Citation for published version:
Liang, I-J, Perkin, O, McGuigan, P, Thompson, D & Western, M 2021, 'Feasibility and acceptability of home-based exercise snacking and tai-chi snacking delivered remotely to self-isolating older adults during COVID-19.', *Journal of Aging and Physical Activity*, vol. 21, pp. 1-11. https://doi.org/10.1123/japa.2020-0391

DOI:
10.1123/japa.2020-0391

Publication date:
2021

Document Version
Peer reviewed version

Link to publication

Feasibility and acceptability of home-based exercise snacking and tai-chi snacking delivered remotely to self-isolating older adults during COVID-19.

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Abstract

The purpose of this study was to examine the feasibility and acceptability of remotely delivered, home-based exercise programmes on physical function and wellbeing in self-isolating older adults during the COVID-19 pandemic. In a four-arm randomised controlled trial, 63 participants (aged 65+) were allocated to one of three home-based daily (2x 10-min) exercise interventions (exercise snacking, tai-chi snacking, combination) or control (NHS webpages). Functional assessments were conducted via video-call at baseline and four-week follow-up. A web-based survey assessed the acceptability of each exercise programme and secondary psychological/wellbeing outcomes. Ecological momentary assessment data, collected in week one and four, explored feeling states as antecedents and consequences of exercise. All intervention groups saw increased physical function at follow-up and displayed good adherence, with exercise snacking considered the most acceptable programme. Multilevel models revealed reciprocal associations between feelings of energy and exercise engagement. Further studies are needed with larger, more diverse demographic samples.

Key words

Homebased, exercise, physical function, COVID-19

Background

During the COVID-19 pandemic, adults aged over 70 years in the UK were directed to remain in their homes at all times for 12 weeks from 22nd March 2020, except for emergencies (UK Government, 2020). The experience of 'shielding' will no doubt have varied widely for older adults; however, it is likely that the constraints on movement and social contact will have altered physical activity behaviours.

Maintaining physical activity is crucial in preventing age-related loss of muscle strength and other key health outcomes (Booth & Hargreaves, 2011). Reduced strength increases the likelihood of frailty, falls, and loss of independence, hugely impacting on individuals' quality of life, whilst also placing an enormous burden on health and social care systems (Pinedo-Villanueva et al., 2019). Even a small period of reduced activity can lead to meaningful losses in muscle function (Oikawa, Holloway, & Phillips, 2019). In a recent global survey, gerontology researchers and clinicians ranked the wider societal impact, identification of interventions to promote healthy behaviours, remote delivery of treatments, and use of technology in older adults, as COVID-19 research priorities (Richardson et al., 2020).

The UK Chief Medical Officer's guidance specifies the importance of exercises for muscle strength in older adults, recommending that resistance exercise be performed twice per week, and those with poor mobility train their balance three times a week (UK Government, 2019). However, many older adults report a dislike for structured exercise (Burton, Lewin, & Boldy, 2013) and very few UK older adults meet the recommended strength and balance guidelines, even in usual conditions (Department of Health, 2016; Strain, Fitzsimons, Kelly, & Mutrie, 2016). Identifying strategies to facilitate strength and balance training in self-isolating older adults is a key step in mitigating functional decline. Furthermore, higher physical activity levels are associated with better wellbeing (Anokye, Trueman, Green, Pavey, & Taylor, 2012). Studies have shown that improvements in older adults' quality of life can result from positive effects on fitness functions, performance of daily activities, and enjoyment of exercise interventions (Elavsky et al., 2005; Kallings, Leijon, Hellénius, & Ståhle, 2008; Langlois et al., 2013). Consequently, exercising may also alleviate the impact of shielding on wellbeing in older adults during a sustained period of self-isolation. It is imperative that the introduction of exercise into older adults' lives is in compliance with self-isolation guidelines and does not bring undue risk of adverse events, particularly whilst the NHS is under the strain of a pandemic.

Home-based exercise snacking has been identified as an accessible and low-risk alternative to traditional resistance exercise in older adults, with the potential to improve leg strength without the need for specialist facilities (Perkin, McGuigan, & Stokes, 2019). The exercise snacking model previously explored saw participants attempt as many repetitions as possible in one minute for one exercise, before resting for one minute and repeating the process with four more exercises. This temporal structure and intensity of exercise deviates from the traditional resistance exercise model but allows more frequent bouts of exercise. Alternatively, practicing tai-chi has been demonstrated to improve mobility in community-dwelling older women to a similar extent as the Otago home-based strength and balance training programme (Son, Ryu, Jeong, Jang, and Kim (2016). Tai-chi also requires no equipment and little space, with movements performed slowly and gently, so is considered relatively safe for older adults to perform in the home and unsupervised (Huston & McFarlane, 2016; Wayne, Berkowitz, Litrownik, Buring, & Yeh, 2014).

Several studies have indicated that practicing tai-chi can improve cardiopulmonary function and balance in older adults (Kutner, Barnhart, Wolf, McNeely, & Xu, 1997; Rogers, Larkey, & Keller, 2009), but none have explored tai-chi in a simple ‘snacking’ format, which may help novices engage with this form of exercise in a home setting (Barrado-Martín, Heward, Polman, & Nyman, 2019). Evidence suggests that for the more frail older adults, tai chi alone may not be sufficient to prevent falls (Nyman & Skelton, 2017), and so combining both strength exercise- and tai-chi snacking may be a useful light touch intervention. These exercise strategies may lend themselves to remote delivery for older adults in the context of the COVID-related lockdown restrictions. As researchers and clinicians adapt to the constraints of fewer face-to-face interactions, it will be crucial to understand the attitudes of older adults towards the remote delivery of health interventions.

