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RESEARCH ARTICLE

Physiological responses to "AgeWell Europe" an 8-week online and on-demand multimodal exercise programme for middle-aged and older adults

[version 1; peer review: awaiting peer review]

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Abstract

Introduction

Ageing, sedentary behaviour and/or poor nutrition contribute to increased vulnerability to chronic disease, frailty and loss of independence. An ageing population places greater demands on healthcare systems; thus highlighting the need for accessible, intrinsically motivating and scalable strategies to promote healthy ageing. This study investigated the efficacy of 'AgeWell Europe', an 8-week online and on-demand structured multimodal exercise programme designed specifically for middle-aged (MAA) and older-aged adults (OAA).

Methods

167 participants were recruited in four countries. Balance (45-second eyes open balance test), lower-body and upper-body muscular endurance (sit-to-stand test (STS) and press-up test, respectively), cardiorespiratory fitness (6-minute walk test (6MWT)), muscular strength (maximal voluntary contraction (MVC) for knee flexion and extension) and vertical jump were assessed pre and post intervention.

Physical activity (PA) level (M1 question), wellbeing (WHO-5 Index) and physical self-efficacy (LIVAS) were examined using online questionnaires.

Results

A total of 121 participants completed the intervention. The age-group analysis (all MAA and OAA) identified significant improvements in STS, press-up and 6MWT performance ($p < 0.001$). A significant increase in M1 ($p < 0.001$) and LIVAS (MAA: $p = 0.02$; OAA: $p = 0.04$) was observed in both groups. MAA improved vertical jump ($p = 0.02$) and balance in the left leg ($p = 0.02$). No significant changes were found for right leg balance, knee strength, or WHO-5 scores ($p > 0.05$). The sex based analyses revealed significant group-by-time interactions for STS ($F = 5.62$, $p = 0.02$) and 6MWT ($F = 5.72$, $p = 0.02$), with greater improvements in males than females, while both sexes significantly improvement their press-up scores ($p < 0.001$). Females significantly increased M1 ($p < 0.001$), LIVAS ($p = 0.003$) and right-leg balance ($p = 0.03$), whereas vertical jump improved only in males ($p = 0.03$).

Conclusion

The 'AgeWell Europe' intervention significantly improved upper- and lower-body muscular endurance, cardiorespiratory fitness, weekly PA participation and physical self-efficacy in both MAA and OAA. These findings support the effectiveness of digital exercise in promoting functional health in MAA and OAA across Europe.

Plain Language summary

As one ages, we naturally tend to lose muscle strength, balance and fitness, increasing the risk of falls, chronic diseases and loss of independence. Exercise can help prevent these problems, but many middle-aged and older adults face barriers like lack of time, difficulty accessing exercise classes and not knowing where to start. Online, on demand and at-home exercise programmes could help overcome these obstacles.

This research programme called "AgeWell Europe", conducted across four European countries, is a free online exercise programme for adults aged 40–85. The programme featured exercise videos in four languages with options for the participant to take part at varying difficulty of exercise intensity levels. Participants could complete the online exercise or health education modules at a time that suited them.

121 adults completed two 25–34 minute exercise sessions per week for 8 weeks. Each session included a warm-up and cool down and a combination of strength, cardio, balance and flexibility exercises.

The participants' fitness was assessed before and after the intervention to measure how far they could walk in 6 minutes, how many push-ups and sit-to-stands they could do along with their balance. After 8 weeks, the participants had meaningful improvements across multiple fitness measures. Lower-body muscular endurance improved by approximately 20%, while upper-body muscular endurance increased by 25%. Cardiorespiratory fitness also improved significantly, with participants able to walk considerably further during the 6-minute test. Beyond physical improvements, participants reported exercising more frequently throughout the week and felt greater confidence in their physical abilities. These improvements occurred consistently in both middle-aged and older adults, and in both men and women.

This study highlights that a short, home-based online on demand programme with just two 30-minute sessions per week can lead to real improvements in strength, endurance and confidence. All key indicators important for the maintenance of independence, to reduce fall risk and prevent the onset of chronic diseases. This online on-demand format makes healthy aging accessible to everyone.

Keywords
Healthy Ageing, Multimodal Exercise, Home Based Exercise, Exercise Intervention, Middle Aged, Older Aged

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Introduction

Ageing combined with unloading due to hospitalisation, physical inactivity, sedentary behaviour, and/or poor nutrition, is associated with loss of muscle mass, strength and function (i.e., sarcopenia), decreased bone mass and strength, increased adiposity, a higher prevalence of long-term conditions (such as prediabetes, type 2 diabetes, cardiovascular disease, osteoporosis etc.), mobility disability and loss of independence (Rosenberg, 1989; Rosenberg, 1997). Muscular fitness (muscular endurance and strength) and cardiorespiratory fitness are two of the most important health-related components of fitness for middle-aged adults (MAA) and older-aged adults (OAA) (Hoeger et al., 2019). Sarcopenia is related to both the loss of muscle mass and a decline in the quality and function of the remaining muscle tissue. This progressive loss of muscle mass varies from 3 to 8% per decade (English & Paddon-Jones, 2010) after the age of 30 and is implicated in decreased muscular fitness, balance, increased risk and incidence of falls (Wolfson et al., 1995), decrements in cardiovascular (CV) and metabolic health, morbidity and ultimately mortality (Manini et al., 2007). Regardless of the aetiology, sarcopenia increases susceptibility to muscle injury (Faulkner et al., 1995), serious falls, physical frailty (Cruz-Jentoft et al., 2010; Cruz-Jentoft et al., 2014; Tinetti, 2001), obesity (Stenholm et al., 2008) and diabetes (Ghosh et al., 2015; Kim et al., 2010). Total muscle mass declines by approximately 20–30% from young adulthood to 80 years of age (Carmeli et al., 2002). This is particularly evident in untrained individuals and contributes significantly to frailty (Larsson et al., 2019).

