Impact of a self-autonomous evaluation station and personalized training algorithm on quality of life and physical capacities in sedentary adults: a randomized controlled trial.

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Submitted to: JMIR Formative Research
on: January 02, 2023

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Abstract

Background: Physical inactivity is a major risk factor for noncommunicable diseases and the fourth leading cause of premature death worldwide. Nowadays, the World Health Organization (WHO) recommends performing at least 30 minutes of physical activity (PA) five times a week. However, these recommendations are independent on a person's age, gender or habits. In the field of sports performance, as well as in the clinical field, it is recognized that individualized training is more effective than general recommendations.

Objective: We hypothesized that an automatic personalized training program based on some initial physical evaluations would increase overall quality of life, quality of sleep, and physical capabilities, as well as reducing fatigue and depression, better than the WHO’s recommendations.

Methods: Our study was a 5-month randomized single-blinded controlled trial. One hundred and twelve sedentary or poorly active subjects were recruited and randomly split into two groups: personalized training (PT) or free training (FT). Physical capabilities and subjective measures such as quality of life, sleep, depression and fatigue were evaluated on both groups. After 1 month, both groups were asked to realize 150 minutes of PA per week for 4-months. To do so, PT group could either follow a “virtual coach” on a mobile application to follow some personalized PA or do what they would like to, while the FT group was to follow the general PA recommendations of WHO.

Results: We did not find any group × time interaction for PA duration or intensity, physical qualities and subjective measures between PRE and POST. However, considering both groups together, there were a significant time effect between PRE and POST for duration of PA (18.2 vs 24.5 min/day of PA, p<0.001), intensity (2.36 vs 3.11, p<0.001) and workload (46.8 vs 80.5, p<0.001). Almost all physical qualities were increased between PRE and POST, i.e. estimated VO2max (26.8 vs 29 mL.min-1.kg-1, p<0.001), flexibility (25.9 vs 26.9 cm, p=0.049), lower limb isometric force’s (328 vs 347 Nm, p=0.002), reaction time (0.680 vs 0.633 s, p<0.001), power output on cyclo-ergometer (7.63 vs 7.82 W, p<0.003) and balance for left and right leg (215 vs 163 mm2, p<0.003 and 186 vs 162 mm2, p=0.048 respectively). Finally, still considering PT and FT group together, there were a significant improvement of the mental component of quality of life, well-being, depression and fatigue between PRE and POST.

Conclusions: The individualized training was not more effective than general recommendations. A slight increase of PA (from 18 to 24 min/day) in sedentary or poorly active people is enough to observe a significant increase of the physical capabilities and a significant improvement of the quality of life, well-being, depression and fatigue. Clinical Trial: NCT04998266

(JMIR Preprints 02/01/2023:45461)
DOI: https://doi.org/10.2196/preprints.45461

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Impact of a self-autonomous evaluation station and personalized training algorithm on quality of life and physical capacities in sedentary adults: a randomized controlled trial.

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Abstract

Background: Physical inactivity is a major risk factor for noncommunicable diseases and a leading cause of premature death. The World Health Organization (WHO) recommends at least 150 minutes of moderate intensity physical activity (PA) weekly, regardless of age, gender, or personal habits. However, in both sports performance and clinical settings, personalized training regimens have shown superior efficacy over general guidelines.

Objective: We hypothesized that an automatic personalized training program, informed by initial physical evaluations, would increase overall quality of life, quality of sleep, and physical capabilities, and reduce fatigue and depression compared to adherence to WHO recommendations.
Methods: This 5-month randomized, single-blinded controlled trial involved 112 sedentary or minimally active participants, divided randomly into personalized training (PT) and free training (FT) groups. Physical capabilities and subjective measures such as quality of life, sleep, depression, and fatigue were evaluated on both groups. After 1 month, both groups were asked to realize 150 minutes of PA per week for 4-months. To do so, PT group could either follow a "virtual coach" on a mobile application to follow some personalized PA or do what they would like to, while the FT group was to follow the general PA recommendations of WHO.
Results: We did not find any group × time interaction for PA duration or intensity, physical qualities and subjective measures. However, considering both groups together, there were a significant time effect between PRE and POST for duration of PA (18.2 vs 24.5 min/day of PA, *P*<.001), intensity (2.36 vs 3.11, *P*<.001) and workload (46.8 vs 80.5, *P*<.001). Almost all physical qualities were increased between PRE and POST, i.e., estimated VO_2max (26.8 vs 29 $mL.min^{-1}.kg^{-1}$, *P*<.001), flexibility (25.9 vs 26.9 cm, *P*=.049), lower limb isometric force's (328 vs 347 Nm, *P*=.002), reaction time (0.680 vs 0.633 s, *P*<.001), power output on cyclo-ergometer (7.63 vs 7.82 W, *P*<.003) and balance for left and right leg (215 vs 163 mm^2, *P*<.003 and 186 vs 162 mm^2, *P*=.048 respectively). Finally, still considering PT and FT group together, there were a significant PRE to POST. improvement of the mental component of quality of life using SF-12 (41.9 vs 46.0, *P* <.006), well-being using WEMWBS (48.3 vs 51.7, *P* <.002), depression using CES-D (15.5 vs 11.5, *P* .024), and fatigue using FACIT-F (37.1 vs 39.5, *P* <.048).
Conclusion: The individualized training was not more effective than general recommendations. A slight increase of PA (from 18 to 24 min/day) in sedentary or poorly active people is enough to observe a significant increase of the physical capabilities and a significant improvement of the quality of life, well-being, depression and fatigue.

Trial registration: ClinicalTrials.gov NCT04998266. The University Hospital of Saint-Etienne (France) was the sponsor of this study.

Keywords: physical activity; sedentary behavior; quality of life; mobile health; health-related interventions; mobile application.

Introduction

Physical activity and health

Low level of physical activity (PA) and predominantly sedentary lifestyles are major risk factors for noncommunicable diseases such as cardiovascular disease, chronic obstructive pulmonary disease, cancer and type 2 diabetes [1–3]. Noncommunicable diseases are the foremost causes of death globally [4]. According to the World Health Organization (WHO) quoting the work of Lee at al. [5], physical inactivity is the cause of 5% of coronary heart disease, 7% of type 2 diabetes, 9% of breast cancers and 10% of colon cancers. Scientific data now clearly demonstrate the favorable effects of PA in the prevention of chronic pathologies [6]. In addition to its effects on physical health, PA is also recognized for its mental health benefits, with several studies showing that engaging in regular activity can reduce symptoms of depression and anxiety, which can also improve mood and help manage stress [7–9]. Last but not least, it has been shown that PA can improve overall sleep quality [10]. More specifically, sleep quality improved by 12% in a 1-year study where workers were encouraged to increase their PA using different challenges (number of steps using pedometer for example). The consensus is that regular PA markedly enhances quality of life [11,12].

The beneficial effects of PA on health and the harmful effects of a sedentary lifestyle have led to the development of recommendations to guide the population in acquiring an active and healthy lifestyle. For people aged 18 to 65, the recommendations from the WHO and from the American College of Sports Medicine are to perform moderate PA, at least 30 minutes a day, five times a week, for a total of 150 to 300 minutes per week, avoiding two consecutive days without PA [13]. However, to date, the threshold of a sedentary lifestyle harmful to health has not yet been clearly defined. According to Chau et al. [14], each additional hour spent in a seated position increases the risk of mortality by 2% between 3 and 7 hours of sedentary time and by 5% beyond 7 hours of sedentary time. In addition, PA improves the work performance of employees [15] and some recent surveys show that 53% of employees would welcome a sports offer from their company and that employees can increase their exercise time by as much as 34% when given a motivating and individualized program [16].

Despite all positive impacts of PA on health, there are many barriers to actually exercise, which explains why the level of PA in the general population remains low. Known barriers to PA across a range of settings include lack of time, fatigue, lack of knowledge, poor self-efficacy, lack of social support and self-motivation [17].

Technology and physical activities

Information and communication technologies appear to be a promising tool for providing recommendations, providing personalized follow-up and real-time feedback and *in fine*, improving compliance to PA requirements. Recent reviews and meta-analyses have found web- and smartphone-based interventions to be effective in increasing PA in the general population. Some studies have investigated whether new technologies could have a positive impact on the amount of PA. In their systematic review, Muntaner, Vidal-Conti, and Palou [18] show that half of the articles analyzed (6/12) show an increase in the level of PA through the use of applications on mobile phones. Davies et al. [19] showed in a meta-analysis that interventions delivered by internet can increase the amount of PA, both in sedentary people and in patients. More recently, the systematic review of Buckingham [20] shows that the use of "mHealth" (mobile health) is a good alternative for promoting PA at workplace. The COVID-19 pandemic has further underscored the significance of digital interventions in public health [21].

Personalized training

General PA recommendations are the same for everyone, regardless of age (at least between 18 and 65 years), gender, physical capacities, type of professional activity, body composition, etc.
Current general recommendations for physical activity emphasize the importance of engaging in at least 150 to 300 minutes of moderate-intensity aerobic activity per week, or 75 to 150 minutes of vigorous-intensity aerobic activity. Additionally, it is recommended to include muscle-strengthening activities on two or more days a week. These guidelines apply universally, regardless of age (specifically between 18 and 65 years), gender, physical capacities, type of professional activity, body composition, etc. This consensus is supported by numerous studies, including the one of Bull et al. [22], which provides comprehensive evidence on the health benefits of regular physical activity across diverse populations.
In the field of sports performance (e.g. [23]), as well as in the clinical field, it is recognized that individualized training is more effective than general recommendations. For example, it was shown that when PA is adapted to the symptoms, the reduction in the level of perceived fatigue was greater, in patients with cancer [24] or multiple sclerosis [25]. Brown et al. [24] suggested that exercise interventions need to be tailored based on health outcomes. Therefore, the recommendations of PA adapted and personalized to the deficits of the patients should lead to better quality of life than a classic PA intervention. We hypothesized that a tailored intervention should also be efficient in sedentary or poorly active people.

Profiling people

In order to tailor the training intervention to the physical capacities of the subjects, it is fundamental to appropriately evaluate them prior to the program [26]. For instance, the use of an objective method using an ergometer to assess aerobic capacity, rather than the use of a field testing (i.e., six minute walk test), has been proposed by Genin et al. [27]. We decided to also use objective measures of subjects' main physical capacities and capabilities to get the most accurate evaluation of their fitness level, identifying strengths and weaknesses with respect to gender and age.

Objectives

We hypothesized that an automatic personalized training program based on some initial physical evaluations would increase the overall quality of life, physical capabilities, and quality of sleep, as well as reducing fatigue and depression. The main objective of this study was to evaluate the effectiveness of our personalized intervention compared to applying the standard WHO recommendations.

Methods

Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki and approved by a national ethics committee (CPP Tours Ouest 1, approval number: 2021T2-19 HPS). Our study involved human subjects and adhered strictly to ethical standards for research. All participants provided written, informed consent prior to their involvement in the study. They were fully informed about the study's procedures, its purpose, the voluntary nature of their participation, and their right to withdraw at any time without any consequence. To protect participants' privacy and confidentiality, all personal data were anonymized. Access to these data was limited to researchers directly involved in the study. Instead of financial compensation, participants were allowed to keep the mobile application used during the study for ongoing personal use, free of charge. This application assists with physical activity, contributing to long-term health benefits for the participants. No individual participants are identifiable in any images or supplementary material associated with this manuscript.

Study design

This study was a 5-month randomized single-blinded controlled trial that entailed a 1-month observation period and a 4-month period of prescribed PA. Subjects were randomized 1:1 to either the intervention group or the control group.
The design of our study evolved from comparing two groups to a pre-post comparison for a single group (both groups pooled together).

Subjects and Recruitment

Enrollment and follow-ups were conducted between September 2021 and February 2022. Subjects were recruited through flyers and emails sent to employees of Jean Monnet university and “Conseil Général de La Loire” (Saint-Étienne, France) and via articles in local newspapers. The inclusion criteria were as follows: aged between 18 and 65, male or female, sedentary people (maximum one session of 1 hour of PA by week) sitting more than 3 hours a day and having smartphone or tablet access to the internet.
This study specifically excluded some populations due to safety considerations and relevance to the research objectives. Exclusion criteria included individuals with degenerative diseases, as the recommended physical activities might negatively impact their condition. Pregnant women were also excluded to avoid any potential risks associated with exercise during pregnancy. Subjects with cardiovascular issues were not included, considering the associated risks of physical activity under these conditions. Additionally, subjects unable to understand the study's procedures or providing informed consent were excluded to ensure ethical standards and the validity of the outcomes. Furthermore, all willing subjects were orally questioned to ascertain their level of sedentariness and inactivity, specifically if they remained seated for more than 3 hours per day, and if they engaged in less than one hour of physical activity per week. This information was crucial to identify individuals who met our study's criteria.

