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Physical activity and health during the SARS-CoV2 pandemic

Dissertation

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List of contents

Zusammenfassung

Zahlreiche Staaten haben während der SARS-CoV2-Pandemie das öffentliche Leben eingeschränkt. Da die ergriffenen Maßnahmen auch den Zugang zu Sporteinrichtungen reduzierten, verfolgte diese Dissertation das Ziel, (1) in betroffenen Ländern Veränderungen der körperlichen Aktivität (KA) und des Wohlbefindens zu untersuchen sowie (2) vor diesem Hintergrund die Wirksamkeit eines digitalen Heimtrainingsprogramms zu ermitteln.

Teil 1 (KA/Wohlbefinden) der Dissertation besteht aus einer digitalen Umfrage in 14 Ländern. Die Teilnehmer (n=13.503 gültige Antworten) gaben an, dass sich ihre KA (NPAQ-SF) während der Restriktionen um 41 - 42% reduziert hat. Der Erfüllungsgrad internationaler KA-Empfehlungen sank um knapp 19%. Weiter kam es zu einer Abnahme des mentalen Wohlbefindens (n=14.975 gültige Antworten; 68,1 auf 51,9 Punkte im WHO-5 Index) und einer Verdreifachung des Anteils an Personen mit erhöhtem Depressionsrisiko (14,2% auf 45,2%). Beim physischen Wohlbefinden (SF-36 Schmerz) ergab sich eine geringfügige Abnahme (85,8% auf 81,3%). Etwas mehr als zwei Drittel (68,1%) der Befragten gaben an, an digitalen Heimtrainingsprogrammen interessiert zu sein.

Für Teil 2 (digitales Heimtraining) der Dissertation wurden in einer internationalen Multicenter-Studie gesunde Erwachsene (n=763; 33±12 Jahre) zufallsbasiert einer Interventions- (IG) oder Kontrollgruppe (KG) zugeteilt. Im Gegensatz zur KG konnte die IG für vier Wochen an mittels Live-Videostreaming übertragenem Heimtraining teilnehmen. Hiernach erhielten beide Gruppen weitere vier Wochen Zugang zu aufgezeichneten Trainingseinheiten. Die Outcome-Erhebung erfolgte wöchentlich mittels validierter Fragebögen. Die Mixed-Models-Datenanalyse ergab gegenüber der KG eine Steigerung der KA um das bis zu 1,65-fache (95% CI: 1,4 - 1,94; Woche 1) sowie geringfügige Verbesserungen von Sportmotivation (SKK-Skala), psychischem Wohlbefinden (WHO-5 Index), Schlafqualität (MOS Sleep Scale) und Angst-Symptomen (GAD-7 Scale).

Die Ergebnisse vorliegender Dissertation zeigen erstmals, dass pandemiebedingte Einschränkungen des öffentlichen Lebens negative Auswirkungen auf das Bewegungsverhalten und Wohlbefinden haben. Digitale Heim-Trainingsprogramme stellen eine wirksame Maßnahme zur Erhaltung

und/oder Steigerung von gesundheitsförderlicher KA und Wohlbefinden dar und eignen sich daher als unterstützende Bausteine der Pandemie-Bekämpfung.

Summary

Many countries have restricted public life during the SARS-CoV2 pandemic. As related measures limited the access to sports facilities, this dissertation aimed (1) to examine changes in physical activity (PA) and well-being in affected countries, and (2) to determine the effectiveness of a digital home exercise program in this context.

Part 1 (PA/well-being) of the dissertation was a digital survey administered in 14 countries. Participants reported a 41 - 42% reduction of PA (NPAQ-SF) during restrictions (n=13,503 valid responses). Compliance with international PA guidelines decreased by nearly 19%. Mental well-being declined substantially (n=14,975 responses; 68.1 to 51.9 points on the WHO5 index) and the proportion of individuals at risk of depression tripled (14.2% to 45.2%). Physical well-being (SF-36 Pain) decreased slightly (85.8% to 81.3%). About two thirds (68.1%) of the respondents reported being interested in digital home exercise.

For Part 2 (digital home exercise) of the dissertation, an international multicenter randomized, controlled trial was performed allocating healthy adults (n=763; 33±12 years) to an intervention (IG) or control (CG) group. In contrast to the CG, the IG was offered live-streamed home exercise for four weeks. Subsequently, both groups had access to pre-recorded workouts for another four weeks. Outcomes were measured weekly using validated questionnaires. Mixed-models data analyses revealed an up to 1.65-fold (95% CI: 1.4-1.94; week 1) increase of PA relative to the CG. Moreover, small improvements in exercise motivation (SKK scale), psychological well-being (WHO-5 index), sleep quality (MOS Sleep Scale), and anxiety symptoms (GAD-7 Scale) were observed for IG.