The average life expectancy in Europe is currently 81.7 years of age, however, the average age of disease onset is 62 years, but may be as young as 54 years (Denmark). Further, the average perceived onset of old age, or the age at which Europeans believe they are elderly has been increasing over time and is now at 74 years (Wettstein et al., 2024). There is a clear mismatch between how active and healthy individuals are, when old age begins and therefore, when a decline in physical capability occurs. Physical activity interventions that target MAA to mitigate the effects of ageing may not be perceived as necessary by the average person, but the evidence supports that early intervention is beneficial. Physical activity has been consistently identified as a key modifying factor that can mitigate many of the adverse effects of ageing. More specifically, regular participation in multimodal exercise, incorporating aerobic, strength, balance, and flexibility exercise, is recommended for improving cardiovascular function, preserving musculoskeletal integrity, enhancing cognitive performance, and reducing the risk of metabolic and neurodegenerative diseases, as well as morbidity and mortality (Garber et al., 2011). Each of the four components of multimodal exercise are pivotal in achieving specific health benefits. For example, strength exercises can offset sarcopenia, improve bone mass and strength and balance, reduce the risk of falling and fall-related injuries, enhance mobility and functional independence and cardiometabolic health (Chodzko-Zajko et al., 2009). Despite this growing body of evidence, participation in multimodal exercise typically declines with age, and many MAA and OAA across Europe do not achieve the weekly recommendations for multimodal exercise (Cooper et al., 2020; Krug et al., 2013; OECD/WHO, 2023).

Several barriers may exist that prevent individuals from taking part in exercise in a public domain and therefore home-based exercise offers a solution to provide access. Home-based physical activity and exercise interventions, with and without health education, provided through digital technology are safe and effective in improving health-related outcomes including physical health and functional health in MAA and OAA (Raquel Costa-Brito et al., 2024). Digital physical activity, exercise, and health education interventions may overcome barriers like mobility limitations, transportation issues, community infrastructure barriers (e.g., community hall availability), exercise instructor availability, and time constraints (Raquel Costa-Brito et al., 2024). A motivating factor may be the convenience and privacy of a home-based physical activity or exercise intervention. Additionally, it appears that most MAA and OAA like to perform exercise in the morning and have the ability to self-select the frequency, intensity and duration of physical activity and exercise (Mehra et al., 2020). In the same regard, an online and on-demand structured programme would provide flexibility for people to watch or listen or perform specific practices at a time that is suitable for them, which may coincide with other activities of daily living (e.g., listening while ironing or cleaning, or commuting to work).

Two research studies conducted by the co-authors (Cooper et al., 2021; Kavanagh et al., 2022) found that 60 minutes of multimodal exercise performed two times per week for 12-weeks (Cooper et al., 2021) and 6-weeks (Kavanagh et al., 2022) significantly improved cardiovascular fitness, strength, power, flexibility and balance. Based on the positive outcomes of this work, the aim of this study was to investigate whether an online and on-demand version of a similar exercise regime of shorter duration would impart comparable benefits. Therefore, an 8-week online and on-demand structured multimodal exercise intervention with two exercise sessions to be conducted per week ranging from 25–34-minutes was developed.

Methods

The present study was part of a research program called 'AgeWell Europe' with a consortium comprising four countries (Ireland, Germany, Italy and Slovenia) and as such data collection took place in all four locations simultaneously.

AgeWell Europe is an 8-week online and on-demand structured programme for MAA and OAA in Europe, offering tailored multimodal exercise classes and health education workshops promoting healthy ageing. The multimodal exercise involved strength, fitness, balance, and flexibility exercises, and were supported by an on-demand library of resources. 'AgeWell Europe' is a free resource and may be accessed at the following site https://agewelleurope.eu. All voiceovers for the exercise videos and health education material were translated from English to Italian, German and Slovene, so that the participants registered in each individual country could take part in the study in their native language. Prior to being able to watch any exercise video, the participants were required to watch a mandatory video on exercise intensity to allow them to self-select the correct level of exertion. All exercise videos were designed with multiple intensity levels (level 1: beginner, level 2: intermediate and level 3: advanced) so that the participants could select the exercise variety that was most appropriate to their current physical ability. Therefore, the aim was that all participants would select a relative exercise intensity that was similar and thus overall exercise stimulus across participants would be similar. Each exercise video consisted of approximately a 10-minute warm up, 10-minutes of exercise and 10-minutes of cool down. Each exercise was firstly demonstrated by the instructor, after which the participants choose the appropriate level of difficulty (level 1–3) in order to complete that activity for 30 seconds.

Ethical considerations

Ethical approval for this study was obtained from each of the relevant local ethics committees in Ireland (Ethics Approval from Dublin City University, REC Reference: DCUREC/2024/212), Germany (Ethics Committee of the Institute of Psychology and Sport Sciences 7 at the University of Muenster, No. 2024–77-EB), Italy (Comitato Etico Territoriale CET Ara Nord Veneto, No 0024851/24) and Slovenia (National Medical Ethics Committee at the Ministry of Health Republic of Slovenia, approval no. 146/3/2025). All participants provided their written informed consent to participate in the study, which was performed according to the guidelines of the Declaration of Helsinki.

Experimental design

A total of 167 participants were recruited through local advertisement, social media and word of mouth. Participants were male and female MAA (40–64 years) and OA (65–85 years). General physical and mental fitness was required for inclusion and only those with serious medical conditions were excluded (i.e., heart failure, unstable angina, heart attack, stroke within the last year, dyspnoea) or musculoskeletal injuries currently being treated that would prevent them from undertaking any exercise or physical activity. Participants attended an in-person information briefing session to explain the study in full detail and were afforded an opportunity to ask any questions or raise concerns.