Eligible subjects underwent a medical examination with one of the doctors of the laboratory who, after checking that they could safely follow the study protocol, included them in the trial after the subjects provided informed consent. Right after this medical examination, randomization of the subjects was performed using a centralized secured management system, REDCap (Research Electronic Data Capture; Vanderbilt University). At registration, subjects were asked to download a custom-developed mobile application (Ionic/Angular JS application framework, available on iOS and Android) and to register an account. Initially, participants were required to complete five questionnaires through the mobile application, that aimed at gathering information on various subjective measures.

Measurements and Follow-up

The data collected during the study and follow-up were recorded using the mobile application and saved on the university server. Each month, exports were done to fill a centralized secured management system, REDCap, in accordance with ethical committee recommendations.
Each subject performed a medical check-in with a physician who gave a complete explanation of the study. Then, the subjects performed the physical assessment with the main instructor of the experiment (see Figure 1). Demographic variables gender, date of birth, height, body mass and percentage body fat using bioelectrical impedance (Tanita RD-545 HR, Tanita Corporation, Tokyo,

Japan) were also included.

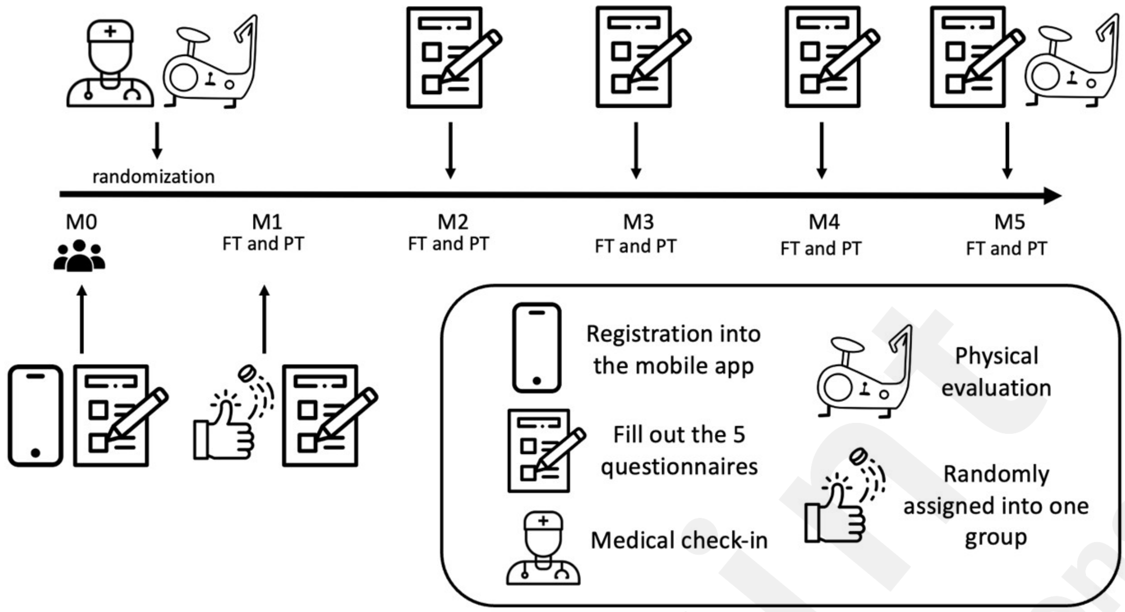

Figure 1 - Detailed study flowchart and timelines for sedentary adult participants : this figure illustrates the comprehensive process and timelines of our randomized control trial. Starting with enrollment (M0), sedentary adult subjects were recruited and underwent a medical examination to ensure eligibility. Following registration in the custom-developed mobile application, participants were asked to complete five questionnaires to capture baseline health data. After a physical evaluation (M0), subjects were randomly assigned into groups for the intervention. Each subsequent month (M1-M5) involved the same five questionnaires. A final physical evaluation was done at the end the study period (M5).

Objective physical capacities tests (station)

Physical fitness was evaluated in both groups based on the following 7 tests (Figure 2):
(i) Flexibility was measured with a custom, instrumented (Figure 2A) Sit and Reach Test [28] using linear encoder to measure the distance (Linear Encoder 1100mm, Phidgets Inc., Calgary, Canada). Subjects performed two trials separated by 30 s of rest.
(ii) Balance was assessed with a single leg balance test performed on both legs. The test consisted in staying as immobile as possible on one leg on a platform for 15 s while fixing a fixed point on the wall. Measurements were obtained using a customized stabilometry platform (Figure 2B, data was acquired at 62 Hz and was then filtered with a 4^{th} order low pass Butterworth filter at 20 Hz). The other leg was free in the air; the only rule was to not touch the other leg (i.e., the one standing on the custom platform). Subjects performed two trials by leg with 30 s of rest between tests. The 95% ellipse area (in mm^2) was computed, it represents the area covered in the ML (medio-lateral) and AP (antero-posterior) direction (an example the ellipse area is available in supplement material). It is considered to be an index of the overall postural performance; the smaller the surface, the better the performance [29].
(iii) Reaction time was evaluated using a custom test (Figure 2C) inspired from Zwierko et al. [30]. The test consisted of 6 units (ROXs Pro, Barcelona, Spain) placed on a semi-circle on the table. When these units lit up randomly one by one, the goal was to touch the lighted unit as fast as possible to turn it off. Each light was set to light up for a time between 0.1 and 3 s to avoid the subject getting used to a rhythm. A total of 22 touches was performed. The reaction time was computed for each correct touch. Subjects performed two trials with 1 minute of rest between trials.

(iv) Grip strength was measured on both hands using a custom dynamometer (Figure 2D, data were acquired at 62 Hz, an example of the data acquired is available in supplements materials) equipped of a gauge strain and designed to have the same size (i.e., 4.8 cm) as the Jamar (Sammons Preston, Rolyan, Bolingbrook, IL). Subjects performed 2 MVCs (maximal voluntary contraction) per side with 30 s of rest between trails and were vigorously encouraged to squeeze as hard as possible during each trial.
(v) VO_2max was indirectly evaluated using the test of Astrand [31], which is a submaximal effort of 6 minutes on a cyclo-ergometer (Figure 2E) (Monark LC6 novo, Varberg, Sweden). The estimated VO_2max was calculated using a nomogram that links the average heart rate and the average power output between minute 4 and 6. The nomogram is calibrated to gender and age.
(vi) A Force-Velocity test was performed on a friction-load cycle ergometer (Figure 2F) (Monark, Varberg Sweden) in order to measure maximal power. All features of the ergometer have been detailed in previous studies [32,33]. Briefly, the signal was acquired at 1000 Hz, and data was then filtered with a 4th order low pass Butterworth filter at 20 Hz (an example of the signal is in the supplement material of the paper). Subjects performed two sprints lasting 8s maximum, separated by a 2-min rest period, with friction loads of 0.3 and 0.4 $N.kg^{-1}$ body mass for women and 0.4 and 0.7 $N.kg^{-1}$ for men, respectively. They were vigorously encouraged to pedal as fast as possible during the entire sprint.
(vii) Knee extensors maximal strength was assessed on a dynamometric chair (Figure 2G) (ARS dynamometry, S2P, Ltd., Ljubljana, Slovenia). Data were acquired at 1000 Hz and filtered with a smoothing window of 0.005s (an example of the signal is available in supplement material of the paper). Subjects were seated in an upright position on the chair with both right knee and hips at 90° of flexion with chest and hips securely strapped. Subjects performed two 4-to5-s MVCs with 1-min of rest between trials. They were vigorously encouraged to force as intensely as possible during the task.

Figure 2 - Assessment equipment for measuring physical fitness in sedentary adults : this figure presents the seven tools utilized to evaluate the physical fitness of sedentary adults. These include A) a custom sit and reach device for flexibility measurement; B) a stabilometry platform to assess balance; C) a reaction time testing setup; D) a custom dynamometer for grip strength measurement; E) a cyclo-ergometer used for indirect VO2max estimation; F) a friction-load cycle ergometer for the Force-Velocity test; and G) a dynamometric chair for assessing maximal strength of knee extensors.

Subjective measurements (questionnaires)

Quality of life was assessed using the Short Form Health Survey-12 (SF-12; version 2). The SF-12 assesses functional limitations via 12 items. It consists of two subscales measuring physical health (physical component subscale) and mental health (mental component subscale). It rates the presence and severity of different impairments over the past four weeks. The following subjective measures were also assessed: fatigue using Functional Assessment of Chronic Illness Therapy – Fatigue, FACIT-F, quality of sleep using Insomnia Severity Index (ISI), well-being using the Warwick Edinburg Mental Well-Being Scale (WEMWBS) and depression using the Center for Epidemiologic Studies-Depression Scale (CES-D). Each questionnaire was to be completed every month for 5 months (see Figure 1).

Personalized training and free training

The intervention group (personalized training, PT) beneficiated, for 4 months, from a custom mobile application designed to automatically recommend personalized PA (this feature was called the "virtual coach"), aiming to help subjects achieve recommended levels of PA. An algorithm was developed to recommend PA sessions, considering the subject's profile (based on his/her physical capabilities evaluated beforehand, see supplements materials). The personalized PA sessions are based on predefined sequences of 10 minutes from a database of over 500 sequences, using approximately 100 different exercises (see an example in Figure 3).

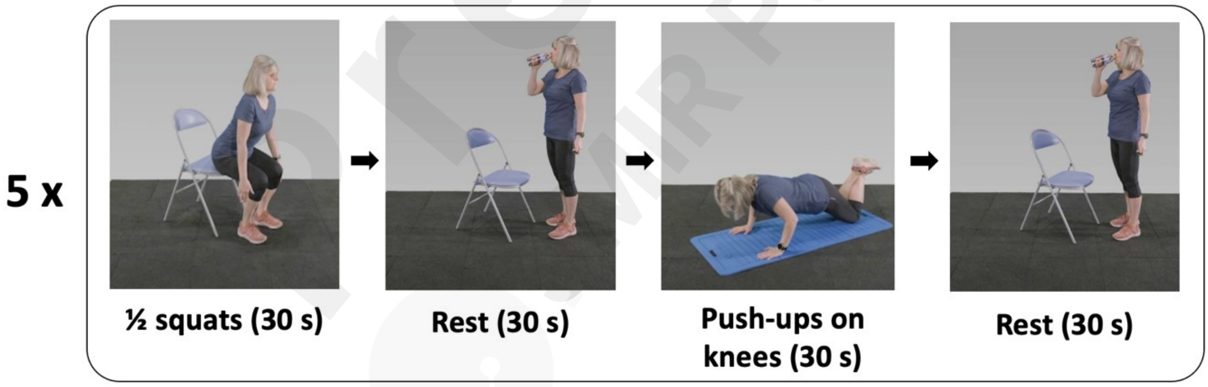

Figure 3 - Sample exercise sequence from the mobile application for home-based physical activity : a 10-minute home exercise sequence used in our study for enhancing physical capacity in sedentary adults. This example includes repeated cycles of ½ squats for 30 seconds, followed by a rest period of 30 seconds, push-ups on knees for 30 seconds, and another rest interval of 30 seconds, to be completed five times. The sequence is designed to be performed with minimal equipment, requiring only a chair and a mat, facilitating accessibility for participants.

Each sequence was classified according to its nature (aerobic, strength or balance) and difficulty. The algorithm selected the appropriate sequence based on the subject's physical capacities (see supplements materials) as well as the available sports equipment (such as dumbbells, Swiss ball, bands, bike ergometer, jump rope), location (indoor or outdoor) and the available/desired duration (multiples of 10 minutes, from 10 minutes to 60 minutes). Each sequence was composed of 1 to 3 different exercises. Each exercise was set either as a period of time (e.g., 30 s) or as a number of repetitions. Exercises were separated by periods of rest. For each exercise, the mobile app displayed a short explanation and a video showing how to perform the exercise properly (see Figure 4). After each sequence of 10 minutes, the rating of perceived effort (RPE) was to be reported using the Borg Scale [35]. RPE was considered by the algorithm for the next session; RPE ≤ 2 led to an increase of the difficulty in the following session, and to the opposite, an intensity ≥ 5 selected an easier next-session exercise. For further analysis, workload of each session was calculated as the RPE (i.e., intensity) multiplied by the duration. The home page showed the goal of 150 minutes of PA per week in order to follow the WHO's recommendations. A gauge was displayed and each time the subject was exercising, the gauge increases until she/he reached the goal (see Figure 4). If the subject exercised more than the goal, the displayed value increased but the gauge stayed full. In addition to the sessions recommended by personalized training, the subjects were also allowed to add their own activities on the mobile app, e.g., walking, cycling, swimming, rowing, fitness or gardening and housework. These activities were considered only if the duration was at least 10 minutes (Figure 4). Finally, the subject could perform some stretching sessions that were not considered as PA. So, the PT group was allowed to perform whatever they wanted to achieve the 150 minutes of PA each week, i.e., they could follow their desired percentage of the personalized training.