The results of this dissertation suggest that public life restrictions associated with the pandemic had significant adverse effects on movement behavior and well-being. Digital home exercise can help to maintain and/or increase health-beneficial PA and well-being and may hence represent a supportive element of viral containment efforts.

List of abbreviations

ASAP – Activity and Health during the SARS-CoV2 pandemic

COVID-19 – Coronavirus Disease 2019

CG – Control Group

CI – Confidence Interval

CPGS – Chronic Pain Grade Scale

GAD-7 – Generalized Anxiety Scale

HEPA - Health-Enhancing Physical Activity

IG – Intervention Group / Interventionsgruppe

KA – Körperliche Aktivität

KG - Kontrollgruppe

LTE – Long Term Evolution

MOS – Medical Outcome Study

MET – Metabolic Equivalent of Tasks

MERS – Middle East Respiratory Syndrome

NPAQ-SF – Nordic Physical Activity Questionnaire – short form

OR – Odds Ratio

PA – Physical Activity

SARS-CoV2 – Severe Acute Respiratory Syndrome – Coronavirus 2

WHO – World Health Organization

WiMAX - Worldwide Interoperability for Microwave Access

Overall summary

Introduction

Physical activity and health

The regular engagement in physical activity (PA) represents an essential cornerstone of health. Meta-analyses pooling data from prospective cohort studies have demonstrated the effectiveness of PA in preventing both, major non-communicable diseases such as cancer, stroke, diabetes, and Parkinson's disease, as well as a variety of mental disorders including anxiety and depression.[1-4] A favorable impact of PA can also be observed in diseased populations. For each 10 MET[1] hours accumulated per week, mortality risk decreases by 4% in diabetes, 12% in ischemic heart disease, 22% in breast cancer, and 30% in chronic obstructive pulmonary disease.[5] On the other hand, physical inactivity, which has been coined the "leading cause of disease and disability" by the World Health Organization (WHO),[6] has substantial adverse effects: Ranking fourth in global causes of death,[7] its worldwide elimination would prevent more than 5 million annual deaths while extending individual life expectancy by almost one year.[8]

In view of the compelling evidence suggesting a pivotal role of PA in health protection, international societies and organizations have developed guidelines detailing optimal amounts of habitual PA. For instance, the WHO recommends a weekly minimum of 150 to 300 minutes of moderate activity, a minimum of 75 to 150 minutes of vigorous activity or any adequate combination of both.[9] A considerable portion of the general population, however, does not achieve the specified activity levels. According to the European Social Survey reporting data from 52,936 individuals, less than two out of three persons (61.5%) comply with the WHO recommendations.[10] The promotion of PA, e.g., via international

[1] Human energy consumption varies depending on the type and intensity of an activity. The metabolic equivalent of tasks (MET) takes this into account by making different activities comparable as a dimensionless quantity. Ten MET hours, for example, correspond to about three hours of walking or just under one and a half hours of jogging.[5]

initiatives such as ‘Exercise is Medicine’[11] or the WHO network HEPA (Health-Enhancing Physical Activity)[12] thus retains high relevance.

Public life restrictions during the SARS-Cov2 pandemic

The novel coronavirus pandemic, recognized as such by WHO in March 2020, not only represents a direct threat to health. In an attempt to curb the spread of the virus (SARS-CoV2), many governments have issued restrictions of public life. While the associated measures, inter alia including stay-at-home orders and business closures, showed some effectiveness in controlling the contagion,[13-15] they also limited the availability of physical activity spaces: Gyms, sports clubs and parks were (partly) rendered inaccessible. It could therefore be expected that the confinements instituted by law – as a side effect – reduced the total amount of PA as well as the degree of compliance with associated guidelines. This would have severe consequences. In addition to their above described general health effects, PA and exercise have a direct impact on the pandemic. Working out increases the concentration of lymphocytes and stimulates the production of cytokines needed for the immune response.[16,17] Active individuals, beyond this, have a lower mortality risk in a variety of virus diseases (e.g., influenza[18]) and less frequently attract upper respiratory tract infections.[19] Sallis et al.[20] analyzed health data from 48,440 adults diagnosed with COVID-19. Inactive individuals had a higher risk of hospitalization (Odds Ratio [OR] 2.3), intensive care unit admission (OR 1.7) and death (OR 2.5) compared to persons meeting physical activity guidelines.

Public life restrictions aiming to reduce interpersonal contact may also compromise mental well-being. Quarantines and isolations mandated during previous epidemics (e.g., SARS, MERS or Ebola) caused a variety of complaints including post-traumatic stress syndrome, confusion, anger and depression.[21] Generally, regular PA is known to avert and improve anxiety and symptoms of depression[22-24] while being significantly associated with positive affect and life satisfaction.[25] If conventional PA (e.g., in gyms, sports clubs, and parks) would be decreased due to government-enforced lockdowns, the above benefits could no longer be exploited. New strategies are consequently warranted to maintain or increase individual PA levels. Specifically, digital home training represents an intriguing alternative to traditional approaches as it can be performed reaching out to many persons while conforming to the demand for social distancing.