Given the unique context afforded by the COVID-19 pandemic, as well as the effectiveness on function, it would be interesting to understand the acute role of exercise and tai-chi snacking on older adults’ psychological states. Ecological momentary assessment (EMA) is used to capture participants’ behaviours, contexts, feeling states, and attitudes by repeatedly sampling in real-time (Shiffman, Stone, & Hufford, 2008). EMA has the potential to yield novel insights into acute psychological factors that may predict or result from participation in exercise interventions (e.g. exercise snacking and/or tai-chi snacking), whilst reducing retrospective response bias that can be observed in a more traditional pre-post design (Dunton, 2017). The use of electronic devices to record survey responses has also been shown to increase compliance rates compared to paper-and-pencil alternatives (Green, Rafaeli, Bolger, Shrout, & Reis, 2006; Stone, Shiffman, Schwartz, Broderick, &

Hufford, 2003). Although disparities in digital literacy skills could influence the success of remote assessments, particularly during COVID-19 (Pantell & Shields-Zeeman, 2020; Xie et al., 2020), there is accumulating evidence to show that electronic EMA is a feasible methodological tool within the older adult population (Cain, Depp, & Jeste, 2009; Maher, Rebar, & Dunton, 2018).

The primary aim of this study was to test the feasibility and acceptability of four weeks of home-based exercise snacking, tai-chi snacking, or combined exercise interventions, delivered remotely to self-isolating older adults during the COVID-19 pandemic. A secondary aim was to explore whether any of these exercise strategies showed signs of improving strength and balance, exercise cognitions, mood, and wellbeing. The purpose of electronic EMA in the present study was to explore 1) the feasibility and compliance of smartphone-based uptake in older adults, and 2) the reciprocal associations between affective and physical feeling states and exercise.

Methods

Study design

This UK based study used a four-arm, assessor blind, randomised controlled trial design, implementing a four-week exercise intervention between two remote assessments. Ethical approval for the study was provided by the XXXXX Ethics Committee (Reference: XXXXX).

Participant recruitment and screening

Participants who were ≥65 years and not participating in regular structured exercise, were recruited between 4th-25th May 2020 to ensure the four-week intervention was undertaken within the prescribed twelve-week COVID-19 lockdown.

The study was advertised on the XXXXX webpage, by local retirement communities or older adult organisations, to prior research participants, and on social media. Potential participants were directed to an online participant information sheet, informed consent form, and screening questionnaire.

Participants were excluded if they had a chronic disease (cardiac, pulmonary, liver or kidney abnormalities, uncontrolled hypertension, or peripheral arterial disease), a current musculoskeletal injury precluding exercise participation, contraindications to exercise (chest pain, dizziness, or loss of consciousness), or had been instructed by their doctor to only do physical activity recommended by them. For safety, potential participants scoring >4 on the Groningen Frailty Indicator (Peters, Boter, Burgerhof, Slaets, & Buskens, 2015) were also excluded.

Eligible participants, all of whom provided informed consent, completed the following validated questionnaires online: the International Physical Activity Questionnaire-elderly short-form (Hurtig-Wennlöf, Hagströmer, & Olsson, 2010); the Short Form (SF-36) Health Survey (Ware, Kosinski, & Keller, 2001), in which higher scores represent better mental or physical health; the Beck Anxiety Inventory (A. T. Beck, Epstein, Brown, & Steer, 1988), in which which low scores and Beck Depression Inventory (A. T. Beck, Ward, Mendelson, Mock, & Erbaugh, 1961), in which lower scores represent low anxiety or depression symptoms; the Subjective Vitality Scale (Ryan & Frederick, 1997), and Satisfaction With Life Scale (Diener, Emmons, Larsen, & Griffin, 1985), both of which are scored from 1 (low) to 7 (high).

Participants were also asked to score various exercise cognitions, namely their perceived competence (Williams & Gill, 1995),which uses a Likert scale from 1 (low competence) to 7 (high competence); self-efficacy (Resnick & Jenkins, 2000), which asks participants to rate their confidence in overcoming eight barriers to exercise such as boredom, pain and stress, from 0 (low self-efficacy) to 100 (high self-efficacy); outcome expectancies (Wójcicki, White, & McAuley, 2009), which uses a Likert scale to rank 15-statements about the expected benefits of exercise from 1 (low outcome expectency) to 5 (high outcome expectency); and habit strength (Verplanken & Orbell, 2003), which uses a Likert scale ranging from 1 (weak habit) to 7 (strong habit). Thereafter, participants were contacted to arrange a video assessment of their strength and balance.

The video assessment was conducted using participants' preferred video calling software. During the call, participants were given the chance to ask questions about the study and provided with instructions for the assessment. Following the initial safety screening using the chair rise (excluded if 5 reps took >16.7s) and balance (excluded if unable to balance >10s with feet together or in semi-tandem stand) components of the short physical performance battery (Guralnik et al., 1994), eligible participants completed a baseline functional assessment. With the camera positioned such that the researcher could see the participant's whole body in the frame, the maximum number of sit-to-stands from a hard-based kitchen chair in 60-seconds was used to assess muscle function. The researcher provided verbal instructions to start and stop the test. Participants then completed tandem stance and single leg balance tests (on both legs), aiming to balance unaided for a maximum possible duration of up to 60-seconds. All functional and questionnaire outcomes were re-assessed at four-week follow-up.

EMA procedures

Participants who were willing and able to partake (i.e. had a compatible smartphone/tablet) received e-mailed instructions on how to install the PIEL Survey application (Jessup, Bian, Chen, & Bundy, 2012) and import the EMA survey file(s). The EMA surveys lasted for up to seven consecutive days and were delivered in two waves, the first in week one and the second in week four. Surveys completed within ten days of participants' planned exercise start-date were considered week one data. Week four data collection was intended to run between days 22-28. Participants received three prompts per day at fixed times: 09:00a.m., 13:00p.m., and 17:00p.m.