The participants were requested to attend an in-person single testing session in the pre- and post-intervention period to conduct all criterium assessments. Following the pre-intervention testing, the participants were provided with their login details to the 'AgeWell Europe' website and instructed to follow the 8-week exercise intervention, consisting of 16 * 25–34-minute evidence-based multimodal exercise (each class contains aerobic, strength, flexibility and balance exercises) classes. These exercise classes were underpinned by clinical exercise physiology and were suitable for adults aged 40–85 years of all functional abilities (beginner, intermediate and advanced levels and chair-based options were also available) and for those living with one or more clinical conditions. The participants were requested to complete 2 of these exercise videos per week. To be included in the data analyses, participants were required to complete at least 10/16 multimodal exercise classes. Participants also had access to 10 health education workshops and 2 mindfulness practices throughout the 8-week intervention, however, viewing these workshops was not mandatory. The final number of participants included in the data analysis was 121 and their characteristics are presented in Table 1.

Experimental procedures

The 45-second single-leg balance test (right leg and left leg), 60-second sit-to-stand test (STS), 60-second press up test and 6-minute walk test (6MWT) were conducted in all four centres during the pre- and post-testing phase. Maximal voluntary contraction and vertical jump were performed as additional assessments in Slovenia, as this was the only facility with access to the necessary laboratory equipment.

45-Second balance assessment (single leg)

This test is a measure of static balance and was adapted from (Springer et al., 2007). Balance was assessed using a single leg stance, whereby the participants were asked to hold this position for up to 45 seconds. Participants were asked to fold their arms across their chest, stand tall and relaxed and when ready lift one leg from the floor in an extended position in front of their body. A researcher would then start the timer when the participant reported being stable, stopping it after 45 seconds or when the participants raised leg touched the floor again, or the arms were introduced to stabilise themselves. Additionally, excessive leg swaying was not permitted. Following a 1-minute rest period, the test was repeated with the opposite leg. This test was performed with eyes open in all countries.

Table 1. Participant characteristics per country and age group. MAA: middle aged adult, OAA: older aged adult.

Country	Number of participants	Male/Female	Age (yrs)
Combined	Total: 121	34/87	61.6 ± 10.3
MAA	71	20/51	55 ± 7.8
OAA	50	15/35	70.9 ± 4.8*
Ireland	Total: 24	3/21	62.7 ± 10.6
MAA	11	2/9	53.8 ± 8.2
OAA	13	1/12	70.2 ± 5.0*
Italy	Total: 21	5/16	64.2 ± 9.6
MAA	10	1/9	56.2 ± 6.9
OAA	11	4/7	71.5 ± 4.3*
German	Total 36	9/27	63.4 ± 6.9
MAA	20	4/16	58.3 ± 4.2
OAA	16	5/11	69.8 ± 3.2*
Slovenia	Total: 40	17/23	58.0 ± 12.3
MAA	30	12/18	52.9 ± 9.2
OAA	10	5/5	73.1 ± 6.6*

*Indicates a significant difference between MAA and OAA.

60-Second sit-to-stand test

This test is a measure of lower-body muscular endurance. An armless chair was placed against a wall for stability and the participants were asked to sit in the middle to front of the chair with their back straight and feet under their knees. They were offered the choice of 2 hand positions: arms folded across the chest, so that their hands rested on the opposite shoulders (harder version) or hands placed on their knees to aid their exertion (easier version). The participants were instructed to move to a full standing position and return to the initial starting position as fast and as safely as possible. This movement was recorded as one repetition. They would repeat this movement pattern as many times as possible in a 60s period. It was permissible to rest during the test. A note of the hand position was made during the pre-testing, so that the same position or a more difficult position could be used in the post-test. Participants were given 1 attempt at this test.

60-Second press up test

This test was used to evaluate upper-body muscular endurance. The participants were asked to start this test in their chosen position (4 possible positions; 1: Full press-up; 2: Modified press-up with extended knees on the floor; 3: Box-press up; and 4: Wall press-up) with their arms fully extended and hands shoulder width or slightly further apart (Cooper et al., 2023). The movement begins by flexing the arms to lower the body until the chest almost touches the target (floor or wall) and the arms are at 90°, at this point, the participants extend their arms, while maintaining a neutral torso, to return to the starting position. This is one repetition. The test requires the participants to perform as many repetitions as possible in 1-minute. A rest break may be taken, but only in the starting position. A note of the hand position was made during the pre-testing, so that the same position or a more difficult one could be used in the post-test.

6-Minute walk test

The 6-minute walk test (6MWT), a measure of cardiorespiratory fitness (Dourado et al., 2021), was performed on a 20-metre flat course with cones placed at either end to indicate the turning points. The participants were requested to walk a maximal distance along this course within a 6-minute period. Running and jogging were not permitted. The participants were informed of the time remaining after every minute and verbal encouragement was provided throughout. The total number of repetitions of the 20-metre course was recorded and then the total distance covered in metres (m) was calculated.

Isometric dynamometry

The participants' maximal voluntary contraction force (MVC) was assessed with an isometric dynamometer (System Pro 4; Biodex Medical Systems, Shirley, NY, USA). The MVC was assessed unilaterally in both extensors and flexors of the knee. The joint angle used for testing was 60 degrees. The dynamometer was calibrated before any testing on a daily basis. Each participant was secured tightly to the apparatus and the centre of rotation of the knee joint aligned with the axis of rotation of the dynamometer. The participants were requested to conduct five warm up contractions of each muscle group (flexion and extension) beginning at 20% of perceived maximum, increasing in a stepwise manner to 90%. The maximal exertion protocol comprised a 5-second isometric contraction of the agonist followed by a 30-second recovery, then a 5-second isometric contraction of the antagonist followed by a 30-second recovery. This pattern was repeated four times for each muscle group. A researcher provided feedback and encouragement. The peak isometric torque was noted as the highest value of force generated during any one of the four contractions. Peak torque was calculated as the highest average during a 50-millisecond segment or epoch.