Objectives

The papers summarized in this dissertation had two central aims. The first was to investigate changes in PA and proxies of mental and somatic health during lockdowns associated with the SARS-CoV2 pandemic. Building on these findings, the second objective was to examine the effectiveness of digital live-streamed home exercise to preserve or improve PA and said markers of health.

Publications of the dissertation

In March 2020, the author of this dissertation founded the ASAP (**A**ctivity and health during the **SA**RS-CoV2 **p**andemic) network to examine the consequences of the pandemic for movement and health. It represents an international and interdisciplinary initiative of members from 17 worldwide academic partner institutions: Goethe University Frankfurt (Germany), Medical School Hamburg (Germany), Karl Franzens University Graz (Austria), Basel University (Switzerland), Free University Amsterdam (Netherlands), Jean Monnet University Saint-Étienne (France), Foro Italico University of Rome (Italy), University of Cádiz (Spain), Technical University of Madrid (Spain), Durban University of Technology (South Africa), University of Queensland (Australia), Harvard Medical School (USA), Changi General Hospital (Singapore), Waterford Institute of Technology (Ireland), University of Santiago of Chile (Chile), Foundation University Health Sciences (Argentina), and University of the city of Sao Paulo (Brazil). Works of the consortium produced a series of papers and the following five[2] are part of this dissertation.

Publication A

The study protocol presented the overall structure and the rationale of the ASAP project. It was composed of a) a large multinational survey assessing changes of PA as well as selected markers of mental and somatic health in the countries of

[2] For the full citation, please refer to the chapter "Overview of publications"

all contributing partners (results reported in publications B-D) and b) a multicenter randomized-controlled trial assessing the effects of a live-streamed digital home exercise program (results reported in publication E).

Publication B

The PA part of the ASAP survey was completed by a total of 13,503 individuals from 14 countries with active lockdown measures (Argentina, Australia, Austria, Brazil, Chile, France, Germany, Italy, Netherlands, Singapore, South Africa, Spain, Switzerland, United States).

From pre- to during restrictions, PA levels, assessed with the Nordic Physical Activity Questionnaire-short form, decreased by 41% (moderate and vigorous activities) and 42.2% (vigorous activities only), respectively. Reductions were larger in young and elderly vs. middle-aged individuals, during occupational vs. leisure time and in more active vs. less active persons. While 81% of the sample reported compliance with the WHO PA guidelines before restrictions, this portion dropped to 62.5% during restrictions. With regard to light PA (e.g. walking), more than three quarters of the sample (75.5%) indicated decreases during restrictions.

Publication C

A total of 14,975 valid responses were obtained in the well-being section of the ASAP survey. During restrictions, mental well-being (assessed with the WHO-5 index) decreased substantially from 68.1 to 51.9 points which was associated with a more than threefold increase in persons meeting the cut-off score for depression screening (14.2% pre-restrictions vs. 45.2% during restrictions). Decreases, although smaller in magnitude, were also seen in physical well-being as measured with the SF-36 bodily pain scale (85.8 to 81.3%).

Adjusted odds ratios (OR) obtained with binary logistic regression demonstrated working entirely or partly outside the own home (vs. working remotely; OR = 1.29 / 1.35), high pre-restriction PA (OR = 1.29), female sex (OR = 1.20), and decreased vigorous PA during restrictions (OR = 1.14) to be associated with clinically relevant reductions in mental well-being. With regard to physical well-being, the odds of experiencing clinically relevant reductions were higher for females (OR = 1.62), persons with high pre-restriction PA (OR = 1.26), and young individuals (OR = 1.10).

Publication D

The final section of the survey covered the preferences and attitudes of the participants towards digital home exercise programs. More than two thirds (68.4%) of the 15,261 participants answering the related questions indicated readiness to engage in digital home exercise. In nine out of ten from these individuals, the preferred exercise frequency was three times per week. The most popular form of exercise was flexibility training, followed by resistance training and endurance training. According to binary logistic regression, factors associated with willingness to exercise included female sex (OR: 1.75), young age (OR: 1.41), part-time occupation (OR: 1.25), and affiliation in a gym (OR: 1.32).

Publication E

To examine the effects of a digital home-exercise program on PA as well as on physical and mental well-being, a two-armed, randomized, controlled multicenter trial was performed. A total of n=763 healthy adults (33±13 years, 523 females) from nine countries (Austria, Argentina, Brazil, Chile, Germany, Italy, Ireland, South Africa, Spain) with active lockdown measures were allocated to an intervention (IG) or control group (CG) using stratified urn randomization. Individuals of the IG engaged in a 4-week multicomponent home exercise program delivered using live-video streaming. They received a ‘virtual gym’ course schedule with workouts (in most cases offered daily in the mornings and evenings) of different focuses such as mobility, coordination, endurance, or strength. During the 4-week intervention, participants could attend *ad libitum* and without prior registration. The CG was inactive, not receiving any PA offer.