Each survey contained 11-13 items depending on participant responses, and took 1-2 minutes to complete. The present study used items assessing participants' current positive affect (summed across three items: happy, cheerful, calm/relaxed), negative affect (summed across four items: stressed, frustrated, tense/anxious, sad/depressed), fatigue, and energy (Liao, Chou, Huh, Leventhal, & Dunton, 2017). Each item was rated on a 5-point Likert-type scale (Liao et al., 2017). Participants had three hours to access each survey; if a prompt was left unanswered, the device emitted a reminder auditory signal after one hour. Once opened, participants had one hour to complete the survey. EMA data were time-stamped; prompts delivered at 09:00 a.m. were coded as morning (reference), 13:00 p.m. as afternoon, and 17:00 p.m. as evening. Day of week was dichotomised as weekday (reference) versus weekend day (coded as 1).

Feasibility and acceptability

To evaluate study feasibility, descriptive data on participant demographics, the remote assessment of physical function, randomisation procedures, retention of participants at follow-up in the main trial and EMA sub study, and completeness of data-collection (including EMA surveys, outcome data and adherence logs), were collated. Acceptability was measured at follow-up with an eight-item online questionnaire based on the dimensions of the theoretical framework of acceptability (TFA, Sekhon, Cartwright, and Francis (2017)). This questionnaire was asked within the context of participants' allocated intervention, with those in the combination group answering twice, once for each mode of exercise. An open question invited participants to provide feedback on the study procedures and the intervention they received.

Intervention

Participants were randomised by an external researcher using block randomisation. To ensure comparability in baseline physical function between study groups, participants were stratified for strength (scoring 'low' if 5 rep sit-to-stand >13.69s, and 'high' if ≤13.69s) and balance (scoring 'low' if time standing on either leg was <10s and high if ≥10s). Couples wishing to take part were allocated to the same group to prevent contamination. Participants were also stratified on the basis of their initial willingness to take part in the EMA component of the study. The lead researcher (IJL) was blinded from participants' group allocation until all follow-up assessments were completed.

Table 1 summarises the interventions. Participants in the exercise snacking (ES), tai-chi snacking (TCS), and combination groups were e-mailed instructions (in written and video format) on how to safely perform the exercises. Participants were also asked to keep an exercise log to record both programme-related and additional outdoor exercise undertaken during the four-week period. They were also instructed to report any adverse events (i.e. injury or illness) that was sustained during the duration of the study. Supplementary file 1 includes the instructions and adherence logs that participants received.

Data handling and analysis

Descriptive statistics on recruitment and adherence were used to interpret the feasibility of this remote assessment, and baseline differences between groups were tested using one-way ANOVA on IBM SPSS Statistics, version 25.0 (IBM Corp., Armonk, New York, USA), or Chi-square/Fisher's exact tests for frequency data on R version 3.6.1 (R Core Team, 2019) with RStudio version 1.2.1335 (RStudio Team, 2019). For quantitative outcomes, baseline and follow-up unadjusted means (SD) were calculated.

EMA data preparation and analysis

EMA data were analysed on R with RStudio. Multilevel logistic regression models examined effects of demographic and time-varying variables on EMA compliance. To test whether prior exercise (recorded in participants' exercise logs) predicted current positive affect, fatigue, and energy, multilevel logistic regression models were used. Feeling states were dichotomised; values below or equal to midscale were coded as 0 (low), and those above as 1 (high). For the reversed sequence, multilevel logistic regression models predicted the probability of participants engaging in some (i.e. non-zero minutes) versus no exercise from their allocated programme (*programme exercise* hereafter) following an EMA survey. For outdoor exercise as the outcome, a two-part model was used (Duan, Manning, Morris, & Newhouse, 1983). The Part 1 equation (multilevel logistic regression) modelled the probability of engaging in some versus no outdoor exercise; the Part 2 equation involved multilevel linear regression models, predicting log-transformed continuous non-zero minutes of outdoor exercise. A detailed account of the EMA analysis plan is presented in Supplementary file 2.

Results

Feasibility

Figure 1 indicates the flow of participants through the study. Of 99 volunteers who responded to the study adverts, 63 passed screening tests and 56 (89%) completed their follow-up assessment. The main reason for exclusion at screening was scoring high for frailty. It should be noted that a further 3 participants initially scored >4 on the GFI owing to mis-interpretation of that particular online survey, which was explained to the lead researcher during an exclusion call. Upon reassessment of GFI those scoring ≤4 were subsequently included in the study providing they also passed the functional safety screening. Baseline characteristics are shown in Table 2. No significant differences were observed in demographic characteristics between groups, which were also well balanced for physical function and inclusion in the EMA component of the study. The sample represented a good split on biological sex and had an age range of 65 to 83 years, but was predominately married, White-British, educated at degree level or greater, and of high socioeconomic status.

Video assessments of included participants, which included the screening and physical function assessment and any discussion about the study or future steps, ranged from 8min19seconds to 16m13s with a mean (SD) duration of 11m33s (2m23s) at baseline. At follow up the assessment time ranged from 05m27s to 15m29s with a mean (SD) duration of 9m04s (2m47s) . The preferred platforms for participants were Zoom (65%) and Skype (25%), with the remaining 10% using

FaceTime and WhatsApp. Anecdotally, we learned that some participants had recently become competent in using Zoom and other video calling mediums during the COVID-19 pandemic to contact friends and family and participate in social events during the lockdown. Others, however, were still novices in using these technologies and needed support locating their camera and positioning their physical device appropriately. There were no adverse events or safety concerns in any of the 119 completed functional assessments completed before and after the intervention. There were however five reported adverse events during the active four-week intervention phase of the study, only one of which was deemed potentially related to undertaking of exercise in the exercise snacking group: an exacerbation of a previously sustained knee injury during the sit-to-stand exercise. The four other adverse events unrelated to the intervention were: a back injury, a minor elective surgery, a severe bacterial infection, and an ankle injury not sustained during the study exercise.