Vertical jump

Lower-body power assessed through vertical jump performance was measured using a Leonardo mechanograph platform (Novotec Medical, Pforzheim, Germany). Following a brief warm-up consisting of 8 parallel bodyweight squats, the participant was instructed to stand comfortably on the platform, feet shoulder width apart with their hands positioned on their hips. Upon hearing an audible beep emitted from the software, the participants performed a countermovement vertical jump as fast as possible and were directd to land safely back on the platform. Three maximal effort jumps were conducted with one minute rest between jumps. However, if the 3rd jump was the highest, a 4^{th} and potentially a 5th repetition was conducted. However, the test was terminated at the 5th jump. The maximal height jumped in cm from any one jump was taken as the metric.

Questionnaires

Participants in Ireland, Italy and Germany completed an online questionnaire before and after the 8-week intervention. All questionnaires were available in respective languages. This questionnaire included (i) the Single-Item Measure (M1) of Physical Activity Participation, which assessed the frequency of physical activity engagement over the preceding seven days (Milton et al., 2011) (ii) the World Health Organization Five Well-Being Index (WHO-5), a five-item self-report instrument measuring current well-being (WHO, 1998) and (iii) the Modified Perceived Physical Activity Questionnaire (LIVAS: Lichamelijke Vaardigheden Schaal), a 10-item measure evaluating participants' perceptions of their physical abilities relative to peers of the same age (Ryckman et al., 1982).

M1-Single item questionnaire

The M1 questionnaire asks the respondents "in the past week, on how many days have you done a total of 30 minutes or more of physical activity, which was enough to raise your breathing rate. This may include sport, exercise and brisk walking or cycling for recreation or to get to and from places but should not include housework or physical activity that may be part of your job". Acceptable and valid responses range from 0 to 7 (Milton et al., 2011).

WHO-5

The World Health Organization-Five Well-Being Index (WHO-5) is a self-report instrument measuring mental well-being (WHO, 1998). It consists of five statements relating to the past two weeks. For example "Over the last two weeks, I have felt cheerful and in good spirits". Each statement is rated on a 6-point scale with anchors of 0 being "at no time" and 5 meaning "all of the time". Higher scores indicate better mental well-being. The questions cover only positive feelings of well-being.

LIVAS (Perceived physical ability subscale)

Physical self-efficacy was measured with the LIVAS-scale. Participants' physical abilities were evaluated through 10 items comparing their own self-perception with that of their age-matched peers. Each item was rated on a five-point Likert scale, starting with more negative to more positive responses regarding their perceived ability (Ryckman et al., 1982). For example "Compared to most people my age, I'm probably: 1) much less flexible, 2) less flexible, 3) just as flexible, 4) a little more flexible, and 5) much more flexible".

Statistical analysis

All statistical analyses were conducted using R (version 4.4.2; R Core Team) with the *lme4*, *lmerTest*, and *effectsize* packages. A significance threshold of $p < 0.05$ was set for all tests. Descriptive statistics were first calculated for each outcome measure, summarised as mean $\pm$ standard deviation at pre (T1) and post-intervention (T2).

Linear mixed-effects models (LMMs) were fitted separately for each outcome variable (i.e., right and left leg balance, sit to stand test, press up test, 6MWT, MVC knee flexion, MVC knee extension, vertical jump, MI, WHO-5 and LIVAS) to evaluate changes over time and whether these changes differed across age and sex subgroups. The LMM framework was considered appropriate given the longitudinal design, where repeated measurements within individuals introduce correlation and variability across participants. Such models are widely recognised for their ability to accommodate incomplete or unbalanced data and to provide robust estimates of group-by-time effects (Twisk, 2013).

The models included fixed effects of group (i.e., age or sex), time (pre vs. post), and the group-by-time interaction, with participants specified as a random intercept to account for within-subject correlation due to repeated measures. The primary analysis evaluated the group-by-time interaction, reported with F-statistics and corresponding *p*-values. Within each subgroup, pre–post changes were further summarised using Cohen's *d* effect sizes, interpreted as small ($d = 0.20$), medium ($d = 0.50$), or large ($d = 0.80$).

Results

Participants who did not return for the post-intervention or those who completed less than 10 of the 16 prescribed exercise videos were removed from the data set. Therefore, a total of 121 participants were included in this analysis. In total, 87 participants (72%) completed all 16 multimodal exercise videos. A total of 12 participants (10%) completed 15 multimodal exercise videos, 13 participants (11%) completed 14 multimodal exercise videos, 3 participants (2%) completed 13 multimodal exercise videos, 1 participant (1%) completed 12 multimodal exercise videos, 4 participants (3%) completed 11 multimodal exercise videos, and 1 participant (1%) completed 10 multimodal exercise videos.

Information regarding the 34 male and 87 female participants who completed the 'AgeWell Europe' programme is provided in Table 1. A total of 85 participants provided data on whether they were living with one or more chronic conditions. In total, 21 participants out of 85 participants (25%) were living with one or more chronic conditions, whereas 64 participants (75%) reported no chronic conditions.

Comparison by age groups

No significant group-by-time interaction effects were observed for any of the outcomes between age groups (all $p > 0.05$, F score between 0.01–1.6) (Table 2), indicating that changes over time did not differ significantly between the MAA and OAA groups. However, several within-group effects were statistically significant, with small to moderate effect sizes depending on the outcome, indicating improvements following the intervention.