After the main study phase, to provide an incentive for the control group, both the IG and the CG had access to a database with pre-recorded workouts for an additional 4 weeks. Each week, PA (Nordic Physical Activity Questionnaire- short form), anxiety (Generalized Anxiety Scale-7/GAD-7), psychological well-being

(WHO-5 scale), sleep problems (MOS sleep scale), exercise motivation (self-concordance scale, SKK), as well as pain and disability (Chronic Pain Grade Scale, CPGS) were assessed. Group differences were examined using 3-level linear or exponential mixed models with restricted maximum likelihood estimation, correcting for age, sex, living environment (urban vs. rural), employment (yes/no), education (university degree: yes/no), country/center, and repeated measurements. In addition to the main intention-to-treat analysis (ITT) including all participants, a complier average causal effect (CACE) with complying individuals only (at least 2 participations per week), and a dose-response analysis with adjustment for confounders were performed.

According to the ITT analysis, digital home exercise consistently increased PA of both moderate (up to 1.65 times more minutes, 95% CI: 1.40 to 1.61) and vigorous (up to 1.31 times more minutes, 95% CI: 1.08 to 1.61) intensity when compared to the CG. In addition, the IG improved psychological well-being (up to +0.99 points, 95%CI: 0.13 to 1.86), sleep problems (up to -2.30 points, 95% CI: -4.43 to -0.17), exercise motivation (up to +0.50 points, 95% CI: 0.02 to 0.97), and anxiety levels (up to 0.87-fold reduction, 95%CI: 0.77 to 0.98). The CACE analysis of compliers showed similar results although with wider confidence intervals. The exercise dose was predictive of improvements in mental well-being.

Discussion of the results and their contribution to the research question

PA and exercise have repeatedly been considered as medicines with excellent side effect profiles.[26,27] Vina et al.[26] concluded in their review that the psychological effects are “so powerful […] that exercise may be considered as a psychoactive drug”. In another literature analysis, Naci and Ioannidis[27] found exercise to be non-inferior to classical medication in a plethora of conditions including diabetes, stroke, heart failure, or coronary heart disease.

The outbreak of the SARS-CoV2 pandemic and the related public life restrictions, have, however, reduced the accessibility of exercise and activity as a medicine. As shown in publication B, both moderate and vigorous PA decreased by more than 40 percent, meaning that the manifold beneficial health effects of PA could no longer be exploited to the same extent as before. Our findings, made using digital questionnaires, accord with objectively measured data. For instance, Tison et al.[28] analyzed the development of daily step counts in 455,404 smartphone application users from 187 countries. One month after the onset of the pandemic, reductions of 27% or 1432 steps per day were observed. Similar findings were made by McCarthy et al.[29] who found a 37%-decrease in daily counts of participants from the United Kingdom.

A central hypothesis of the ASAP survey (publications A to D) was that mental health would be reduced during public life restrictions and that such observation could be related to alterations of PA levels. With regard to the first, we indeed found drastic decreases of psychological well-being: the share of individuals meeting the WHO-5 index cut-offs for depression screening tripled from 15 to 45 percent (publication C). Although our study is a cross-sectional short-term observation not necessarily indicating causality, it may be of considerable relevance. Using a representative German sample, König et al.[30] calculated the per capita excess costs of depression treatment to be 5,047 Euros per year. Based on these data, in a worst-case scenario[3] (all individuals below cut-off during restrictions develop a depression requiring treatment), this could cause additional medical costs of up to 125.7 billion Euros per year in Germany only. With reference to the relation of well-being and PA decreases, the survey suggested a slight to modest association. It was found that a) people who were highly active before restrictions and b) persons who reduced vigorous activity during restrictions had 29% and 20% higher odds of experiencing a clinically relevant reduction in well-being, respectively. These data indicate that maintaining sufficient PA during pandemic-related public life restrictions could help to mitigate losses in mental health. With regard to the available evidence, our observation of reduced well-being during the pandemic is in line with the findings of other studies. Chiesa et al.[31] performed an extensive systematic review of published systematic reviews on the effects of public life restrictions.

[3] Germany has a population of approximately 83 million persons. Assuming that 15% (share of persons below cut-off before restrictions) or 12.45 million individuals develop a depression, yearly excess costs (5.047 € per person) would be 62,835,150,000 € in absence of a pandemic. If the share would triple to 45% (persons below cut-off during restrictions), or 37.35 million individuals, excess costs during pandemic would increase to 188,505,450,000 €. This results in a difference of 125,670,300,000 € per year. Note that this calculation represents a simplified estimate of the worst case (all persons below cut-off develop a depression requiring treatment).