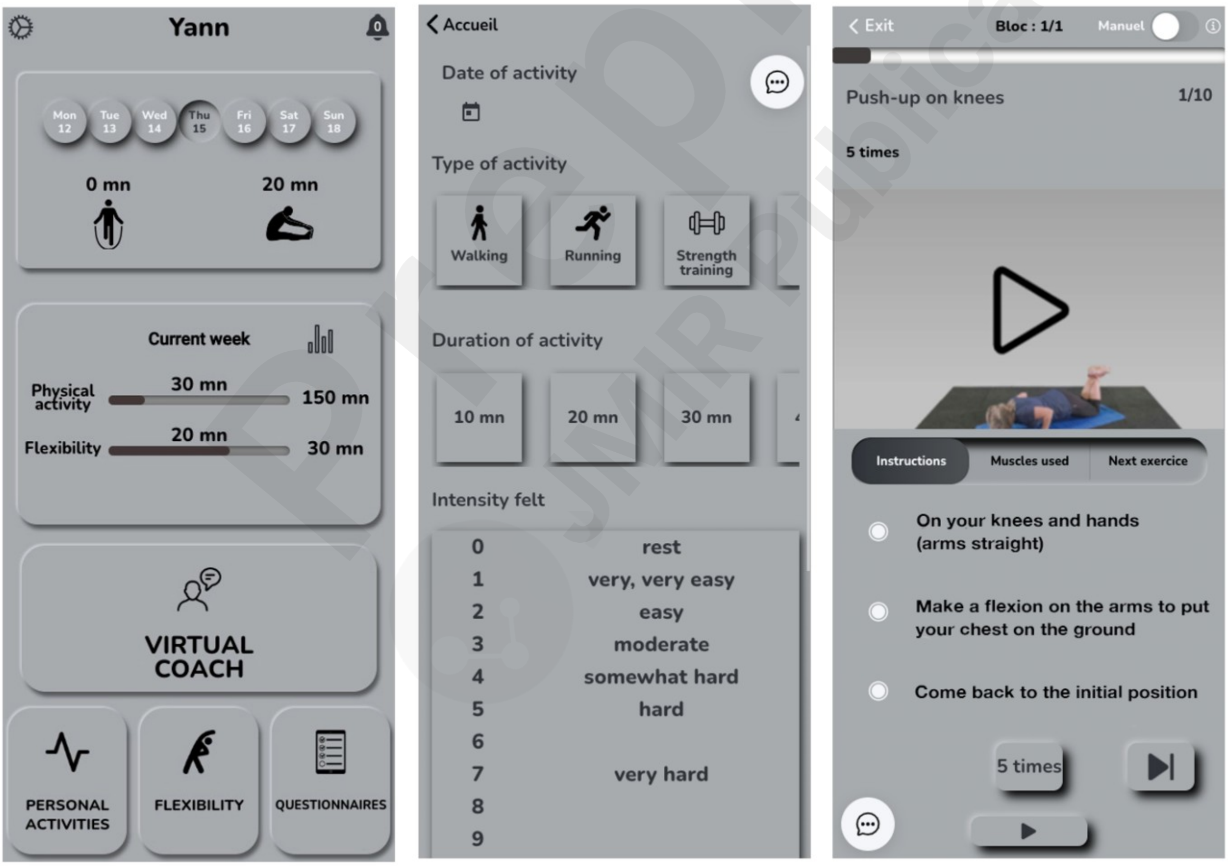

Figure 4 - This image showcases the mobile app developed for the study, displaying the home screen with gauges for tracking time spent on physical activity (PA) and stretching (left), a self-report section for PA input (middle), and a personalized virtual coach screen providing detailed exercise instructions (right). Screenshots are translated into English for clarity in this paper, and the color scheme has been adjusted for enhanced legibility. Original screenshots are available in the supplementary material.

Subjects allocated to the control group (free training, FT) received the same mobile application without the "virtual coach". The 150 minutes gauge was displayed on the home page as for the intervention group and the subjects had to add all their physical activities manually. To help them to reach their goal, the general guidelines (i.e., the goal is to reach 150 minutes of physical activities per week of aerobic exercises at moderate intensity and do some resistance training a least 2 times a week [36]) of PA were written in the mobile application.

Sample Size

Based on the hypothesis of a difference of 4.2 points [37] (± 5.8 [38]) in the variation of the SF-12 score between the two types of training, with an alpha risk of 2.5 (Bonferroni's correction, the score of SF-12 being composed of two sub-scores corresponding to physical and mental components) and a power of 90%, we initially calculated a requirement of 48 subjects per group. To accommodate an anticipated drop-out rate of 20%, we adjusted the number to 58 subjects per group, ensuring robustness against potential loss to follow-up.

The adjustment of the study (from comparing two groups to a pre-post comparison for a single group) changes the statistical power calculation. For the adjusted design, focusing on a power of 90%, a mean difference of 4.2 (as per Jayadevappa [37]), a standard deviation of 5.8, and an alpha of 0.025 (considering the Bonferroni correction for the SF-12's two components), the required sample size was 23 subjects. The initial sample rate calculation largely fits with the new design which makes the statistical analysis powerful enough.

Data Analysis

In order to keep the same duration between PRE and POST, we defined the POST period as the last 30 days counting backward from the POST date.

Statistics

Statistical analysis was performed with R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Results are expressed as mean and standard deviation (SD). Normality of the data was assessed via Q-Q plot and the Shapiro–Wilk test. The presence of outliers was evaluated using the interquartile range method. Mixed model analysis of variance (ANOVA) was computed with group (FT vs PT) as the between-group factor, and with time (PRE vs POST) as the within-subject factor.

For each ANOVA conducted, the Mauchly test was employed to assess sphericity for the dependent variables in within-group analyses. Levene's test was used to check the assumption of equality of variances for between-group analyses. The test was performed at each time frame, PRE and POST. To check the assumptions of the homogeneity of variances of the between-subject factor (FT vs PT) Box's M-test was used, with a significance threshold $\alpha=0.01$.

Bonferroni's corrections were only applied to pairwise comparisons to follow up a significant main effect for condition (i.e., time effect). When there was no time × group interaction, the main group effect (FT vs PT) or time effect (PRE, POST) was assessed using pairwise comparisons. Statistical significance was set at $P<.05$.

Finally, Pearson correlation coefficients have been computed between all variables (i.e., pre, post and pre-post variations of subjective measures, physical capabilities, physical activities) to check for correlation between any of these parameters.

Data availability

The data sets generated during and/or analyzed during this study are available from the corresponding author on reasonable request.

Results

Subjects

The recruitment was conducted from September 2021 to February 2022. A total of 112 subjects were enrolled and randomly assigned to either FT (n=54) or PT (n=58). Subjects' characteristics are presented in Table 1. The mean age of the sample was 45.1 (SD 9.05) and 74% of them were women (83).

Table 1 - Demographic and physical characteristics of study participants. This table summarizes the baseline demographic and physical attributes of the subjects involved in the study, categorized into two groups: those who received personalized training (n=58) and those who followed a free training program (n=54), with a combined total of 112 participants. Reported data include age, gender distribution, body mass, and body mass index (BMI), providing mean and standard deviation (SD), as well as median and range values for each group and the total cohort.

	Personalized Training (n=58)	Free Training (n=54)	Total (n=112)
Age (years)			
Mean (SD)	45.2 (9.02)	45.1 (9.16)	45.1 (9.05)
Median [Min, Max]	47.0 [22.0, 60.0]	46.0 [24.0, 59.0]	46.0 [22.0, 60.0]
Gender			
Women	45 (77.6%)	38 (70.4%)	83 (74.1%)
Men	13 (22.4%)	16 (29.6%)	29 (25.9%)
Body mass (kg)			
Mean (SD)	75.5 (16.6)	78.5 (18.3)	76.9 (17.4)
Median [Min, Max]	73.1 [49.4, 136.0]	74.7 [51.0, 118]	74.6 [49.4, 136.0]
Body Mass Index (kg/m²)			
Mean (SD)	26.7 (4.5)	27.4 (5.6)	27.0 (5.1)
Median [Min, Max]	26.2 [19.8, 39.6]	26.3 [18.9, 41.9]	26.2 [18.9, 41.9]

We observed a drop-out of 34% during the study, meaning that 74 subjects came back at the second physical evaluation (POST). Out of the 74 subjects who came back, 44 to 47 subjects (depending on the questionnaires) have filled-out the questionnaires at POST (less than 20 days before or after the second evaluation).

Duration, intensity, workload

There was no group × time interaction for PA duration (P=.055), intensity (P=.54) or workload (P=.21). However, PT group was doing less PA than FT at PRE (22.4 vs 14.6 min / day, P=.022, d=0.54) but not at POST (Figure 5), the assignment to groups at PRE was done independently from the level of prior PA. The PT group only used the personalized training 0.85 min/day (± 1.76).

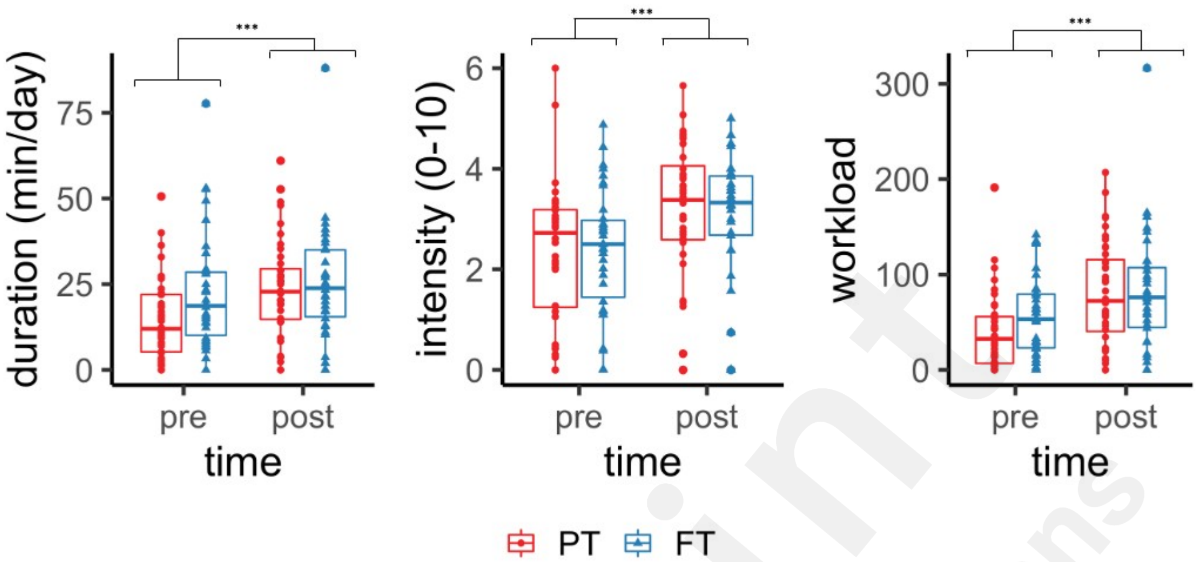

Figure 5 - Comparison of exercise duration, intensity, and workload in personalized vs. free training programs. This boxplot illustrates the variations in exercise duration (minutes/day), perceived intensity (scale 0–10), and total workload before and after the intervention for both personalized training (PT) and free training (FT) groups. Statistical comparisons are shown for the two time points (pre- and post-intervention) across the groups. Significant differences are indicated by asterisks.

Daily average duration, intensity and workload are presented in Table 2. There was a significant time effect for the average duration, intensity and workload.

Table 2 – Pre- and post-intervention changes in physical activity characteristics. The table displays the differences in daily exercise duration, intensity, and workload before and after the intervention among the participants (n=74). It reports mean and standard deviation (SD), median, and range values for each variable, along with the percentage change, p-value, and effect size to evaluate the significance and magnitude of the intervention's impact.