Both age groups (MAA and OAA) demonstrated improvements for STS and press up performance, which reached statistical significance, with large effect sizes ($d = 0.86$–1.20, $p < 0.001$). Similarly, the 6MWT and M1 in both groups achieved statistical significance with medium-to-large effects ($d = 0.51$–1.08, $p < 0.001$). LIVAS achieved a statistically significant outcome with small effect sizes in both age groups (MAA: $d = 0.39$, $p = 0.02$; OAA: $d = 0.34$, $p = 0.04$).

No significant improvements were observed for balance on the right leg ($p > 0.05$). However, on the left leg, only the MAA significantly improved ($d = 0.30$, $p = 0.02$). Similarly, for the vertical jump, only the MAA exhibited a significant improvement with a small effect ($d = 0.47$ and $p = 0.02$).

No significant changes in knee extension and flexion strength or WHO-5 scores were observed ($p > 0.05$).

Comparison by sex

In the sex analyses, statistically significant group-by-time interaction effects were observed for two outcomes: Sit-to-Stand (STS) ($F = 5.62$, $p = 0.02$) and the 6MWT ($F = 5.72$, $p = 0.02$), indicating that changes over time differed significantly between males and females for these measures (Table 3). Both males and females significantly improved their STS and 6MWT performance ($p < 0.001$), with large effect sizes observed in both groups but slightly larger in males (STS: $d = 1.17$; 6MWT: $d = 0.91$), compared to females (STS: $d = 1.01$; 6MWT: $d = 0.86$). No significant interaction effects were found for the remaining outcomes (all $p > 0.05$, F-score range: 0.01–2.42).

Within group analysis indicated that press up performance reached statistical significance in both groups ($p < 0.001$), with males demonstrating a medium effect size ($d = 0.70$) and females a large effect size ($d = 0.92$). For both the M1 ($d = 0.547$, $p < 0.001$) and LIVAS ($d = 0.38$, $p = 0.003$), statistically significant improvements were only found in females, but not in males ($p > 0.05$). Similarly, significant improvements in balance were only observed in females on solely the right leg ($p = 0.03$, $d = 0.23$). In contrast, vertical jump only statistically significantly improved in males ($d = 0.56$, $p = 0.03$).

Discussion

This study set out to investigate whether an 8-week online and on-demand structured multimodal exercise intervention consisting of two 25–34-minute sessions per week would have a positive benefit on several key physiological parameters. The key findings of 'AgeWell Europe' are that the intervention significantly improved upper- and lower-body muscular endurance and cardiorespiratory fitness in male and female MAA and OAA. Additionally, participation in the study led to significantly increased physical activity and physical self-efficacy in MAA and OAA, but only in females when analysed by sex. Single-leg static balance significantly improved for the left leg of MAA only and a significant improvement of balance in the right leg of females only was noted. For vertical jump height, which was solely examined in Slovenia, a

Table 2. **Linear mixed model results for outcomes by age group and time.**

Outcome	N	Group	T1 (Mean ± SD)	T2 (Mean ± SD)	Group-by-Time		Within Group	
					F-score	p-value	Cohen's d	p-value
Right Leg Balance (seconds)	70	MAA	39.29 ± 12.54	41.13 ± 9.95	0.60	0.44	0.206	0.09
	51	OAA	29.04 ± 17.28	32.39 ± 16.6			0.268	0.06
Left Leg Balance (seconds)	70	MAA	40.9 ± 9.97	43.1 ± 6.6	0.04	0.85	0.294	0.02
	51	OAA	32.06 ± 15.70	34.63 ± 14.84			0.193	0.17
Sit-to-Stand (repetitions)	69	MAA	34.64 ± 9.55	40.90 ± 11.55	1.15	0.29	1.20	<0.001*
	51	OAA	28.14 ± 6.59	33.29 ± 8.57			0.86	<0.001*
Press Up (repetitions)	70	MAA	30.21 ± 8.06	36.4 ± 9.85	0.88	0.35	0.746	<0.001*
	50	OAA	27.32 ± 7.20	34.88 ± 8.27			1.024	<0.001*
6MWT (meters)	69	MAA	641.46 ± 118.77	688.61 ± 118.77	0.26	0.61	0.757	<0.001*
	50	OAA	539.18 ± 101.24	581.24 ± 112.82			1.079	<0.001*
MVC Knee Flexion (Nm)	29	MAA	81.31 ± 27.41	78.96 ± 25.52	1.33	0.26	−0.285	0.13
	11	OAA	64.50 ± 23.66	65.56 ± 24.33			0.124	0.68
MVC Knee Extension (Nm)	29	MAA	188.24 ± 63.43	189.44 ± 56.25	0.07	0.80	0.047	0.80
	11	OAA	170.69 ± 52.32	174.20 ± 58.4			0.148	0.62
Vertical Jump (cm)	29	MAA	30.14 ± 6.97	31.07 ± 6.96	0.97	0.33	0.466	0.02*
	11	OAA	24.36 ± 7.34	24.55 ± 7.12			0.072	0.81
M1 (days per week)	41	MAA	3.05 ± 2.24	4.24 ± 1.65	0.88	0.35	0.548	0.001*
	40	OAA	4.18 ± 1.97	4.97 ± 1.61			0.514	0.002*
WHO-5	41	MAA	15.2 ± 4.34	14.49 ± 4.26	1.60	0.21	−0.171	0.27
	38	OAA	15.82 ± 4.16	16.21 ± 4.15			0.111	0.49
LIVAS	41	MAA	29.49 ± 4.85	31.44 ± 5.06	0.01	0.91	0.388	0.02*
	39	OAA	32.59 ± 5.89	34.69 ± 6.34			0.337	0.04*

T1; pre-testing. T2; post testing.
*denotes statistical significance. SD; standard deviation. 6MWT; 6-Minute Walk Test. Nm; Newton-meters. MVC; maximal voluntary contraction. M1; single-item measure physical activity participation. WHO-5; World Health Organization Five Wellbeing Index. LIVAS; Lichamelijke Vaardigheden Schaal or perceived physical activity.