They reported an adverse impact on a variety of mental health conditions inter alia including anxiety, depression, and post-traumatic stress disorder.

Numerous researchers have called for the development of newly-tailored PA programs aimed at maintaining or improving movement habits during the pandemic[32-35] with a special focus on home-based interventions.[32,34] In fact, such offers exhibit a high potential to help mitigate the physical and psychological impairments resulting from pandemic-related lockdowns - not only in view of the known health-beneficial effects of PA but also because there is a high readiness in the population. Publication D revealed that a good 7 out of 10 surveyed individuals would be interested in digital home exercise.

The ASAP-Move project (Publication E) was the first worldwide randomized, controlled multicenter trial examining digital home exercise during public life restrictions. It showed that the tested program is highly efficacious in enhancing PA levels which is paramount to secure adherence to the international activity guidelines and to reduce risk factors of chronic diseases (e.g. increased blood pressure or reduced insulin sensitivity). Another key finding was that the intervention improved well-being, anxiety symptoms, sleep quality, and exercise motivation in as little as 4 weeks. Although the effects were small in magnitude, they are still noteworthy. Our participants were classified as rather healthy meaning that the potential to improve well-being was presumably smaller when compared to patients with lower baseline well-being. In a meta-analysis, Stathopoulou et al.[36] demonstrated a large effect of exercise on mental disorders such as depression and therefore, it would be intriguing to examine the efficacy of live-streamed tele-exercise in patients, too. On the other hand, the study also showed a worrisome dropout rate, amounting about 50% in the main study part. However, as dropout was even higher in the CG, it can be assumed that withdrawing from the trial was not related to the intervention but rather to other factors such as the high frequency of outcome assessments (weekly) and/or the highly dynamic and challenging situation during the pandemic (e.g. re-opening of gyms or sports facilities).

The findings of this dissertation have significant implications for clinical and political practice. Policy makers should be aware that securing access to physical activity spaces and opportunities can be crucial for mental (and physical) health when public life is restricted. On another note, the ASAP-move intervention trial (Publication E) clearly demonstrated that specific exercise offers cannot only help to maintain but even improve physical activity levels and markers of psychological well-being. If social distancing is required, live-streamed exercise can temporarily mimic the benefits of in-person training, which include meeting with a group and getting individual feedback from an instructor. However, still, our study had considerable drop-out rates. Future research hence needs to be geared towards improving implementation and securing participant adherence.

Another aspect which merits consideration relates to the use of e-technology. Digital exercise is not only compatible with social distancing mandates, but also has the advantage of reaching a steadily growing audience at relatively low costs. The portion of households with fixed or mobile broadband access in the European Union increased from 55 percent to 89 percent between 2009 and 2020.[37] In Africa, population access to at least mobile LTE or WiMAX[4] mobile network experienced a surge from 10 to 45 % between 2015 and 2020 only.[38] These growth rates impressively reflect that digital exercise solutions may be able to deliver exercise to the almost entire world population in the near future. Beyond this, streamed exercise could be particularly valuable in areas with low population density, where large distances need to be covered to access local workout offers. However, on the other hand, it also needs to be acknowledged that at least currently, there are still relevant populations which may have difficulties in handling (e.g., elderly persons[39]) or getting access to (e.g. lack of education or social inequality[40,41]) digital media. Notwithstanding, tele-exercise may continue to play a significant role in exercise delivery after the end of the pandemic. Beyond exercise interventions, local (analogue) PA counseling could be complemented by virtual offers (e.g. consultation hours via video-chat) and in this sense, the pandemic-related research efforts may represent a catalyst for the creation of new and the refinement of existing e-health approaches.

In summary, this dissertation has demonstrated that governmental public life restrictions may represent a direct threat to health as they reduce PA and well-

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[4] LTE (Long Term Evolution) and WiMAX (Worldwide Interoperability for Microwave Access) are mobile broadband standards for wireless internet access.

being. Furthermore, it was also shown for the first time that live-streamed home exercise could represent a highly promising solution to maintain or improve PA and health both during and in absence of a pandemic. Future research should be designed to translate the promising findings to hitherto not targeted populations such as patients with chronic diseases or elderly persons.

Overview of publications

A Wilke J, Mohr L, Tenforde AS, et al. Activity and Health During the SARS-CoV2 Pandemic (ASAP): Study Protocol for a Multi-National Network Trial. *Front Med.* 2020, doi: 10.3389/fmed.2020.00302 **[Impact factor/IF: 5.1]**

B Wilke J, Mohr L, Tenforde AS, et al. A pandemic within the pandemic? Physical activity levels have decreased substantially in countries affected by COVID-19. *Int J Environment Res Pub Health* 2021; doi: 10.3390/ijerph180522352021
[IF 3.4]

C Wilke J, Hollander K, Mohr L, et al. Drastic reductions in mental well-being observed globally during the COVID-19 pandemic. *Front Med.* 2021; doi: 10.3389/fmed.2021.578959 **[IF 5.1]**