	PRE (n=74)	POST (n=74)	% change	P-value	Effect size
Duration (min/day)					
Mean (SD)	18.2 (14.8)	24.5 (15.3)	34.6%	< .001	0.403 (small)
Median [Min, Max]	15.6 [0, 77.7]	23.2 [0, 88.0]			
Intensity (0-10)					
Mean (SD)	2.36 (1.32)	3.11 (1.32)	31.7%	< .001	0.600 (moderate)
Median [Min, Max]	2.53 [0, 6.00]	3.34 [0, 5.65]			
Workload					
Mean (SD)	46.8 (41.1)	80.5 (57.5)	72%	< .001	0.647 (moderate)
Median [Min, Max]	35.3 [0, 191]	75.0 [0, 316]			

Questionnaires

There was no time × group interaction for any questionnaire but a time effect was found for the mental component (MCS) of SF12, Well-Being Scale (WEMWBS), CES-Depression and FACIT-F. For the FACIT-F, 40% of the subject were considered as “fatigued” (score ≤ 34) at PRE vs 18% at POST. No time effect was found for physical component (PCS) of SF12, nor for the Insomnia Severity Index (ISI).

Table 3 - Comparative analysis of questionnaire outcomes before and after the intervention. This table details the pre- and post-intervention scores for a suite of questionnaires assessing mental and physical health. Measurements include health-related quality of life (SF12 Mental and Physical Component Subscales), well-being (WEMWBS), depressive symptoms (CES-D), fatigue levels (FACIT-Fatigue), and sleep quality (Insomnia Severity Index). Data are presented as mean with standard deviation (SD), and median with range, alongside the percentage of change, p-values, and effect sizes for 74 participants.

	PRE (n=74)	POST (n=74)	% change	P-value	Effect size
SF12 (mental component subscale, n=47)					
Mean (SD)	41.9 (7.07)	46.0 (9.99)	9.8%	.006	0.415 (moderate)
Median [Min, Max]	42.4 [27.1, 55.7]	46.9 [19.0, 63.1]			
SF12 (physical component subscale, n=47)					
Mean (SD)	50.7 (6.61)	52.3 (6.37)	3.1%	.12	0.228 (small)
Median [Min, Max]	51.0 [35.8, 62.6]	54.6 [37.3, 59.6]			
Well-Being WEMWBS (n=47)					
Mean (SD)	48.3 (8.56)	51.7 (8.41)	7.0%	.002	0.484 (small)
Median [Min, Max]	50.0 [26.0, 67.0]	53.0 [33.0, 64.0]			
CES-Depression (n=45)					
Mean (SD)	15.5 (10.8)	11.5 (12.2)	-25.8%	.024	0.349 (small)
Median [Min, Max]	13.0 [0, 50.0]	6.00 [0, 46.0]			
FACIT-Fatigue (n=44)					
Mean (SD)	37.1 (8.73)	39.5 (8.71)	6.5%	.0483	0.306 (small)
Median [Min, Max]	39.0 [14.0, 51.0]	42.0 [19.0, 51.0]			
Insomnia Severity Index ISI (n=44)					
Mean (SD)	9.67 (5.39)	8.42 (5.79)	-12.9%	.08	0.265 (small)
Median [Min, Max]	10.0 [0, 24.0]	8.00 [0, 22.0]			

SF12: Short Form Health Survey, version 2; WEMWBS: Warwick Edinburg Mental Well-Being Scale; CES-D: Center for Epidemiologic Studies-Depression Scale; FACIT-F: Functional Assessment of Chronic Illness Therapy – Fatigue, ISI: Insomnia Severity Index

Physical capabilities

There was no time × group interaction for any physical quality but a significant increase was found for flexibility (*P*=.049, d=0.233), isometric force of the lower limb (*P*=.002,0.381), estimated VO_2max (*P*<.001, 0.404), reaction time (*P*<.001, 0.705), power output (*P*=.003, 0.355) and balance (both for left and right leg, *P*=.003, d=0.359 and *P*=.048, d=0.234 respectively). Surprisingly, a significant decrease was found on the handgrip strength (*P*<.001, d=0.537).

Table 4 - Changes in physical capabilities pre- and post-intervention. This table outlines the pre- and post-intervention values for physical capabilities of participants (n=74), including body mass, body fat percentage, flexibility, balance, reaction time, handgrip strength, estimated VO2max, maximal lower limb power (Pmax) and lower limb maximal force. The data show means and standard deviation (SD), median and range, with the percentage change, p-value, and effect size also indicated to reflect the impact of the intervention on physical health parameters.

	PRE (n=74)	POST (n=74)	%	P-value	Effect size
Body mass (kg)					
Mean (SD)	76.4 (17.1)	76.2 (16.8)	-0.3%	.54	0.071 (negligible)
Median [Min, Max]	74.3 [49.4, 136]	73.9 [50.2, 136]			
Body fat (%)					
Mean (SD)	26.3 (9.03)	27.1 (9.29)	3%	.13	0.178 (negligible)
Median [Min, Max]	26.4 [10.3, 50.6]	27.0 [8.70, 52.4]			
Flexibility (cm)					
Mean (SD)	25.9 (9.45)	26.9 (8.53)	3.9%	.049	0.233 (small)
Median [Min, Max]	26.7 [3.40, 45.2]	26.7 [11.7, 46.6]			
Balance - Ellipse Area left (mm^2)					
Mean (SD)	215 (194)	163 (138)	-24.2%	.003	0.359 (small)
Median [Min, Max]	151 [25.7, 886]	110 [19.1, 886]			
Balance - Ellipse Area right (mm^2)					
Mean (SD)	186 (137)	162 (156)	-12.9%	.048	0.234 (small)
Median [Min, Max]	152 [40.7, 795]	115 [29.4, 795]			
Reaction time (ms)					
Mean (SD)	0.680 (0.0630)	0.633 (0.0788)	-6.9%	<.001	0.705 (moderate)
Median [Min, Max]	0.680 [0.573, 0.861]	0.636 [0.416, 0.842]			
Handgrip strength (kg)					
Mean (SD)	68.6 (16.7)	65.7 (16.9)	-4.2%	<.001	0 .537 (moderate)
Median [Min, Max]	62.3 [41.1, 108]	60.6 [37.0, 106]			
Estimated VO_2max					

	PRE (n=74)	POST (n=74)	%	P-value	Effect size
(mL/min/kg) (n=73)					
Mean (SD)	26.8 (9.48)	29.0 (10.1)	8.2%	<.001	0.404 (small)
Median [Min, Max]	24.9 [7.06, 53.7]	28.4 [7.34, 54.6]			
Pmax (W/kg)					
Mean (SD)	7.63 (2.11)	7.82 (2.14)	2.5%	.003	0.355 (small)
Median [Min, Max]	7.02 [3.01, 13.0]	7.35 [2.88, 13.4]			
Lower limb isometric force (Nm) (n=73)					
Mean (SD)	328 (109)	347 (121)	5.8%	.002	0.381 (small)
Median [Min, Max]	308 [143, 614]	329 [158, 725]			

One subject did not complete the Astrand test at POST. The power output was set 50 W higher than at PRE because the subject's HR did not increase during the first minutes. For the balance test, three subjects fell at PRE (only for one side) and three subjects fell at POST (only for one side). In order to be able to analyze the data, the maximal value of the whole dataset for each fall have been inputted. For the leg extension, one subject did not complete the test at POST due to back pain. For the force-velocity profile, Pmax was associated with a r^2 of 0.871 and 0.896 at PRE and POST, respectively.

Link between variables

No correlations were found between the PRE/POST changes (Δ) objectives measures (i.e., physical capabilities) and the Δ subjective outcomes (i.e., questionnaires). There was a strong correlation between ΔCES-D and ΔWEMWBS (r=-0.76, *P*<.001). Correlations were also found between ΔCES-D and ΔSF12 (MCS) (r=-0.64, *P*<.001), ΔCES-D and ΔISI (r=0.57, *P*<.001), ΔCES-D and ΔFACIT-F (r=-0.58, *P*<.001), ΔSF12 and ΔWEMWBS (r=0.67, *P*<.001) and ΔFACIT-F and ΔISI (r=-0.59, *P*<.001).

Discussion

This study was conducted to evaluate the impact of a personalized intervention, comprising an initial physical assessment and a supportive mobile application, on self-reported outcomes such as quality of life, and objective physical capacities measurements. The key findings reveal that although the overall quality of life and the physical capacities significantly increased during the training period when the two groups were combined, no group effect was observed, meaning the PT group did not improve subjective and objectives measures significantly more than the FT. This lack of significant difference between groups may be attributed to the limited engagement with the personalized training program.

Duration, intensity, and workload of the training interventions

A significant increase in PA duration, intensity and total workload was observed during the four months of the study. We recruited subjects who self-declared being poorly active (i.e., less than 1 hour of PA per week). However, 18.2 minutes of PA per day were reported at PRE, i.e., 127 minutes per week, which is more than what was expected, although still 23 minutes below the cutoff between active and inactive. Several reasons can explain this result. First, the subjects were asked to add manually everything they were doing (walking, cleaning the house, gardening, etc.) and they were probably initially not considering this type of activity as PA. Secondly, a large variability of PA was observed (SD=14.8 minutes per day), meaning that many subjects matched perfectly our criteria whereas others did not. In order to determine if this relatively high volume of PA at PRE had an impact in our analysis, we performed the same analysis (mixed model, i.e., 2-way ANOVA PRE-POST × PT/FT) without subjects reporting more than 150 minutes of PA per week at PRE. The main conclusions were the same, i.e., a time effect was found but there was no time × group interaction. Finally, what could have led to this relatively high volume of PA at PRE is the Hawthorne effect [39] since the subjects self-reported their PA, making them potentially subject to social desirability [40]. In other words, because the subjects were observed, they may have manually added more PA than what they were doing. This effect is unlikely to have an effect on the difference of PA between PRE and POST, but the volume of PA itself may have been impacted.

The difference between PRE and POST could actually have been even higher. In fact, some subjects mentioned that after reaching the goal of 150 minutes of PA per week, they stopped entering their PA in the mobile application, despite the guidelines. As a result, the true difference between PRE and POST in terms of PA duration may have been artificially reduced. In addition, we have observed a decrease of house-cleaning time between PRE and POST which is probably due to the fact that people considered this activity as PA at PRE but no longer included it at POST, which is in line with our results showing a significant increase in PA intensity. Therefore, we can speculate that if 100% of PA had been manually entered in the mobile application, the difference between PRE and POST would have been greater.

We did not observe any time × group effect for the PA duration, which was not totally unexpected since we asked both groups to complete at least 150 minutes of PA each week. Yet a slightly greater volume in the PT group was anticipated since they had a personalized training which is more motivating as noted by Jirathananuwat and Pongpirul in their systematic meta-review about promoting PA in the workplace [41]. In summary, both the total duration of PA and the intensity of exercise were significantly greater at POST, which obviously led to a significant increase of the total workload.

A 34% drop-out was observed in the present study (74 subjects came at POST vs 112 at PRE), which is in accordance with the literature. For instance, a 37% drop-out was observed in a pilot study using smartphone technology to reach 150 minutes of PA per week with the goal of losing weight in an program on obesity [42]. [43] observed a 29% drop-out between PRE and POST (5 months) for an onsite PA program where a coach was coming in the company to coach workers 2 times a week. Jakobsen et al. [44] asked tertiary employees to exercise five times per week (10-minute sessions) for 10 weeks and observed a dropout rate of 22%.

Questionnaires

In the present study, the mental component of quality of life (MCS-SF12) was improved after four months of training in both groups. The benefits of PA on mental health have been demonstrated in many papers (e.g. [45,46]) which matches the findings of the present study that also showed a significant decrease of depression level (CES-D). A significant increase in well-being (WEMWBS) was also found following four months of more active lifestyle, which is in accordance with the literature as well [47]. Similarly, an inverse relationship between fatigue and the level of PA has been reported in the general population [48,49] and it has been shown that PA intervention is the best method to reduce fatigue in chronically fatigued patients [44]. Again, our FACIT-F findings are in line with these results.

It has been shown that PA can improve overall sleep quality [10], a result that was not observed in this work. Although validated, the use of self-reported questionnaires to assess sleep quality (ISI), as well the relatively low increase in the level of PA, may explain the lack of significant beneficial effect of PA on sleep quality. It is important to mention that the present study took place between

2021 and 2022, i.e., during the COVID-19 pandemic. In the present work, low values of the mental component of the SF12 have been reported, although a significant increase between PRE and POST was observed. Those low values are in line with the decrease of the quality of life in the general population [50–52] due to the COVID-19 pandemic. In France, the national institute of statistics has published data showing that in 2021, the quality of life of the general population was at its lowest for the last decade [53]. Finally, we did not observe a significant increase in the physical component of the SF-12, despite increases in the individual physical qualities themselves (see below).