Table 3. Linear mixed model results for outcomes by sex group and time.

Outcome	Group	T1 (Mean ± SD)	T2 (Mean ± SD)	Group-by-Time		Within Group	
				F-score	p-value	Cohen's d	p-value
Right Leg Balance (seconds)	Male	33.88 ± 15.06	36.56 ± 14.02	0.02	0.90	0.24	0.16
	Female	35.39 ± 15.75	37.79 ± 13.79			0.23	0.03*
Left Leg Balance (seconds)	Male	36.50 ± 13.14	40.38 ± 10.94	1.04	0.31	0.34	0.05
	Female	37.44 ± 13.54	39.20 ± 11.88			0.18	0.10
Sit-to-Stand (repetitions)	Male	31.38 ± 9.20	39.06 ± 12.14	5.62	0.02*	1.17	<0.001*
	Female	32.07 ± 8.95	37.12 ± 10.57			1.01	<0.001*
Press Up (repetitions)	Male	28.44 ± 7.81	34.68 ± 9.04	0.21	0.65	0.70	<0.001*
	Female	29.23 ± 7.85	36.20 ± 9.31			0.92	<0.001*
6MWT (meters)	Male	624.18 ± 132.81	687.79 ± 148.34	5.72	0.02*	0.91	<0.001*
	Female	588.63 ± 117.33	626.50 ± 114.96			0.86	<0.001*
MVC Knee Flexion (Nm)	Male	88.30 ± 32.08	87.70 ± 30.77	0.27	0.60	−0.08	0.72
	Female	68.10 ± 19.58	66.09 ± 16.34			−0.22	0.30
MVC Knee Extension (Nm)	Male	207.48 ± 64.89	209.72 ± 63.17	0.01	0.93	0.08	0.75
	Female	165.63 ± 51.35	167.17 ± 44.21			0.07	0.72
Vertical Jump (cm)	Male	32.12 ± 8.07	33.29 ± 7.83	1.32	0.26	0.56	0.03*
	Female	25.91 ± 5.82	26.30 ± 5.82			0.18	0.39
M1 (days per week)	Male	3.53 ± 2.53	4.35 ± 1.93	0.18	0.67	0.44	0.08
	Female	3.62 ± 2.09	4.67 ± 1.59			0.55	<0.001*
WHO-5	Male	13.67 ± 4.84	14.33 ± 5.58	0.87	0.35	0.10	0.68
	Female	15.92 ± 4.01	15.55 ± 3.92			−0.12	0.33
LIVAS	Male	30.59 ± 4.43	33.18 ± 5.39	0.21	0.64	0.33	0.12
	Female	31.11 ± 5.87	32.98 ± 6.09			0.38	0.003*

T1; pre-testing. T2; post testing.
*denotes statistical significance. SD; standard deviation. 6MWT; 6-Minute Walk Test. Nm; Newton-meters. MVC; maximal voluntary contraction. M1; single-item measure physical activity participation. WHO-5; World Health Organization Five Wellbeing Index. LIVAS; Lichamelijke Vaardigheden Schaal or perceived physical activity.

significant improvement was evident in MAA only and in males only. This intervention, which is underpinned by clinical exercise physiology, led to improvements in key health-related components of fitness including muscular endurance and cardiorespiratory fitness. Therefore, these findings support the efficacy of 'AgeWell Europe' as a home-based, digitally-driven strategy to provide accessible, flexible, practical and scalable multimodal exercise to improve physical performance physical activity participation and physical self-efficacy in community-dwelling MAA and OAA in Europe. The observed positive effects are indicative that short-term low volume multimodal exercise interventions are effective at mitigating the physiological maladaptations associated with ageing. Thereby preventing, managing and treating long-term conditions and reducing healthcare burden and recovery, as well as improving autonomy and confidence to engage in healthy lifestyle behaviours.

Single-leg static balance

The age group based analysis indicated a significant improvement in left leg balance in MAA only, but no significant change in balance on the right leg for either age-group were observed. When analysed by sex, there was a significant improvement identified in females only for balance on the right leg. In consideration of the training volume used in the study, the time spent performing balance exercises may not be conducive to permit improvements in bilateral single-leg static balance after 8 weeks in MAA and OAA. The average time allocated to balance exercises per exercise video was 2 minutes, although it ranged from 1–3 minutes. It is not necessarily a given that longer time and volume practicing balance will lead to increasingly significant results (Gebel et al., 2018; Muehlbauer, 2021), however, there is very likely a threshold prior to which no improvement will be statistically significant, with most participants obtaining over an average of 30 seconds prior to the current program. Muehlbauer, (2021) found improved balance after 240 minutes across 4 weeks of training, while others report that balance requires up to 11–12 weeks of three 30-minutes sessions per week in order to elicit improvements in balance (Lesinski et al., 2015). This is in agreement with the recommendations from the American College of Sports Medicine, with a minimum training duration of 20–30 minutes 2 to 3 days per week for neuromotor exercise (Liguori et al., 2019). Furthermore, the authors assessed static balance only, rather than dynamic balance. With regard to the efficacy of the exercise intervention to reduce the risk of failing, the currrent authors recommend that dynamic balance testing is included to provide further data supporting the use of strength training in an ageing population.