D Wilke J, Mohr L, Tenforde AS, et al. Restrictercise! Preferences Regarding Digital Home Training Programs during Confinements Associated with the COVID-19 Pandemic. *Int J Environment Res Pub Health* 17, doi: 10.3390/ijerph17186515 **[IF 3.4]**

E Wilke J, Mohr L, Yuki G, et al. Train at home, but not alone: a multicentre randomised controlled trial assessing the effects of live-streamed tele-exercise during COVID-19-related lockdowns. *Br J Sports Med*. 2022; doi: 10.1136/bjsports-2021-104994 **[IF: 13.8]**

Publications

Publication A

frontiers in Medicine

STUDY PROTOCOL
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Activity and Health During the SARS-CoV2 Pandemic (ASAP): Study Protocol for a Multi-National Network Trial

Jan Wilke[1]*, Lisa Mohr[1], Adam S. Tenforde[2], Oliver Vogel[1], Luiz Hespanhol[3,4,5], Lutz Vogt[1], Evert Verhagen[4,5] and Karsten Hollander[2,6]

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Introduction: The worldwide spread of the novel coronavirus (SARS-CoV2) has prompted numerous countries to restrict public life. Related measures, such as limits on social gatherings, business closures, or lockdowns, are expected to considerably reduce the individual opportunities to move outside the home. As physical activity (PA) and sport participation significantly contribute to health, this study has two objectives. The objectives of this study are to assess changes in PA and well-being since the coronavirus outbreak in affected countries. Additionally, we will evaluate the impact of digital home-based exercise programs on PA as well as physical and mental health outcomes.

Method: A multinational network trial will be conducted with three planned phases (A, B, and C). Part A consists of administering a structured survey. It investigates changes in PA levels and health during the coronavirus outbreak and measures the preferences of the participants regarding online training programs. Part B is a two-armed randomized-controlled trial. Participants assigned to the intervention group (IG) will complete a digital 4-week home exercise training (live streaming via internet) guided by the survey results on content and time of program. The control group (CG) will not receive the program. Part C is 4-week access of both CG and IG to a digital archive of pre-recorded workouts from Part B. Similar to Part A, questionnaires will be used in both Part B and C to estimate the effects of exercise on measures of mental and physical health.

Results and Discussion: The ASAP project will provide valuable insights into the importance of PA during a global pandemic. Our initial survey is the first to determine how governmental confinement measures impact bodily and mental well-being. Based on the results, the intervention studies will be unique to address health problems potentially arising from losses in PA. If proven effective, the newly developed telehealth programs could become a significant and easy-to-distribute factor in combating PA decreases.

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Results of the study may hence guide policy makers on methods to maintain PA and health when being forced to restrict public life.

Study Register: DRKS00021273.

Keywords: physical activity, coronavirus, exercise, isolation, home-based, e-health

INTRODUCTION

Abundant evidence supports the value of physical activity (PA) and exercise as essential cornerstones of physical and mental health (1–3). For instance, it has been shown that regular movement lowers all-cause mortality by up to 80% while decreasing the odds of developing cardiovascular, neurological, musculoskeletal or psychiatric diseases (4). In view of these effects, specific guidelines detailing optimal PA have been developed for a variety of populations including children or older adults (5, 6) and health professionals and policy makers strive to implement them with considerable effort (7–10).

Since the outbreak of the novel coronavirus (SARS-CoV-2) in December 2019 and the classification as a global pandemic in March 2020, the opportunities to engage in sport and exercise have been greatly limited (11). Due to governmental regulations that restrict activities in public life [e.g., bans of public gatherings, business closures or city lockdowns; (12)], the ability to move freely has been reduced for the general population. Similar to initial actions in China, various countries (among others, United States of America, France, Germany, Spain, United Kingdom, and Italy) have taken measures that limit activities. The restrictions in access to sports clubs, gyms, and self-organized outdoor activities are assumed to result in a considerable decrease in global and individual PA levels (11).

Reductions in PA are not only relevant because of the unexploited benefits of regular movement. Inactivity and sedentary behavior, characterized as time spent in sitting, lying or reclined posture at low energy expenditures, have substantial adverse effects on health (13). A meta-analysis, pooling data from more than 1.3 million participants, demonstrated that particularly sitting and TV viewing time are both strongly associated with premature death (13). Such activities and other sedentary behavior may increase in populations affected by the coronavirus pandemic.

Government measures that aimed to control illness after the virus outbreak in China limited movement for millions of people over weeks to months (12). As other countries with registered cases implemented restrictive measures too, it is of the utmost importance to understand how such restrictions will change PA, physical health and mental well-being. Further, novel strategies may be required to maintain or improve PA at home. The objectives of our study are to examine the effects of public restrictions by geography on (a) PA and (b) individual well-being using an international population-based survey. Using these results, we plan to investigate the feasibility of digital home-exercise programs as well as their effectiveness in increasing physical and mental health.