Adherence and acceptability

Of the 56 participants who completed follow-up, 5 stopped exercising before the end of the four-week programme. Completed logs were available for 47 participants. These indicated a mean(SD) number of days attempted (out of 28) of 26(3) for the ES group, 26(6)for the TCS group and 26(4) for the combination group. The mean percentage adherence in completing all prescribed intervention exercises over the four weeks (out of 280) was 90% for the ES group, 84% for the TCS group and 83% for the combination group. From the exercise logs, we observed that primary reasons for missing exercises included symptoms of illness, fatigue, bodily pain, or lack of time due to other commitments (e.g. work). The control group reported a mean of 12 out of 28 days upon which NHS website informed exercises were completed. Conversely, they reported a higher mean(SD) amount of ‘other outdoor exercise’ across the intervention period, recording 103(76) minutes per day compared to 49(28) minutes in the ES, 48(27) minutes in the TCS, and 68(60) minutes in the combination groups.

Exercise snacking was rated as the most acceptable intervention, outscoring TCS and NHS control in all TFA domains apart from coherence (clarity on *how* the intervention helps strength and balance) (Figure 2). Qualitative feedback provided at follow-up indicated that exercise snacking had clear instructions and was easy to do and record. However, for some participants who were used to doing more strenuous sport or exercise, it was deemed ‘boring’. For others, focussing on upper- *and* lower-body muscles would have been of interest. Several tai-chi snacking participants mentioned the video and descriptive instructions lacked clarity and would prefer to follow mirrored demonstrations in real time. While some liked the tai-chi, others said that their lack of ability to perform exercises accurately was frustrating and undermined their confidence to continue. The NHS website was criticised for lacking specificity, although did help some individuals initiate new exercises.

Outcome data

Table 3 displays the mean pre and post scores for all outcome data in each trial arm. In all four groups saw an increase in 60s chair rise number and reduction in 5 repetition time at four weeks. Balance scores were mixed, with the ES and combination groups observing a reduction in right leg balance, albeit with wide at the group level variance in scores. Total physical activity, MVPA and sedentary time all improved at follow-up relative to baseline, however walking time went down in each group. There was a notable trend in barrier self-efficacy reducing between pre and post assessment across the four groups, with little change in other exercise cognitions. Vitality, life satisfaction and quality of life scores remained stable in all groups, and although some fluctuation in anxiety and depression scores were observed these remained at sub-clinical levels (i.e. scores <9 anxiety (Julian, 2011), <13 depression (A. Beck, Steer, & Brown, 1996)).

EMA data availability and compliance

30 individuals (of the 58 contacted) participated in EMA in week one, and 23 were retained in week four. The most frequently encountered technical issues impeding participation in the EMA component included 1) device incompatibility with the PIEL Survey application (i.e. old smartphone/tablet models), and 2) difficulties installing the application and/or importing the survey file(s) (Figure 1, Supplementary file 2). This led to 1017 observations out of a maximum of 1260 (if all participants had 14 days of complete data), and a compliance rate of 96% (i.e. out of 1059 delivered surveys). 28 participants had at least some available exercise log data.

Participants completed an average of 34 surveys. Participants were more likely to miss a survey later in the day (OR = 2.01, $p = 0.001$), and on weekend days versus weekdays (OR = 2.24, $p = 0.013$).

EMA descriptive statistics

Participants completed an average of 3.3 (SD = 6.4) minutes of programme exercise, and 24.0 (SD = 51.3) minutes of outdoor exercise, prior to an EMA survey. Conversely, participants averaged 3.3 (SD = 6.2) minutes of programme exercise, and 24.5 (SD = 51.9) minutes of outdoor exercise, after a survey. Older adults also reported, on average across all observations, moderate positive affect (Mean = 11.47, SD = 2.23, 1–15 scale), low negative affect (Mean = 4.90, SD = 1.50, 1–20 scale), low fatigue (Mean = 1.79, SD = 0.83, 1–5 scale), and moderate energy (Mean = 3.24, SD = 0.93, 1–5 scale).

Prior exercise predicting current feeling states

Completing more programme exercise (minutes) prior to an EMA survey was associated with a greater probability (OR = 1.52, p = 0.014) of reporting high energy levels at the between-person level, and a lower probability (OR = 0.67, p = 0.021) of reporting high energy levels at the within-person level (Table 4). Prior exercise was unrelated to current positive affect and fatigue.

Feeling states predicting subsequent exercise

Feeling more energetic than one's usual level (within-person effect) was associated with a higher probability of engaging in some outdoor exercise following an EMA survey (OR = 1.73, p = 0.021; Table 5). No significant relationship was found for positive affect, negative affect, or fatigue and subsequent exercise.

Discussion

In this study, we provide evidence for the acceptability of remotely delivered home-based exercise programmes for older adults undergoing self-isolation, and of assessing older adults' physical function via video calling technology. Remote assessments that comprised two components of the validated SPPB, and other bespoke strength and balance activities, were performed safely and efficiently, with

89% of participants completing their follow-up assessment. The intervention arms were well adhered to in the trial, with exercise snacking being considered the most acceptable format, and all groups improving functional outcome scores.

Only one adverse event (exacerbating a pre-existing injury) relating to the intervention was observed, in the exercise snacking group, suggesting each programme was safe. Qualitative feedback suggests that exercise snacking was considered useful in the self-isolation context but may be better suited to people who are otherwise unable or lack the desire to do other forms of exercise in normal conditions. Tai-chi snacking may be made more acceptable for home delivery with improved real-time video instruction and simpler movements for novices.