Physical capabilities

The slight increase in the level of PA was enough to induce improvement in most physical capabilities in the inactive population involved in the present study. An 8.3% increase of VO_2max, evaluated with a valid and reliable method [54], was found between PRE and POST. This in line with the literature [55–57], although this increase is generally associated with high intensity interval training (HIIT) [58] or polarized training [59] with high volumes of aerobic exercise. The present work shows that for inactive people with low VO_2max values, this important physiological outcome can be increased by being slightly more active. All but one of the other physical qualities were significantly increased between PRE and POST. This finding was previously found in a study on tertiary employees who practice two PA sessions per week for a period of 5 months, thereby significantly increasing their overall level of fitness (cardiovascular, upper and lower body strength and balance) [60]. Strength training appears to offer aging adults many physiological benefits such as increased muscle mass [61]. Increased strength has been shown to help individuals maintain their daily functioning and mobility as they age [62], suggesting that strength training may positively affect quality of life. Moreover, muscular weakness associates with lack of balance (in the present study, the balance score improved by 10.9%) which correlates with an increased risk of falls [63,64]. Also, flexibility increased by 3.9% in this study, whereas lack of flexibility is associated with a higher incidence of muscular injury and a greater flexibility favors decrease of back pain [65].
The only objective outcome that was not positively associated with the training intervention was grip strength which decreased between PRE and POST. This result can be explained by methodological issues related to the handgrip size. In fact, it has been shown in the literature that handgrip size could lead to different results [66] explained by the force-length relationship [67]. In the present study, a custom handgrip was used, that included the possibility to change handgrip size. An error was made with the settings of the handgrip between PRE (handgrip size to 4.8 cm) and POST (5.2 cm). Also, no decrease in body weight or body fat was observed in the present study, which is in accordance with [68]. These authors explained that weight loss is associated to large volume of aerobic exercise, which is not what asked to the subjects in the present study.

Limitations

A limitation of our study was the management of automatic reminders and the collection of questionnaire data. Despite our efforts to systematize the process and allow participants to complete questionnaires autonomously, we observed variable response rates, with 44 to 47 subjects filling out the questionnaires at POST (less than 20 days before or after the second evaluation), depending on the questionnaire. This variability was partly due to some participants forgetting to complete one of the questionnaires. Given the fully autonomous design of the study, we were not allowed to directly remind them to fill out the missing questionnaires. Additionally, the automatic reminder system was based on the participant's last response, meaning that any delay in completing the questionnaires resulted in a subsequent delay in sending follow-up reminders. For the POST evaluations, we selected the questionnaire that was completed closest to the evaluation day, arbitrarily setting a cut-off of 20 days. We recommend future researchers conducting fully automated studies to set specific dates for questionnaire completion to minimize accumulated delays, and to consider conducting the

POST questionnaire on the day of evaluation to ensure more consistent and reliable data collection. A second limitation is that PA level was self-reported. Actigraphy could have led to a more objective assessment of PA level, yet it was not possible due to the number of subjects enrolled. A third limitation is the low use of the "virtual coach" for the PT group. Participants were asked to get at least 150 minutes of PA each week, whereas the use of the "virtual coach" was recommended but not mandatory. It appears that lot of subjects were highly motivated to be enrolled in this study, but most of the subjects of the PT group took part in some personal PA, on their own or by going to some clubs, and did not use the "virtual coach". This may be partly due to the way exercises were presented in the mobile application. More work is needed to determine whether or not the PT program can lead to more optimized beneficial effects than a traditional one. For instance, a better gamification in the app could be proposed and the way the mobile application adjusts the intervention to the weakness of the subject must be improved.

Conclusion

To the best our knowledge, this study is unprecedented in its provision of a fully automated, web-based program that tailors to individuals based on their initial physical assessments. The low use of the personalized training in the PT group likely explains why the subjects did not improve subjective and objectives measures significantly more than the FT. Enhancements to the virtual coach's appeal are necessary before a definitive conclusion about PT can be made. Notably, participants expressed satisfaction with their study involvement, anticipated to foster greater motivation and consistency in their daily activities—an insight derived from a post-study survey with a 60% response rate. Ultimately, a small (i.e., 6 minutes per day) but significant increase of daily PA was observed in the present study, regardless of the type of intervention, i.e., personalized, or free training. A slight increase of exercise intensity was also found, leading to an overall increase in the workload. These slight changes were enough to improve quality of life, well-being and to decrease fatigue and depression level in this sedentary or poorly active population. Moreover, improvements in physical capacities across the board underscore the notion that even slight increases in PA can profoundly influence overall fitness.

Acknowledgments

The authors would like to thank Dr T. Besson and A. Ravel for their help with the PRE and POST measurements. Also, we would like to thank Dr D. Rimaud for helping writing the ethics application, E. Romdan for participating in the development of the mobile application and C. Rogers for the revision of the English language.

Conflicts of Interest

None declared

Abbreviations

CES-D: Center for Epidemiologic Studies-Depression Scale
FACIT-F: Functional Assessment of Chronic Illness Therapy
FT: Free Training
HIIT: High Intensity Interval Training
HR: Heart Rate
ISI: Insomnia Severity Index
PA: Physical Activity
PT: Personalized Training
RPE: Rating of Perceived Effort
SF12: Short Form Health Survey-12
WEMWBS: Warwick Edinburg Mental Well-Being Scale
WHO: World Health Organization

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Supplemental materials

Custom mobile application

For the purpose of the project, a custom mobile application was developed in order to obtain self-declarations of physical activity (PA) but also to propose the personalized training program (i.e., the "virtual coach"). The mobile application also included questionnaires to be filled out. In the following explanation, "users" are the subjects of the present study.

Personalized training (PT)

A user profile was computed, based on the physical evaluation. Using some standard norms (VO_2max [69], handgrip [70]) and some subjectively determined norms (balance and leg extension), scores between 0 and 100 were established for each physical quality (endurance, strength and balance) of the users. The score 100 can been defined as being the "optimal value" of being perfectly in shape for a given gender and age. By definition, it is therefore possible to get more than 100 for a relatively active person.

About 500 sequences of physical activity lasting 10 minutes, composed from 1 to 3 different exercises, were created by a fitness coach. The coach assigned to each of them 3 scores between 0 and 100 for endurance, strength and balance. The sum of the 3 scores should be 100. For example, 10 minutes of running was codified as (100,0,0) since it develops "only" endurance. Also, for each sequence, a level between 1 and 20 has been assigned; 1 for beginner and 20 for advanced users.

The user had to set the mobile app, describing the fitness equipment he/she had, such as dumbbells (or a bottle of water), Swiss ball, bands, bike ergometer, jump rope, steps).

In order to use the personalized training, the user has to click on the 'virtual coach" button and to choose the duration of the session (by slots of 10 minutes) and the place (inside or outside) (see Error: Reference source not found). Then, the algorithm matched the user's profile with the most appropriate sessions, i.e., the sessions that will maximize the improvement in the 3 physical components (endurance, strength and balance).

For each of the 500 sequences in the database, the algorithm computed the expected user profile if the user would do the sequence, and ranks the sequences depending on the distance between the expected user profile and the final goal: 100,100,100. The level of the sequence was also considered in order to adjust its difficulty to the level of the user. Finally, after each sequence the user estimated the RPE (Rating of Perceived Effort), which is a value between 0 and 10 (0 meaning the sequence was really too easy and 10, the session was really hard). The RPE allows the algorithm to adapt the user's level. When the RPE was between 3 and 5, meaning that the intensity of the session was appropriate, the difficulty of the proposed sequences did not change. However, if the RPE was < 3, meaning the session was too easy, the difficulty of the sequences was increased. On the opposite, if the RPE was > 5, the difficulty of the sequences was decreased. Using this method, the algorithm tended to propose sequences that had an appropriate level.