MATERIALS AND METHODS

Ethical Standard and Study Design

The ASAP (**A**ctivity and health during the **SA**rs-CoV2 **P**andemic) project (**Figure 1**) consists of a structured, multinational cross-sectional survey (study Part A), a two-armed, randomized-controlled, multicenter parallel group trial (study Part B), and a controlled multicenter crossover trial (study Part C). It will be conducted according to the Guidelines of Good Clinical Practice and adhering to the Declaration of Helsinki. This study protocol reports according to the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) guidelines (14). Approvals are obtained from the study center's review board (Ethics committee of the faculty of psychology and sport sciences at Goethe-University Frankfurt) as well as from all universities actively included into participant recruitment. The intervention parts of the study have been prospectively registered at the German Registry of Clinical Trials (DRKS00021273).

All participants will provide informed consent. Outcomes in all three portions of the study (Part A, B, and C) are assessed using digital questionnaires. After being provided with information on the investigation including purpose, aims, voluntary nature of participation and data use on the first page of the questionnaires, each individual will be asked to choose whether to select the "Participate" button, which signalizes digital consent to participate in the study. All data will be either collected anonymously without patient identifiers (survey for study Part A) or retrospectively anonymized (Parts B and C).

Participants

The target population will include residents aged 18 and older from countries with (1) officially registered cases of the novel coronavirus (SARS-CoV-2) and (2) active governmental restrictions limiting public life via bans of public gatherings, forced restrictions of social, contact business closures, or lockouts. Recruitment will be performed by means of advertising in social media platforms (e.g., Youtube, Facebook, Twitter, Instagram) as well as health-related institutions (e.g., national chapters of the Exercise is Medicine initiative).

Procedures and Interventions

Study Part A

In the first part of the project, a structured multi-national survey will be administered during a 2-week period. The ASAP

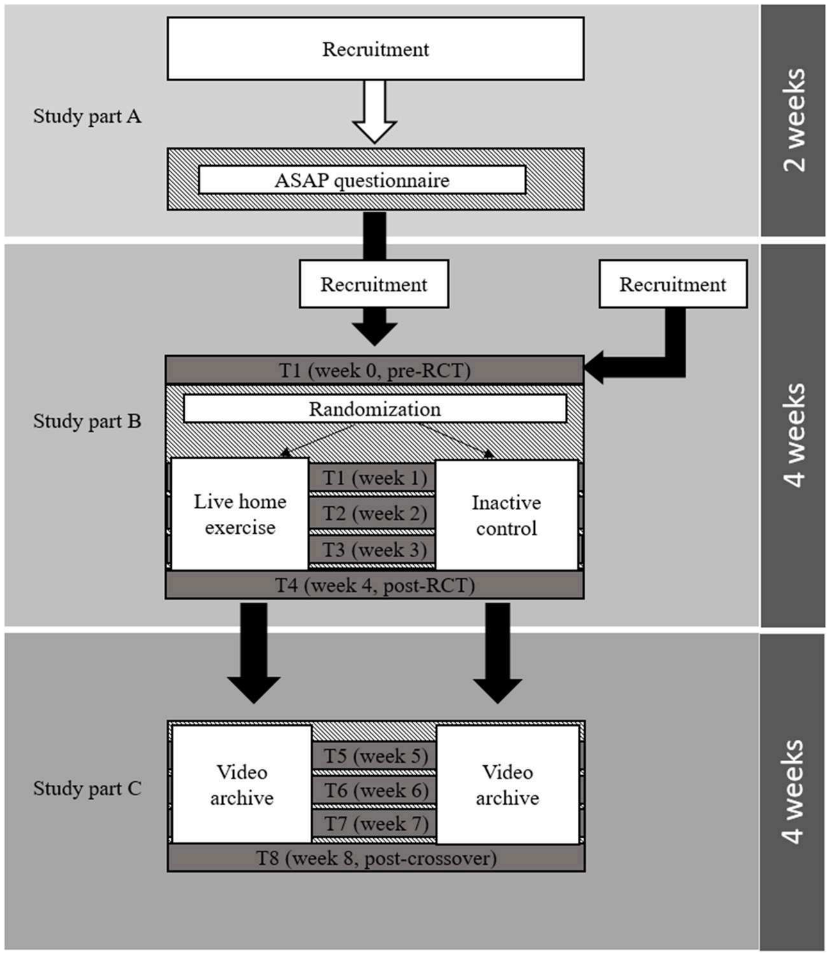

FIGURE 1 | Visualization of the project flow in each center. In study part A, participants are recruited for a cross-sectional survey (ASAP questionnaire). Upon completion they are made aware about the opportunity of registering for the randomized, controlled trial (RCT, study part B). Participants are also recruited among individuals who have not completed the survey. After completing the RCT, participants will receive access to a video database for another 4 weeks (study part C).

questionnaire is answered digitally and requires about 5–10 min to complete.