Lower-body muscular endurance

MAA and OAA significantly increased the number of STS repetitions completed in 60 seconds, indicating a positive effect of the current intervention on lower body muscular endurance. Additionally, both male and female groups significantly improved the STS score, however, there was no statistical difference between sexes. With a similar sex balance to the current manuscript, (Cooper et al., 2021) reported OAA individuals can significantly improve their STS score from 26 to 35 repetitions following a 12-week multimodal exercise intervention. The current participants exhibited similar positive adaptations to those of (Cooper et al., 2021) following a shorter duration intervention. The improvement in lower-body muscular endurance after the 'AgeWell Europe' programme is noteworthy as lower-body muscular endurance is an independent predictor of health (García-Hermoso et al., 2018) and is vital for maintaining independence when engaging in activities of daily living, reducing fall risk (Zhong et al., 2024) and mortality (García-Hermoso et al., 2018; Zhong et al., 2024). All groups on average performed a number of STS repetitions that would place them in the 2nd quartet percentile, indicating good to excellent results post-intervention (Strassmann et al., 2013). As such, the current participants post-programme possess improved lower-body muscular function that is highly desirable for healthy ageing and an independent functional lifestyle, permitting mobility, reduced risk for injuries and falls, and ability to lift and reach things easier.

Upper-Body Muscular Endurance

The present findings demonstrate that MAA and OAA achieved significant improvements in upper-body muscular endurance, as measured by the press-up test, after the 8-week intervention. Additionally, the sex based analysis identified significant improvements in upper-body muscular endurance in both sexes. These findings align with prior research indicating that both resistance and bodyweight exercise programmes can significantly improve muscular endurance in adults (Grgic et al., 2022; Ogawa et al., 2023). This result has important implications as higher levels of upper-body muscular endurance are associated with a reduced risk of all-cause mortality regardless of age (García-Hermoso et al., 2018). Importantly, no significant differences were observed between age groups, suggesting that the programme was equally effective for participants in middle and later adulthood. From examining the mean change, OAA improved repetitions completed in the press-up test similarly to MAA suggesting that neuro-muscular plasticity remains stable and has equal potential to adapt regardless of age. The literature supports this and has continually found that resistance and multimodal exercise can improve strength, endurance, and overall physical ability even later in life (Lopez et al., 2023). These findings suggest that easy-to-follow, structured home-based multimodal exercise has the potential to improve upper-body endurance for anyone, regardless of age or sex.

Cardiorespiratory Fitness

The results of the 6MWT reveal that both the MAA and OAA groups were capable of walking significantly further after the 8-week intervention. Moreover, the sex based analysis found that both males and females walked significantly further post-programme. Therefore, the current 8 week exercise intervention increased cardiorespiratory endurance, as well as lower-limb muscular endurance (according to the STS results discussed above) culminating in reduced fatigue and increased speed and ultimately distance. These findings are in agreement with previous research, which found that structured physical activity increases endurance and exercise ability in adults (Enright & Sherrill, 1998). The improvements in both age groups identify that targeted multimodal exercise programs can improve cardiorespiratory endurance, regardless of their baseline fitness level or age group. In both pre- and post-intervention tests, participants in the MAA group walked farther than those in the OAA group. Although both groups significantly improved, the MAA group's consistently greater distances may be due to differences in initial fitness as importantly, the amount of gain was similar for both groups, suggesting that the intervention was beneficial for all participants, regardless of their starting level. Sex differences were also observed. Males walked farther than females both before and after the intervention and had larger absolute improvements. These results are in line with prior work indicating that males often achieve higher distances in the 6MWT, likely due to physiological factors such as greater muscle mass, cardiovascular capacity, stride length and turnover rate and power (Gibbons et al., 2001). Overall, the data suggest that multimodal exercise programmes can enhance walking performance, but personal factors like baseline fitness and sex affect the degree of potential benefit. This is an important finding as cardiorespiratory fitness is an independent predictor of health (Wei et al., 1999) and is strongly correlated to gait speed (Chen et al., 2021). Slow gait speed is associated with poor neurocognitive functioning and is linked with frailty, and an increased risk and incidence of falls, morbidity and mortality (Figgins et al., 2021; Fritz & Lusardi, 2009; Imran et al., 2019; Rasmussen et al., 2019). Improvements in the distance achieved during the 6MWT post-programme may be related to physiological changes such as greater muscle mass, muscular endurance, cardiorespiratory capacity, stride length, and power (Gibbons et al., 2001). Overall, the data suggest that online, structured, and on-demand multimodal exercise program can enhance walking performance after 8 weeks.

Lower-limb muscular strength (slovenia only)

The current intervention did not lead to significant changes in maximal isometric voluntary contraction (MVC) for knee extension or flexion in either MAA or OAA groups or male or female groups. While the MAA group consistently demonstrated higher absolute strength values compared to the OAA group for both knee extension and flexion, the relative changes over the intervention period were non-significant. The programme improved muscular endurance and functional performance but did not produce significant gains in maximal strength. This is likely due to the multimodal exercise programme emphasising muscular endurance instead of higher-load strength training required for maximal strength improvements. Research has established that substantial gains in maximal strength require progressive, high-intensity training specifically targeting force development (Peterson et al., 2011). The higher strength levels seen in the MAA are consistent with known age-related reductions in muscle capacity. It is therefore possible that the lack of meaningful change in maximal strength highlights that developing maximal force requires heavier loads, gradual increases in intensity, or longer training periods with the specific aim of increasing maximal strength and adjusted according to participants' age and initial fitness levels.