Examples of the acquired signals

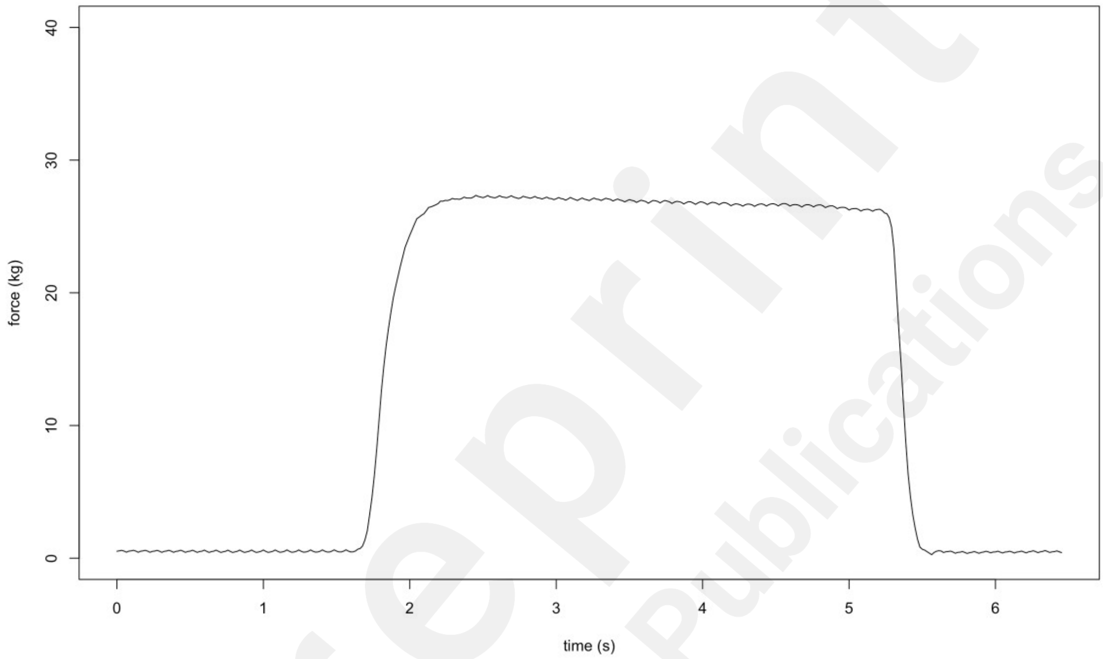


Figure 6 - Example of the signal acquired for the handgrip test

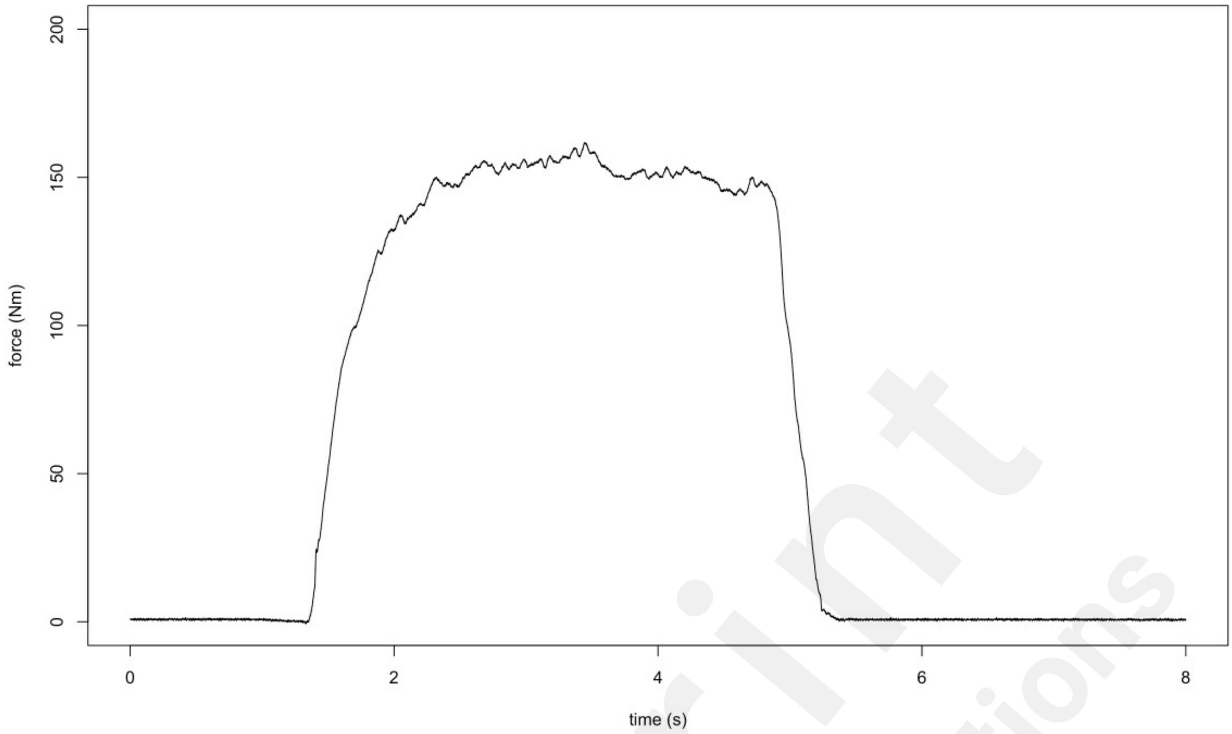


Figure 7 - Example of the signal acquired in the leg extension test

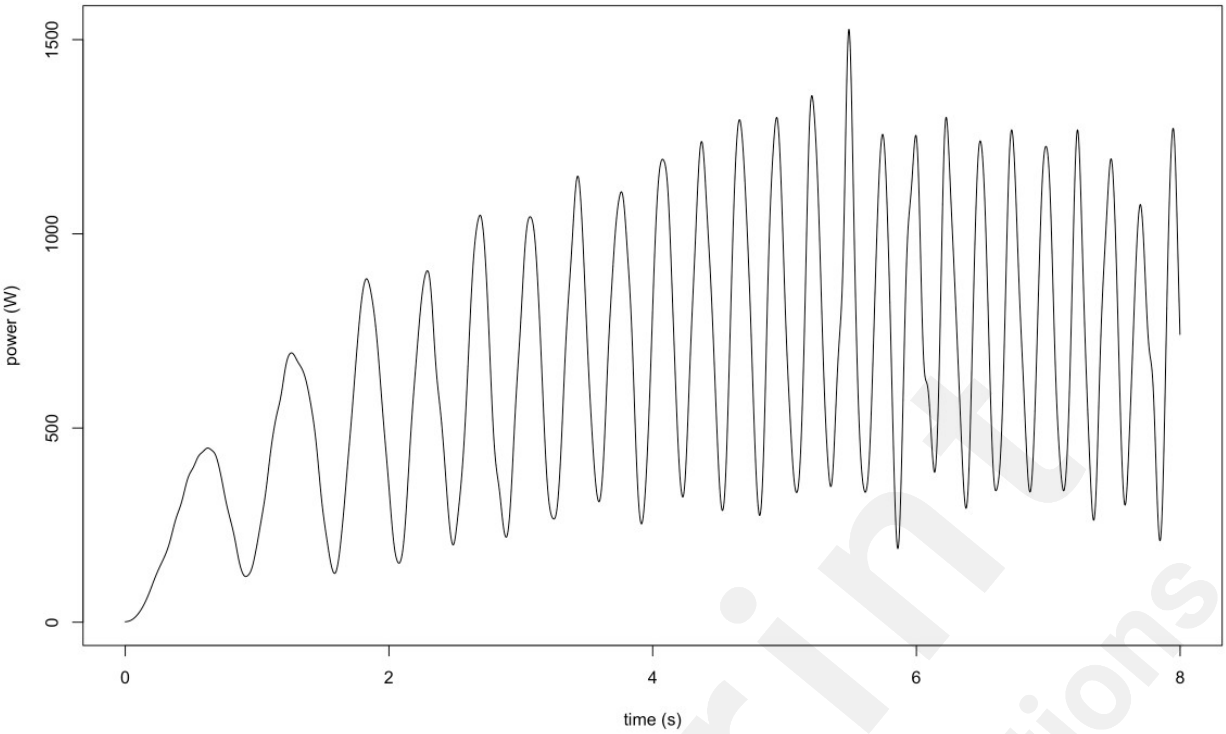


Figure 8 - Example of the signal of the force-velocity test

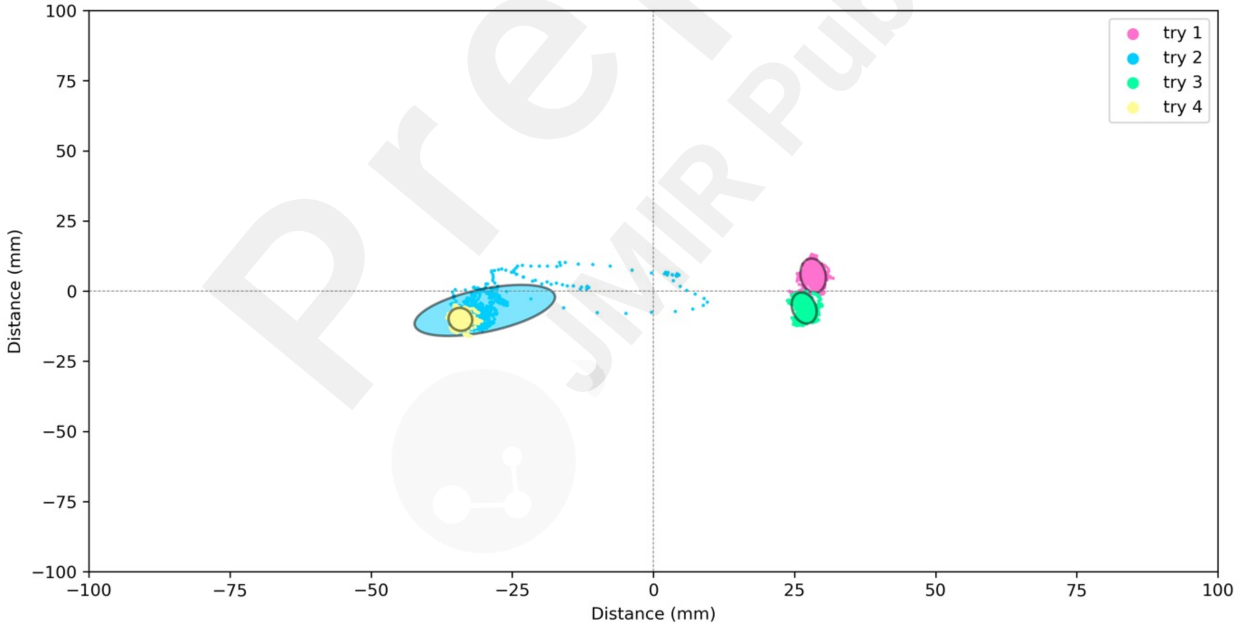


Figure 9 - Example of the ellipse area for the balance test

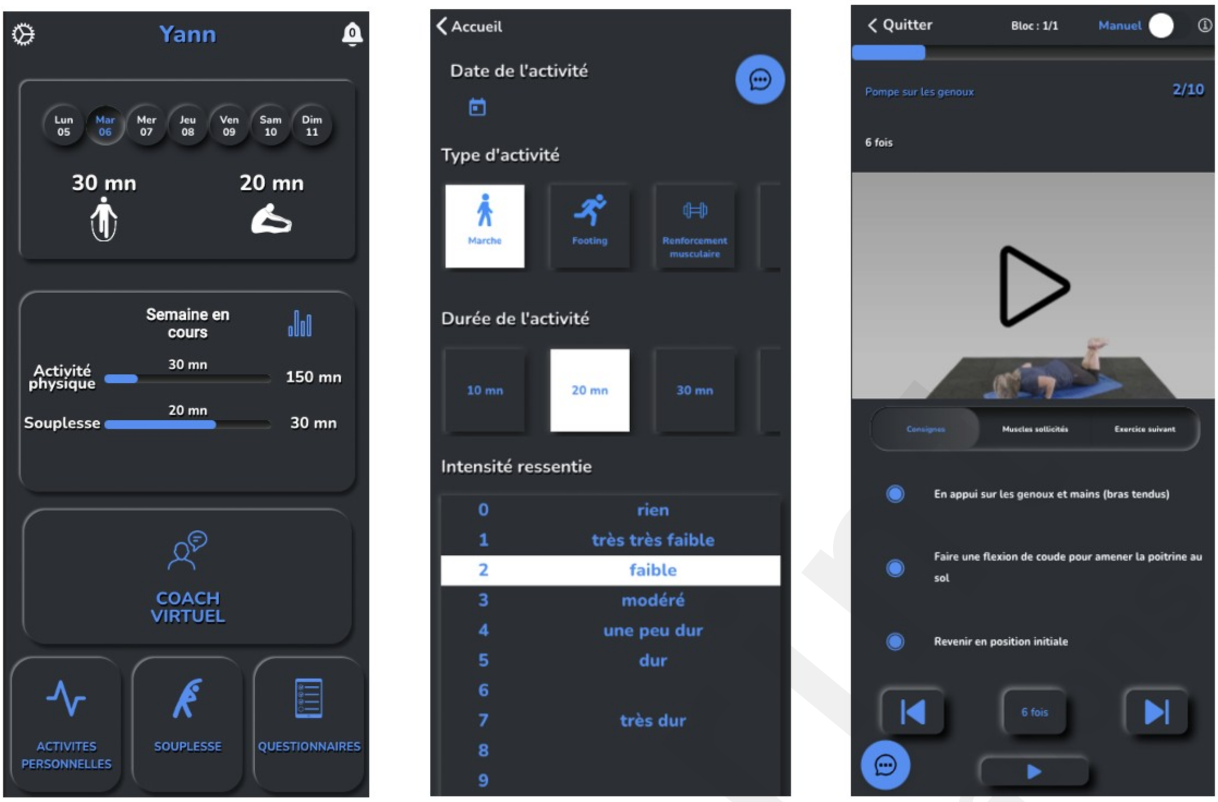
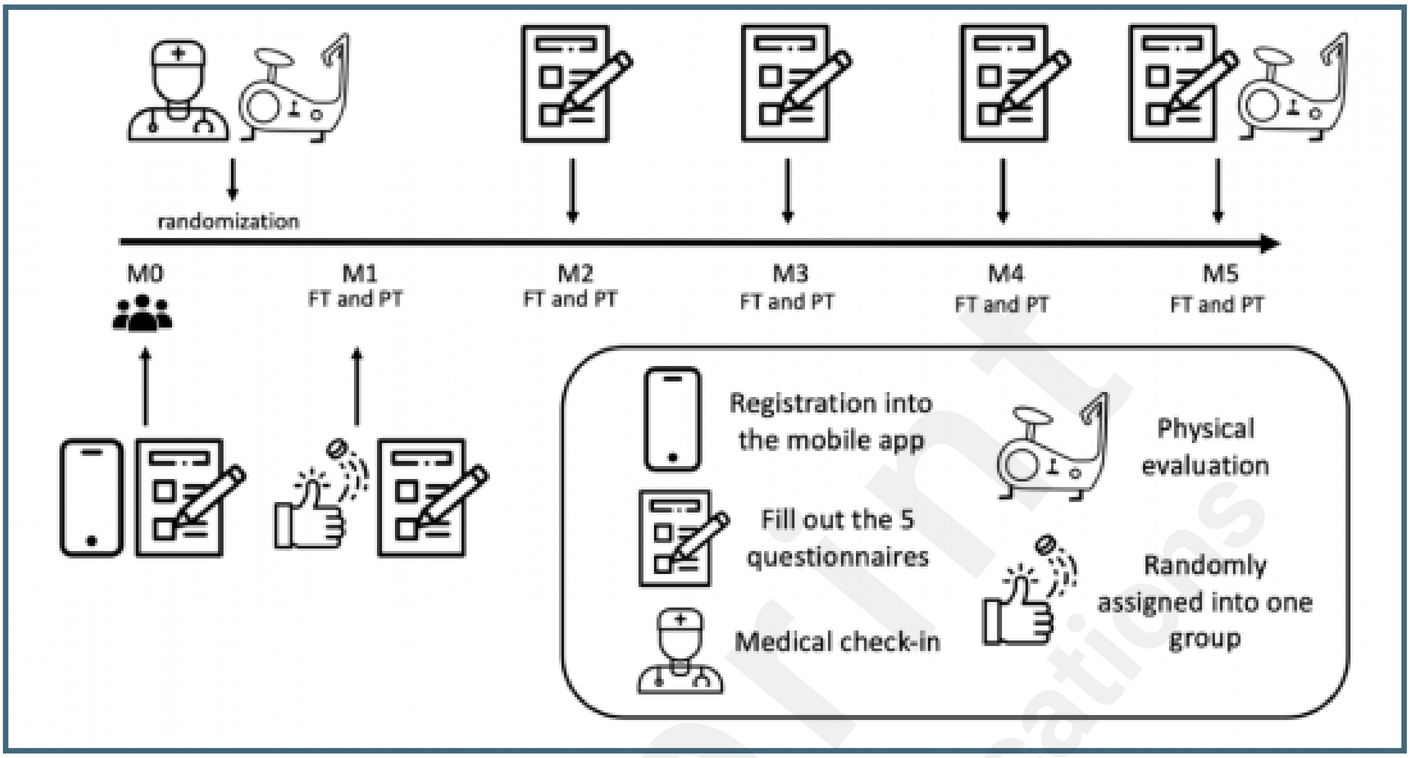