These data suggest that undertaking any form of exercise may help to improve certain measures of physical function and wellbeing over a four-week period of self-isolation. Nevertheless, it is important to consider the context and reliability of measures when interpreting these findings. Sixty-second sit-to-stand scores at baseline in the present study (32±9) were comparable to a previous laboratory-based investigation in healthy older adults (29±11) (Perkin et al., 2019). However, all groups in the present study improved sit-to-stand score, whereas the control group in the aforementioned study saw no change in sit-to-stand score. With low sample sizes, it is difficult to identify whether this was due to the interventions themselves, or due to the lack of a familiarisation with the test before baseline assessment. Moreover, whilst the functional assessments were successfully administrated in this study, the precision of timing and scoring has yet to be validated for remote delivery.

Similarly, in spite of social distancing regulations, some members of the recruited population (i.e. those <70 years old (32% in this study)) may have also increased their overall physical activity behaviour, as was observed in the pre- and post-IPAQ scores for all groups, due to relaxing of social distancing measures. There were certainly differences in the reported amount of outdoor exercise, which was highest in the control group. Multilevel modelling of EMA data showed that the amount of prescribed programme exercise predicted lower momentary feelings of energy at the within-person level, which in turn influenced the likelihood of participants engaging in (reported) outdoor exercise. However, caution is advised when interpreting results from the multilevel logistic and linear regression models reported in the present study, due to a small sample size (or set of observations) at the prompt and person level (Maas & Hox, 2005; Moineddin, Matheson, & Glazier, 2007). Future research may seek to employ accelerometer and gyroscope integrated technology to provide objective data on behaviour and movement characteristics. Combined with event-contingent sampling (e.g. triggering EMA prompts in response to participants reaching pre-defined physical activity thresholds), these suggestions could help to clarify causation in the relationship between exercise and energy (Bernstein, Zawadzki, Juth, Benfield, & Smyth, 2018; Kanning & Hansen, 2017), whilst simultaneously facilitating a more detailed analysis of physical function (Dasenbrock, Heinks, Schwenk, & Bauer, 2016).

As the world moves through and beyond the COVID-19 pandemic, it is expected that telemedicine and remote delivery of health care and research, including preventive medicine, will be commonplace (Richardson et al., 2020). It is important to ensure that moves towards an eHealth landscape do not widen health inequalities (Hargittai, Piper, & Morris, 2019). In the present study, it was encouraging to observe that older adults were able to undergo efficient video call assessments and retrieve video instruction with little requirement for support. However, participants were well-educated individuals from areas of low deprivation who, owing largely to the web and email-based recruitment and assessment methods, may possess a reasonable digital literacy, albeit not all were able to take part in the EMA surveys. Indeed, of the 92% of main study participants who expressed an interest in the EMA component, only 52% were enrolled (and had at least one wave of EMA data). Nevertheless, disregarding missing data caused by technical difficulties, there was a 96% compliance rate. Although high compliance may in part be explained by the low sampling density employed in the present study relative to other EMA protocols with older adults (Cain et al., 2009), the results offer further support for electronic EMA as a feasible tool for assessing dynamic psychological states in this population.

Likewise, the snacking interventions themselves were designed to be inclusive, requiring very little time or equipment, and the general adherence was accordingly very good. However, with 20% of potential participants excluded due to a Groningen Frailty Indicator score over 4 (Figure 1), ensuring that individuals, who arguably are more in need of improving physical function, can safely be provided with exercise interventions remotely remains a challenge. Indeed, in the present study there were three further participants who would have been excluded but for a reassessment of GFI after raising their misreporting with the lead researcher, suggesting that a snapshot assessment using a self-report, multidimensional, measure may not be the optimal strategy for assessing frailty. Investigating ways of recruiting those who would benefit most, i.e. potentially frail clinical outpatient populations, and those of lower socioeconomic status for whom technology may be a pertinent barrier, is another important future step.

Strengths of the study include the randomised design, the successful blinding of the outcome assessment and the comprehensive logging of adherence and other activity undertaken during the intervention period. There are however important limitations to acknowledge. Firstly, given the exploratory nature of this study and primary focus on establishing feasibility this study was not powered for a robust statistical analysis of the intervention effect. Further trials with larger sample sizes are needed to establish the efficacy of the exercise- and tai-chi-snacking interventions used in the present trial and confirm the EMA findings. Secondly, there were elements of the feasibility data capture that were reported anecdotally and whose precision could be improved in further studies. This includes the reporting of participant competence in using video-calling software and the degree of support required, and the call duration which used the total call time from available software and could not disaggregate the assessment from other talking within the call. Finally, although the dose exercise within the three intervention arms was equivalent, the nature of the exercises themselves were not and therefore, differences in how these were received and any impact on functional and mental health may be a result of discrepancies in modality. Future studies should not only look at the efficacy, but also the mechanisms by which exercise and tai-chi- snacking may benefit people when coming up with an optimal implementation strategy.

Conclusion

During the COVID-19 pandemic, older adults were asked to socially distance in their homes, which may contribute to reduced physical function. Finding ways to maintain strength and balance in the home setting that conform to social distancing policy and do not risk injury could be a critical step in this and future pandemics. Remote assessment of physical function, and delivery of exercise snacking and tai-chi snacking interventions were deemed to be acceptable and safe. Future research should seek to optimise these exercise formats, precisely measure physical activity and function, and recruit more diverse samples who would benefit from simple, effective home-based exercise. Such advancements would also help to clarify the reciprocal associations between feelings of energy and exercise engagement observed in the EMA analysis and investigate other psychological states that may serve as antecedents or consequences of home-based snacking exercise.