Vertical Jump Performance (Slovenia only)

The age-group based analysis identified a significant increase (with a medium effect size) in vertical jump height in MAA. Additionally, the sex-group based analysis found a significant increase in vertical jump height in males only, with a small effect size. The countermovement jump is used to assess lower-body explosive power and is linked with maximum speed and explosive speed. The current 8-week multimodal exercise program did not focus on explosive movements but rather muscular endurance-based exercises that could be conducted with bodyweight or light loads. There were significant improvements in lower body muscular endurance in all groups which potentially contributed to increased vertical jump. The contribution here is likely through improvements in neuromuscular control and improved biomechanics and joint control rather than hypertrophy. There is an imbalance in the distribution of participants to the MAA and OAA within this cohort which likely explains why a significant improvement in jump height was identified for the MAA and not the OAA, who were likely underpowered. Lower body power decreases with ageing and may contribute to increased risk and incidence of falls and fall-related injuries and as such the countermovement jump was included in the test battery (Zhu et al., 2025). The current findings are therefore in line with the literature that no improvement was noted (Vitale et al., 2018), however, the caveat being a small sample size and a small effect size. Moreover, it is not clear why the male participants increased their vertical jump height albeit a small improvement with a small effect. Similarly to maximal strength training, the 'AgeWell Europe' programme was not specifically designed in order to improve these functional performance measures specifically and focused on primarily muscular endurance type exercises which could be completed safely at home, without the need for monitoring by an exercise professional. There is the potential that the larger body mass of the males contributed to an increased relative training load that translated to an approximate 1 cm improvement in jump height. Vertical jump may also improve due to improvements in coordination and synchronisation, but why this would be favoured in the male and MAA adults remains unresolved and cannot be determined based on the current methodology.

Questionnaires

The online questionnaire was designed to examine changes in physical activity participation (M1 single-item measure physical activity questionnaire), subjective wellbeing (WHO-5 index) and physical self-efficacy (LIVAS) post-programme. The age-group based analysis found significant improvements in M1 and LIVAS following the intervention for both MAA and OAA. Sex based analysis identified significant improvements in females, but not males, for the M1 and LIVAS. There were no significant differences in WHO-5 from pre- to post-programme when compared by age groups or by sex. Increasing physical activity participation, particularly engagement in the four types of multimodal exercise (aerobic, strength, balance, and flexibility) is pivotal for healthy functional ageing. These four types of exercise have independent and synergistic benefits for physical health, metabolic health, mental health, functionality, independence and quality of life (Faigenbaum, 2017; Garber et al., 2011; Hoeger et al., 2019). For example, strength exercises help to increase muscle mass, increase muscle strength, endurance, and power, increase bone mass and strength, and improve cardiometabolic health. Thus, multimodal exercise can contribute to the prevention, treatment, and management of long-term conditions (e.g., type 2 diabetes, cardiovascular disease, osteopenia and osteoporosis etc.) in MAA and OAA across Europe. This will help to reduce morbidity, morality, and healthcare burden. Self-efficacy refers to an individual's belief in their ability to perform specific behaviours or tasks (Bandura, 1977). Physical self-efficacy has been identified as a key predictor of both the initiation and maintenance of physical activity (Zelle et al., 2016). Individuals with higher levels of physical self-efficacy are more likely to sustain regular participation in physical activity, leading to beneficial health outcomes. The improved physical self-efficacy is likely due to a variety of reasons such as: an increased awareness regarding the importance of multimodal exercise for healthy ageing, receiving clear and accurate exercise technique instructions, improved motivation and confidence to complete exercise at home independently at an appropriate intensity and finally access to a library of health education videos. Despite improvements in physical activity participation and physical self-efficacy, there was no change in wellbeing following the current intervention. The average scores for WHO-5 pre- and post-intervention are above the threshold of a total score of 13 which indicates poor wellbeing and a need for further testing for depression (WHO, 1998). It is possible that the generalised statements of the WHO-5 questionnaire, such as "over the last two weeks, I woke up feeling fresh and rested" were not specific enough to the effect of the present 8-week programme on wellbeing. The scoring of the WHO-5 questionnaire may have been impacted by events or experiences in the personal, social, and professional life domains of participants at the time.

Limitations

The findings of this study should be considered with respect to several limitations. Firstly, this was a one-group pre-post test design study with no control group. Thus, we recommend that a randomised controlled trial should be conducted in each respective country to further bolster the current findings. Secondly, we acknowledge that physical activity and exercise performed outside of the prescribed programme was not monitored or supervised and was not explicitly restricted as part of the study. This may have influenced the findings of this study and we acknowledge that this may need to be considered in any future research particularly with regard to a controlled randomised trial. However, from a health perspective, the inclusion of other physical activity is welcome and may be viewed as beneficial. While the outcome results may be effected by the inclusion of other activity, the aim of use a programme is to instil an intrinsic motivation in the participants to partake in activity and continue it after the interventions ends. Thirdly, only one of the research teams had access to a physiological laboratory to examine muscle strength and vertical jump performance and therefore, these tests couldn't be performed in all four counties. Additionally, one research team did not administer the questionnaires and therefore, this data is available for three countries only.

Conclusions

The present study demonstrates that 'AgeWell Europe', an 8-week online and on-demand multimodal exercise programme is effective at significantly improving lower- and upper-body muscular endurance and cardiorespiratory fitness in differing age groups (MAA & OAA) and sexes (male & female). These improvements support previous literature regarding the benefits of regular engagement in multimodal exercise which have important implications for reducing morbidity and mortality, and maintaining functional independence as people age. Further to this, improvements in overall engagement in physical activity and an increased sense of capability to perform multimodal exercise regardless of age suggests long-term adherence in positive lifestyle behaviours.

Data availability statement

Underlying data

Figshare: Physiological and psychological data collected during AgeWell Europe.

Erasmus+, 2023–1-IE01-KA220-ADU-.

https://doi.org/10.25398/rd.northumbria.31224316 (McDonnell, 2026).

Extended data

Figshare: Physiological and psychological data collected during AgeWell Europe.

Erasmus+, 2023–1-IE01-KA220-ADU-.

https://doi.org/10.25398/rd.northumbria.31224316 (McDonnell, 2026).

The project contains the following extended data:

- Data collection sheets
- Questionnaires: LIVAS, WHO-5 and M1

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