Figure 10 - Original screenshots of the mobile app

Supplementary Files

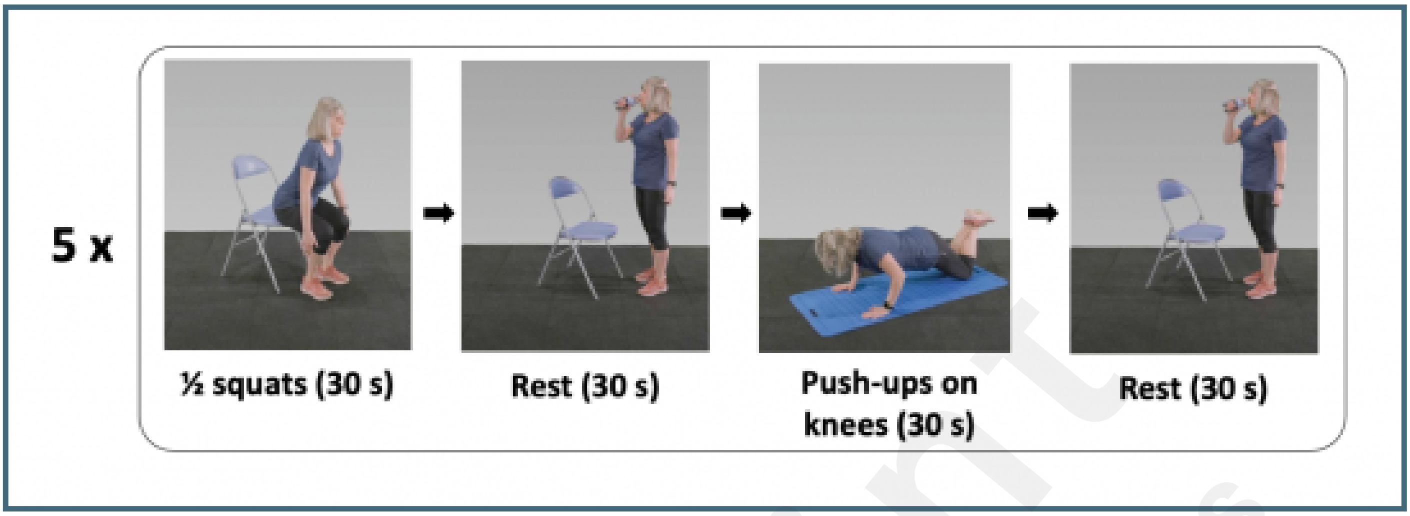
Figures

Overview of the study.

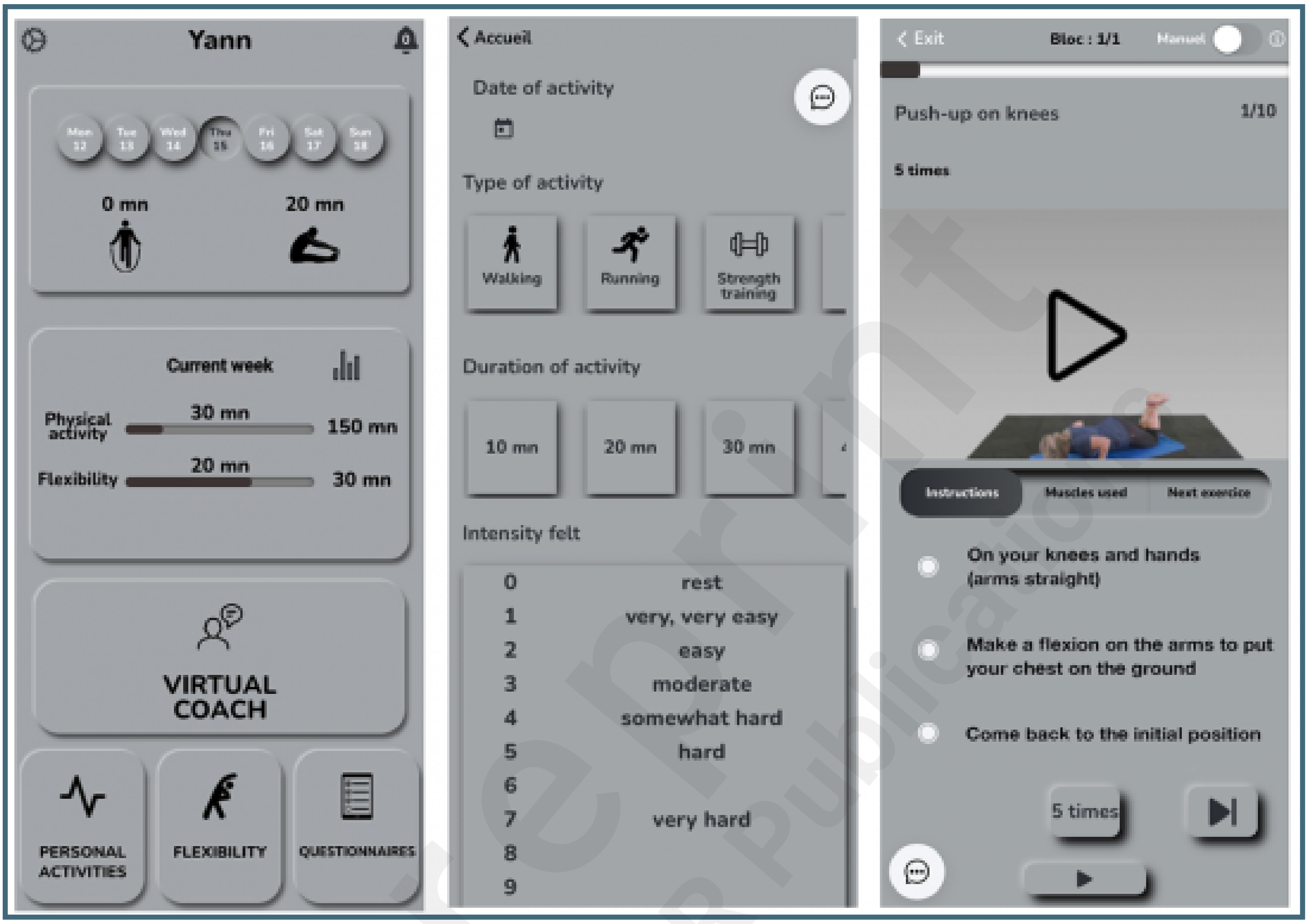


Tools used for physical evaluation.

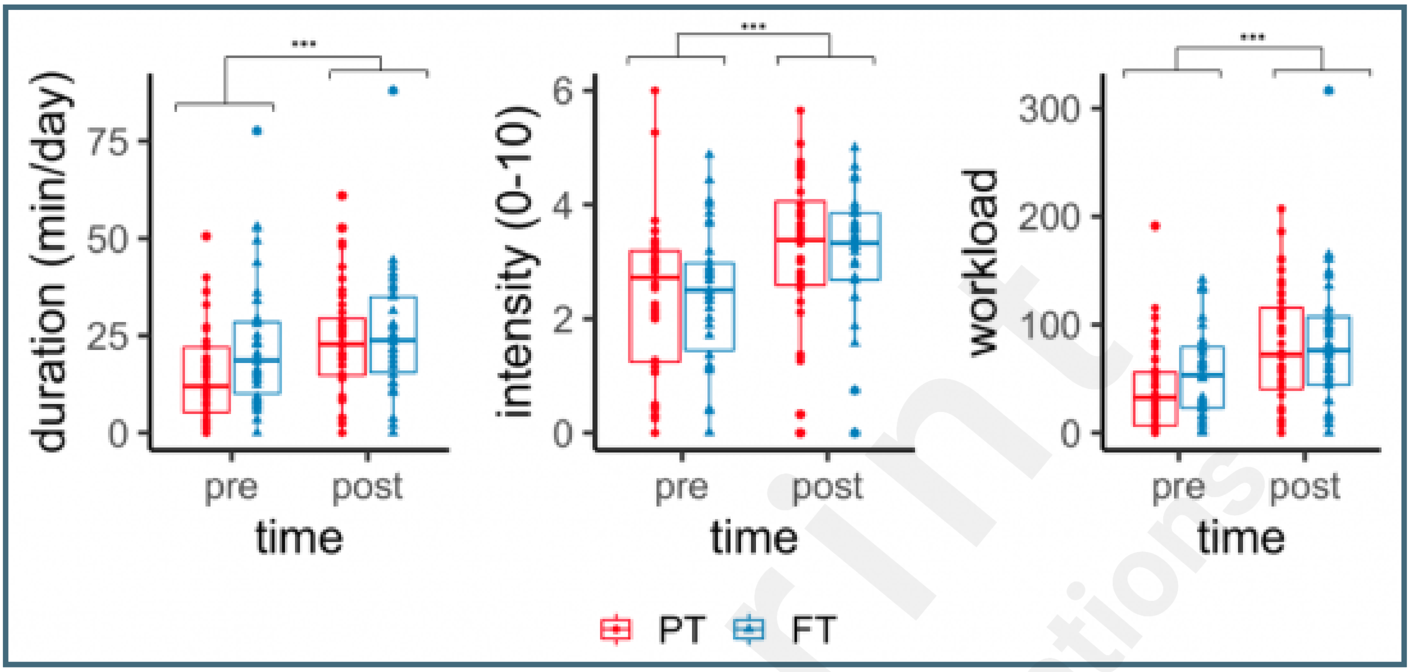
Example of a 10-min sequence of physical activity.



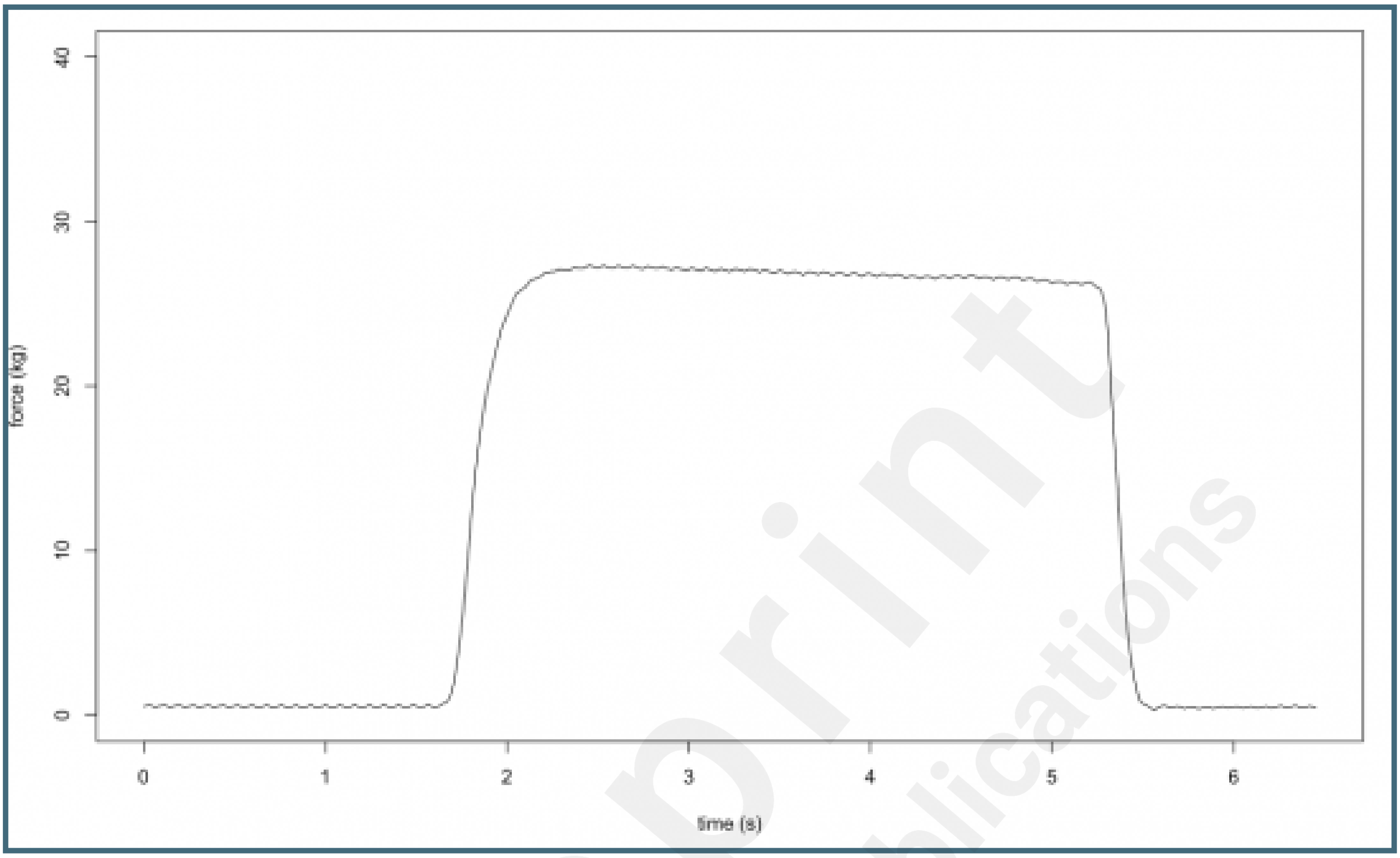
Mobile app (left: home screen with gauges for both PA and stretching time; middle: self-reported PA; right: personalized coach (screenshots have been translated into English for the present paper and colors have been adjusted for better understanding. Original screenshots can be found in supplement material).