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Table 1 – Description of the exercise interventions each trial arm was asked to complete

Intervention Arm	Description	Frequency
Exercise snacking (ES)	Five movements [sit-to-stand from a chair, seated knee extensions of alternating legs, standing knee bends of alternating legs, marching on the spot, and standing calf raises], each undertaken for one minute with the aim of completing as many repetitions as possible. Participants rested for one minute between exercises.	Twice per day for 28 days
Tai-chi snacking (TCS)	Five Chen Style Tai-Chi movements [cloud hands, going left, stand on one leg, single whip, snake creeps through the grass, front heel kick], each undertaken for one minute with the aim of completing them as accurately and gently as possible. Participants rested for one minute between exercises.	Twice per day for 28 days
Combination	Participants were instructed to do one exercise snacking bout and one tai-chi snacking bout (as described above).	One set of each exercise per day for 28 days
Control	Participants were provided with a link to the NHS webpage titled ‘Physical activity guidelines for older adults’[29]	Not prescribed

Table 2. Baseline characteristics of randomised study participants

	Total N=63	ES N=15	TCS N=16	Combination N=15	Control N=17
Female, n (%)	34(54)	10(67)	10(63)	5(33)	9(53)
Age, mean ± SD	72.2±4.7	71.1±3.6	72.6±5.0	73.3±5.3	71.9±4.7
65-73 years old, n (%)	40(63)	12(80)	10(63)	8(53)	10(59)
74+, n (%)	23(37)	3(20)	6(38)	7(47)	7(41)
Living alone, n (%)	13(21)	2(13)	4(25)	2(13)	5(29)
Marital status, n (%)					
Married/ civil part.	47(75)	13(87)	10(63)	12(80)	12(71)
Divorced/Separated	8(13)	2(13)	2(13)	1(7)	3(18)
Widowed	3(5)	0(0)	1(6)	1(7)	1(6)
Cohabiting	3(5)	0(0)	2(13)	1(7)	0(0)
Single	2(3)	0(0)	1(6)	0(0)	1(6)
Employment, n (%)					
Retired	52(83)	10(67)	12(75)	15(100)	15(88)
Employed part-time	8(13)	3(20)	3(19)	0(0)	2(12)
Doing unpaid work	2(3)	2(13)	0(0)	0(0)	0(0)
Unable to work	1(2)	0(0)	1(6)	0(0)	0(0)
Educational status, n (%)					
Secondary Education	5(8)	1(7)	0(0)	2(13)	2(12)
Post-Secondary	8(13)	2(13)	2(13)	2(13)	2(12)
Vocational Qualification	12(19)	2(13)	1(6)	4(27)	5(29)
Undergraduate Degree	18(29)	5(33)	4(25)	4(27)	5(29)
Post-graduate Degree	15(24)	4(27)	8(50)	1(7)	2(12)
Doctorate	5(8)	1(7)	1(6)	2(13)	1(6)
Index of Multiple Deprivation (IMD) decile, n	57	14	13	14	16
mean ± SD	8.0±2.2	8.4±1.8	7.8±2.7	7.6±1.9	8.3±2.4
Physical function, n (%)					
High	40(63)	9(60)	10(63)	9(60)	12(71)
Low	23(37)	6(40)	6(38)	6(40)	5(29)
GFI, mean ± SD	2.0±1.2	1.7±1.2	2.4±1.4	2.1±1.0	1.9±1.3
Pre-COVID IPAQ, n	56	13	15	13	15
MET-mins·week^{-1}, (mean ± SD)	2986±1419	3691±1310	2705±1708	2514±1123	3066±1294

GFI, Groningen Frailty Indicator; IPAQ, International Physical Activity Questionnaire (short form); MET, metabolic equivalent of task. [a]Differences between groups were analysed using Chi-square tests. [b]Analysed using Fisher's exact test. [c]Analysed using one-way ANOVA with a Scheffe post hoc test. IPAQ data were processed, cleaned and analysed in accordance with recommendations outlined in the "Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire" manual. "Pre-COVID IPAQ" refers to participants' estimated physical activity levels in a "typical" week prior to the lockdown period.

Table 3. Mean (SD) unadjusted outcome data for each group pre- and post-intervention

Outcome	Exercise snacking		Tai-chi snacking		Combination		Control	
	Pre (N=15)	Post (N=14)	Pre (N=16)	Post (N=15)	Pre (N=15)	Post (N=14)	Pre (N=17)	Post (N=16)
Physical function, n	15	14	16	13	15	13	17	16
5 reps sit-to-stand speed (s)	9.6(3.3)	7.9(3.5)	10.5(2.3)	9.0(1.7)	10.5(2.6)	8.9(2.5)	11.0(2.4)	9.6(2.5)
60-s sit-to-stand (N reps)	35.6(12.3)	41.9(15.5)	30.1(9.8)	36.0(10.1)	31.5(7.6)	35.3(10.0)	29.5(6.6)	33.2(7.8)
Right leg standing balance (s)	44.9(23.0)	39.5(19.3)	26.0(20.8)	34.5(23.9)	36.9(23.7)	29.8(19.3)	39.3(21.6)	38.9(21.9)
Left leg standing balance (s)	35.0(24.4)	41.2(22.1)	31.5(24.4)	40.0(21.3)	30.6(24.1)	40.2(22.3)	31.1(22.4)	43.1(18.2)
Physical activity, n	13	14	14	14	15	13	16	14
IPAQ score (MET-mins·week^{-1})	3464(1910)	3617(2502)	2916(2422)	3732(2716)	2731(1532)	3665(2678)	3176(2878)	3761(2604)
MVPA time (min·day^{-1})	67.4(56.4)	73.0(60.2)	45.3(46.8)	76.2(56.5)	61.9(59.2)	87.6(81.1)	43.6(62.7)	64.2(57.9)
Sedentary time (min·day^{-1})	408.5(113.3)	357.9(130.7)	413.6(124.1)	382.0(144.3)	452.6(130.8)	382.1(136.3)	449.3(135.2)	395.1(121.4)
Walking Time (min·day^{-1})	64.2(52.6)	63.2(51.4)	62.4(47.8)	58.5(56.3)	40.8(30.5)	38.0(30.1)	78.2(52.9)	71.4(48.2)
Exercise Cognitions								
Barrier self-efficacy	70.5(14.6)	62.9(16.9)	67.3(18.2)	56.3(17.7)	65.1(14.8)	62.4(19.0)	71.4(15.3)	56.4(14.6)
Competence	6.4(0.9)	6.2(1.0)	5.6(1.3)	5.5(1.5)	6.1(1.1)	6.1(1.3)	6.4(0.9)	6.0(1.2)
Habit strength	5.2(1.3)	4.5(1.7)	2.9(1.7)	3.9(1.6)	3.5(1.8)	3.6(1.9)	4.6(1.0)	4.4(1.6)
Outcome expectancies	62.3(7.7)	60.4(8.4)	53.8(10.0)	53.8(13.6)	59.4(7.9)	56.4(10.0)	60.6(6.3)	57.3(8.2)
Health and Wellbeing								
Anxiety	2.1(2.3)	4.0(4.8)	5.3(6.2)	7.9(10.4)	5.1(3.7)	3.9(2.3)	4.6(5.4)	4.2(5.3)
Depression	5.8(4.2)	9.4(8.8)	8.6(7.0)	8.8(8.4)	8.1(4.6)	8.6(5.3)	7.0(3.2)	6.2(4.8)
Vitality	4.9(1.2)	4.7(1.2)	4.2(0.9)	4.6(1.4)	4.3(1.2)	4.5(1.4)	4.4(1.1)	4.7(1.2)
Satisfaction with life	26.5(5.5)	25.2(8.3)	23.7(6.8)	25.1(6.5)	25.4(5.7)	26.1(6.0)	27.6(3.9)	28.5(3.8)
Physical health (SF-36)	51.9(5.2)	49.5(9.7)	47.6(11.1)	46.8(11.2)	47.0(7.3)	48.6(6.6)	49.8(7.3)	48.6(9.1)
Mental health (SF-36)	56.0(7.7)	53.9(6.8)	52.8(10.7)	56.2(5.5)	57.2(5.0)	55.6(7.6)	54.4(6.3)	55.1(7.7)

