table S5

Descriptive statistics of baseline accelerometer measured physical activity variables in the control group. AvAcc=average acceleration; SD=standard deviation; Min=Minimum; Max=Maximum.

OVERALL SAMPLE (N=30)						
CHARACTERISTIC	MEAN	SD	MEDIAN	RANGE	MIN	MAX
OVERALL PHYSICAL ACTIVITY						
AvAcc (mg)	28.6	9.8	27.5	33.2	12.0	45.1
Intensity gradient	-2.792	0.196	-2.845	0.748	-3.152	-2.404
Walking time (min/day)	69.0	41.7	80.7	125.7	2.1	127.8
Daily steps (N)	5052	3076	5503	9100	121	9221
PHYSICAL ACTIVITY PHENOTYPES						
Sleep (%)	46.2	12.0	40.6	39.2	27.1	66.3
Sit/Stand (%)	34.9	6.8	36.2	21.6	21.8	43.4
Mixed-activity (%)	9.1	6.8	7.8	22.2	1.3	23.5
Walking (%)	7.0	4.6	7.9	11.6	1.2	12.9
Bicycling (%)	0.4	0.8	0.1	3.2	0.0	3.2
Vehicle (%)	2.5	1.4	2.2	4.7	0.4	5.1
PHYSICAL ACTIVITY INTENSITY						
Sedentary (%)	47.5	11.7	41.9	40.6	27.5	68.1
Light (%)	16.2	9.0	17.9	29.1	3.1	32.2
Moderate-vigorous (%)	1.0	1.1	0.8	3.4	0.0	3.4

Supplementary Table S6

Descriptive statistics of follow-up accelerometer measured physical activity variables in the control group. AvAcc=average acceleration; SD=standard deviation; Min=Minimum; Max=Maximum.

OVERALL SAMPLE (N=30)						
CHARACTERISTIC	MEAN	SD	MEDIAN	RANGE	MIN	MAX
OVERALL PHYSICAL ACTIVITY						
AvAcc (mg)	28.4	11.6	28.8	42.6	9.9	52.5
Intensity gradient	-2.792	0.209	-2.813	0.756	-3.142	-2.386
Walking time (min/day)	76.0	43.9	86.9	131.1	1.3	132.4
Daily steps (N)	5623	3394	7234	9649	76	9724
PHYSICAL ACTIVITY PHENOTYPES						
Sleep (%)	47.1	12.6	48.1	38.8	27.9	66.7
Sit/Stand (%)	33.4	9.5	35.7	36.1	11.5	47.6
Mixed-activity (%)	9.6	6.9	8.6	22.9	0.4	23.3
Walking (%)	6.8	4.5	6.7	13.6	0.4	13.9
Bicycling (%)	0.5	0.7	0.1	2.2	0.0	2.2
Vehicle (%)	2.6	2.5	2.2	9.8	0.0	9.8
PHYSICAL ACTIVITY INTENSITY						
Sedentary (%)	48.3	12.3	46.9	40.7	27.8	68.5
Light (%)	16.6	9.6	17.7	31.0	1.2	32.2
Moderate-vigorous (%)	1.3	1.6	0.4	4.9	0.0	4.9

References

- (1) Chan S, Small SR, Acquah A, Mertes G, Doherty A. Improved Step Counting via Foundation Models for Wrist-Worn Accelerometers. Version 3.18.2. Zenodo; 2026.
- (2) Doherty A, Jackson D, Hammerla N, et al. Large Scale Population Assessment of Physical Activity Using Wrist Worn Accelerometers: The UK Biobank Study. *PLoS One.* 2017; 12: e0169649. doi:10.1371/journal.pone.0169649
- (3) Doherty A, Smith-Byrne K, Ferreira T, et al. GWAS identifies 14 loci for device-measured physical activity and sleep duration. *Nat Commun.* 2018; 9: 5257. doi:10.1038/s41467-018-07743-4
- (4) Fischer X, Kreppke JN, Zahner L, Gerber M, Faude O, Donath L. Telephone-Based Coaching and Prompting for Physical Activity: Short- and Long-Term Findings of a Randomized Controlled Trial (Movingcall). *Int J Environ Res Public Health.* 2019; 16: 2626. doi:10.3390/ijerph16142626
- (5) Gilchrist H, Oliveira JS, Kwok WS, et al. Use of behavior change techniques in physical activity programs and services for older adults: findings from a rapid review. *Ann Behav Med.* 2024; 58: 216-226. doi:10.1093/abm/kaad074
- (6) Michie S, Richardson M, Johnston M, et al. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Ann Behav Med.* 2013; 46: 81-95. doi:10.1007/s12160-013-9486-6
- (7) Rowlands AV, Edwardson CL, Davies MJ, Khunti K, Harrington DM, Yates T. Beyond Cut Points: Accelerometer Metrics that Capture the Physical Activity Profile. *Med Sci Sports Exerc.* 2018; 50: 1323-1332. doi:10.1249/MSS.0000000000001561
- (8) Schwendinger F, Infanger D, Lichtenstein E, et al. Intensity or volume: the role of physical activity in longevity. *Eur J Prev Cardiol.* 2025; 32: 10-19. doi:10.1093/eurjpc/zwae295
- (9) Vivifrail. Materialien für Fachleute, die für die Verschreibung des Bewegungsprogramms verantwortlich sind. [Accessed July 10, 2026]. <https://vivifrail.com/de/unterlagen/>
- (10) Walmsley R, Chan S, Smith-Byrne K, et al. Reallocation of time between device-measured movement behaviours and risk of incident cardiovascular disease. *Br J Sports Med.* 2021. doi:10.1136/bjsports-2021-104050
- (11) Willetts M, Hollowell S, Aslett L, Holmes C, Doherty A. Statistical machine learning of sleep and physical activity phenotypes from sensor data in 96,220 UK Biobank participants. *Sci Rep.* 2018; 8: 7961. doi:10.1038/s41598-018-26174-1