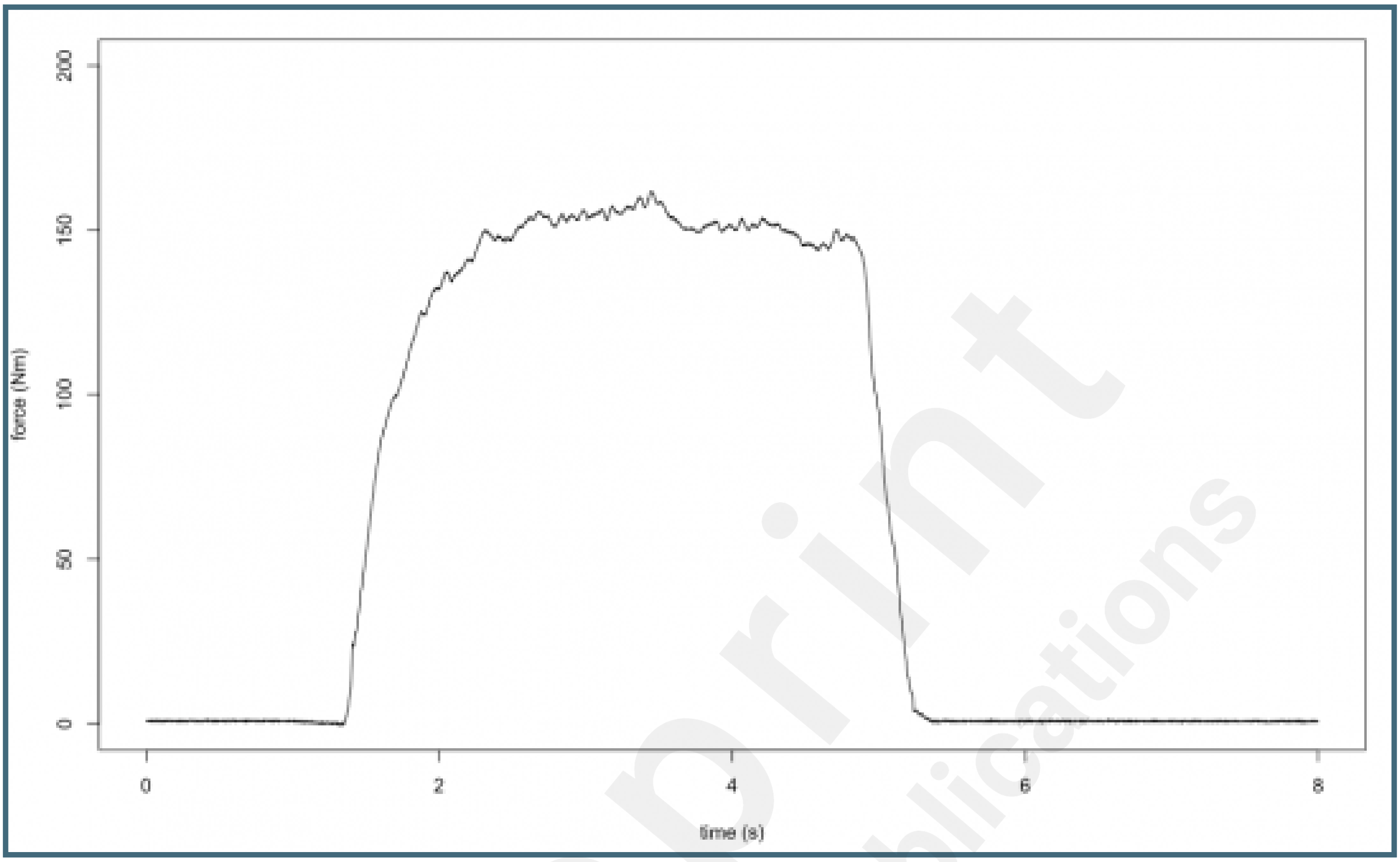
Boxplot of the exercise duration (left), intensity (middle) and the workload (right) between the two groups (PT: Personalized Training; FT: Free Training) and for the two evaluations (PRE/POST).



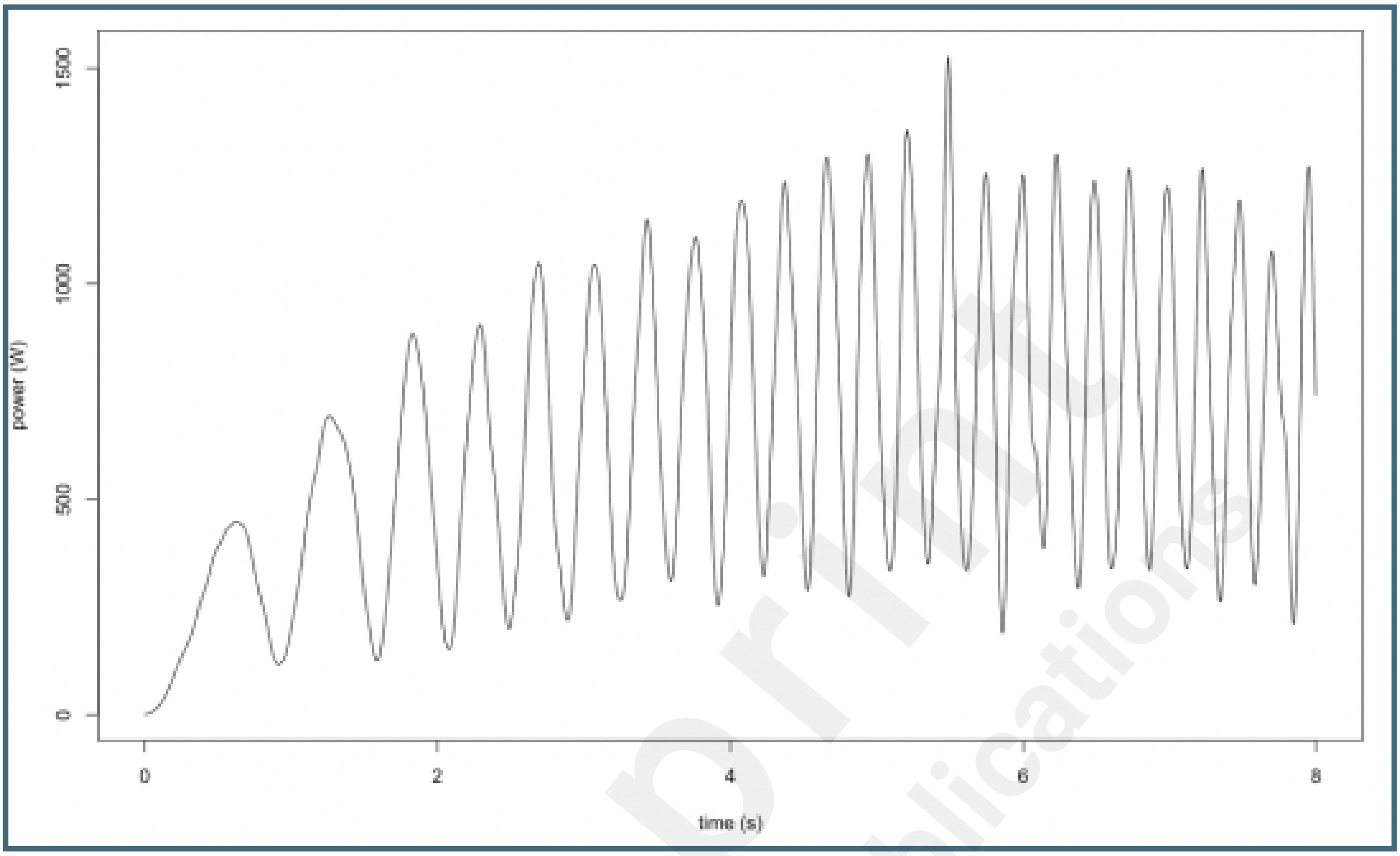
Example of the signal acquired for the handgrip test.



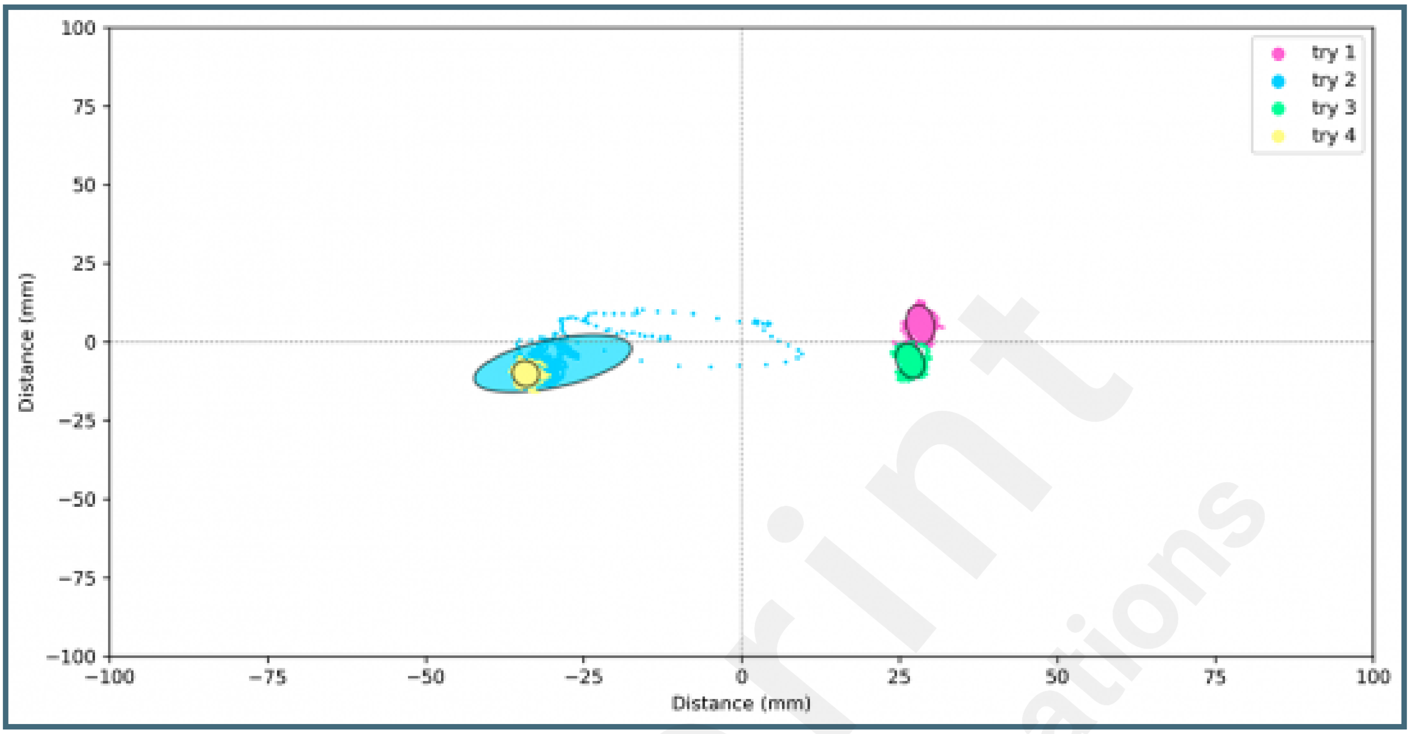
Example of the signal acquired in the leg extension test.



Example of the signal of the force-velocity test.



Example of the ellipse area for the balance test.



Original screenshots of the mobile app.