IPAQ, International Physical Activity Questionnaire (short form); MET, metabolic equivalent of task; MVPA, moderate to vigorous intensity physical activity. IPAQ data were processed, cleaned and analysed in accordance with recommendations outlined in the “Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire” manual.
Note: Item 30 was omitted from the SF-36 Health Survey due to an administrative error in survey construction.

Table 4. Associations between prior exercise and current feeling states

		Feeling states		
		Positive affect	Fatigue	Energy
		Odds ratio (SE)	Odds ratio (SE)	Odds ratio (SE)
Programme exercise	BP effect	1.30(0.18)	0.75(0.17)[a]	**1.52(0.17)*[a-c]**
	WP effect	0.82(0.17)	1.02(0.12)	**0.67(0.17)***
Outdoor exercise	BP effect	1.00(0.02)	1.01(0.02)[a]	1.00(0.02)[a, c]
	WP effect	1.01(0.02)	1.00(0.02)	1.00(0.02)

SE standard error. Bold denotes statistical significance (*$p < 0.05$).
Multilevel logistic regression models predicting current feeling states. Programme exercise as the predictor: Level-2 $n = 27$, Level-1 $n = 905$; outdoor exercise as the predictor: Level-2 $n = 28$, Level-1 $n = 925$
[a]Indicates the model additionally controlled for time of day; [b]Indicates the model additionally controlled for programme allocation; [c]Indicates the model additionally controlled for wave.
Note: Each set of outcome and predictor (variables disaggregated into between- [BP] and within-person [WP] predictors were included in the same model) variables was tested in a separate model. No results are reported for negative affect as all values were below or equal to midscale.

Table 5. Associations between feeling states and subsequent exercise

		Exercise		
		Programme[1]	Outdoor	
			Part 1 model[2]	Part 2 model[3]
		Odds ratio (SE)	Odds ratio (SE)	Estimate (SE)
Positive affect	BP effect	1.06(0.06)[a-c]	0.99(0.07)	-0.05(0.08)[d]
	WP effect	0.96(0.08)	1.01(0.09)	0.09(0.08)
Negative affect	BP effect	1.15(0.11)[a-c]	0.91(0.14)	0.01(0.15)[d]
	WP effect	0.89(0.13)	1.13(0.15)	-0.02(0.15)
Fatigue	BP effect	0.83(0.31)[a-c]	1.18(0.35)	0.01(0.31)
	WP effect	0.95(0.33)	0.64(0.36)	-0.13(0.31)
Energy	BP effect	1.23(0.17)[a-c]	0.97(0.21)	-0.26(0.23)[d]
	WP effect	1.05(0.20)	**1.73(0.24)***	0.27(0.24)

SE standard error. Bold denotes statistical significance (*$p < 0.05$).
[1]Multilevel logistic regression models predicting the probability of engaging in some versus zero minutes of programme exercise. Level-2 $n = 27$, Level-1 $n = 901$
[2]Multilevel logistic regression models predicting the probability of engaging in some versus zero minutes of outdoor exercise. Level-2 $n = 28$, Level-1 $n = 924$
[3]Multilevel linear regression models predicting the log-transformed non-zero minutes of outdoor exercise. Level-2 $n = 28$, Level-1 $n = 289$
[a]Indicates the model additionally controlled for time of day; [b]Indicates the model additionally controlled for programme allocation; [c]Indicates the model additionally controlled for wave; [d]Indicates the model additionally controlled for day of week.
Note: Each set of outcome and predictor (variables disaggregated into between- [BP] and within-person [WP] predictors were included in the same model) variables was tested in a separate model.

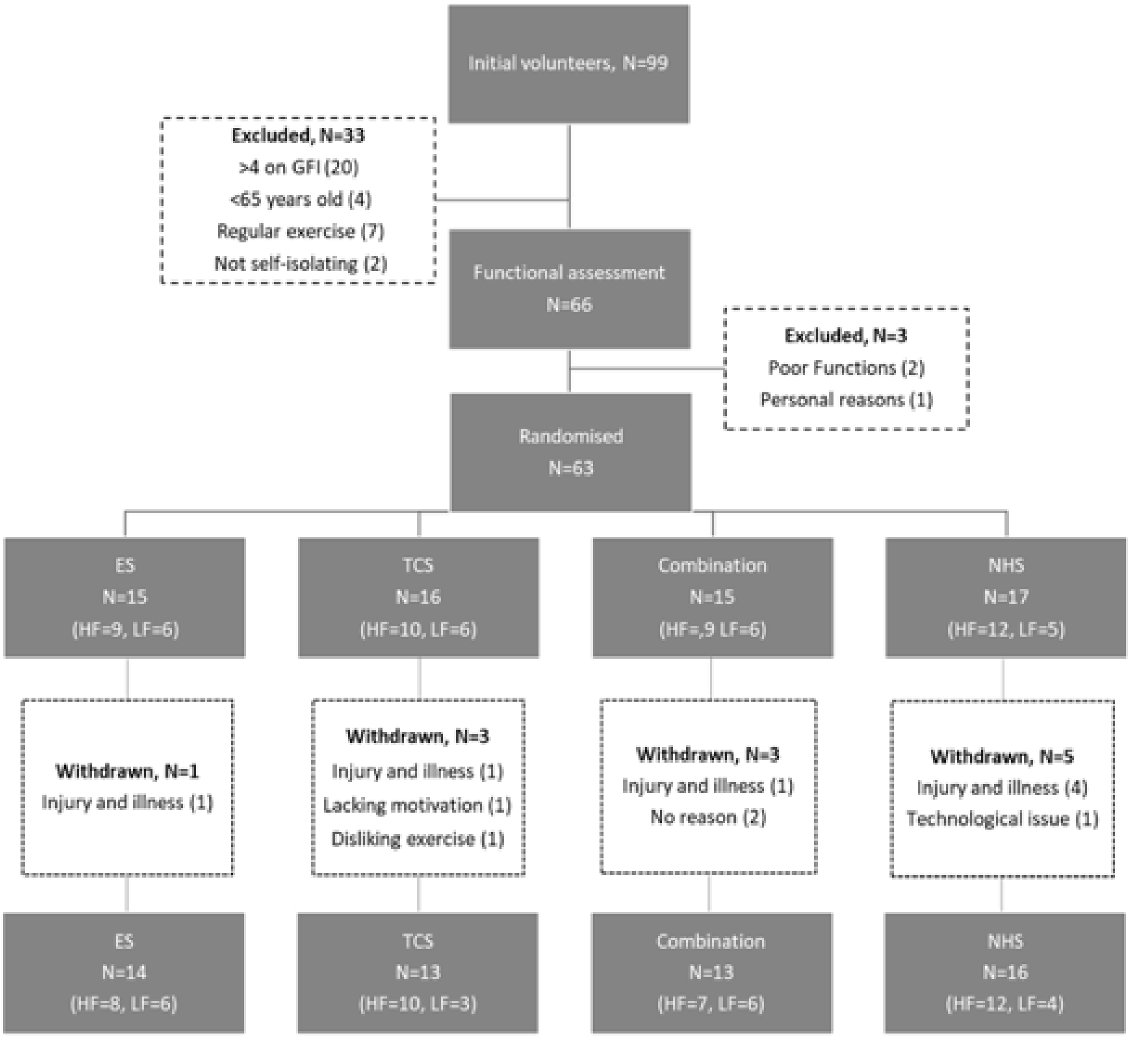

Figure 1. Flow diagram of participation throughout all aspects of the study. 33 participants were deemed ineligible. ES, exercise snacking; TCS, tai-chi snacking; Combination, exercise snacking and tai-chi; NHS, NHS exercise advice; HF, high function; LF, low function; GFI, Groningen Frailty Indicator.

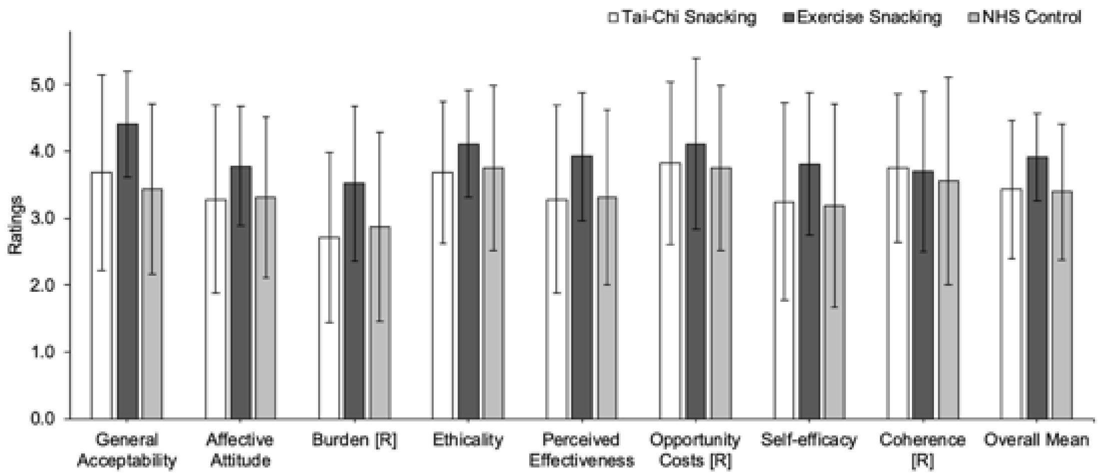

Figure 2. Acceptability of the respective intervention formats based on TFA dimensions. Data are means with error bars representing the SD. Tai-Chi Snacking, *n* = 28; Exercise Snacking, *n* = 27; NHS Control, *n* = 16. [R] indicates ratings were reverse-coded.