The survey instrument has four sections. The first portion assesses demographic data including age, sex and country of residence. The second section captures self-reported physical activity levels and exercise habits prior to and since the outbreak of the coronavirus. The questions have been newly constructed or adopted from valid measures in order to account for the specificities of the situation. Physical activity levels will be assessed using the Nordic Physical Activity Questionnaire-short (NPAQ-short, 15). The 2-item instrument measures the total time spent in free time during moderate to vigorous physical activities and during vigorous physical activities only. The questions were adapted to also account for working/occupational time. The NPAQ-SF has been shown to be reliable and was validated to monitor compliance with the WHO recommendations on physical activity (15). The third section of the ASAP questionnaire addresses the physical and mental well-being of the participants, again comparing the situation before and after the outbreak. Also, this part consists of questions newly constructed as well as psychometrically validated and cross-culturally adapted questionnaires. Regarding the latter, bodily pain is assessed using the sub-scale of the SF-36 questionnaire and mental well-being is measured using the WHO5-scale (16, 17). In the final section, we examine the preferences of the participants for exercise programs that will be developed based on the answers (e.g., total time, type(s) of exercise and activity).

The ASAP questionnaire was developed using an expert consensus process similar to that described in a previous investigation (18). Briefly, after agreeing on the scope and contents of the questionnaire, an initial version of the instrument was independently reviewed by the consensus team members which included physicians, physiotherapists, movement scientists, and sports scientists. Their blinded feedback was used to refine the questionnaire. For content validation, the questionnaire was sent to experts from different professions not belonging to the research team involved in its development (19). To increase face validity, members of the target population without background from a health profession were asked to provide feedback on comprehensibility and clarity of the questionnaire (20). The assessment tool is available in seven languages [Dutch, English, German, French, Italian, (Brazilian) Portuguese, Spanish]. Clarity and comprehensibility have been validated via forward and back translation by native speakers.

Study Part B

Based on the results of study part A, the second part will consist of a multicenter, two-armed, randomized-controlled parallel group trial. Participants in the intervention group (IG), for a period of 4 weeks, will receive online workouts with video live-streaming using the appropriate software (e.g., Zoom, Zoom video communications, San Jose, California, USA; BlackBoard, Washington, DC, USA). Duration, frequency, and contents will be selected balancing (a) the needs of the population as indicated via the ASAP questionnaire and (b) scientific recommendations for exercise prescription. For example, the minimum training frequency will be once per week and minimum duration will be 10 min (21). To allow a higher degree of standardization between the countries, the instructors will be provided with modifiable demo workouts exhibiting different content-related focuses (e.g., strength, endurance, postural control/balance, cognition, relaxation), which can be individually adapted. The control group (CG) will not receive an intervention and is instructed to complete the outcome assessments (see below). Randomization (1:1 ratio) will be performed using a software algorithm of the online database used for survey delivery (Soscisurvey, Soscisurvey GmbH, Munich, Germany). To allow concealed group allocation, the participants will be automatically informed by the system about allocation upon survey completion at baseline.

A two-fold approach is used for recruitment. Firstly, upon completion of the ASAP questionnaire (study part A), each participant will be informed about the opportunity to participate in the subsequent intervention trials (Study Parts B and C). Second, the same recruitment strategies used for the initial survey (social media advertising and promotion via associations and societies) will be used to enhance recruitment.

Study Part C

Study Part C adopts a controlled crossover design. Following completion of the post-measurements of study Part B, the participants of both groups (intervention and control) will receive access to an online database of recorded workouts with contents similar to Part B. All contents can be freely used for four additional weeks.

Outcomes

As indicated above, the ASAP questionnaire represents the outcome of interest for study Part A. For study Parts B and C, eight assessments are planned: at baseline prior to the RCT (T1), as well as weekly during the RCT (T2–T5) and the crossover study (T6–T8). Each survey will include an assessment of basic information (e.g., sex and age) and brief questions assessing general psychological and physical well-being. Additionally, a battery of questionnaires will be applied. The components were chosen based on both, thorough psychometric evaluation and the availability of translation and cross-cultural validation for the languages used. Implemented tools include the WHO5 scale for mental well-being (16, 17), generalized anxiety disorder scale-7 [GAD-7, (22)] for impulsiveness and anxiety, the MOS 12-item scale for sleep quality (23), the self-concordance scale (24) for exercise motivation and the Chronic Graded Pain Scale (25) for pain. In addition to the intervention effects, data on acceptance and adherence will be collected by means of documenting attendance at each workout offered in study Part B as well as by means of asking for the frequency of database use in study Part C (T4 assessment).

Data Processing and Statistics

All datasets will be analyzed using intention-to-treat. The findings from the ASAP questionnaire (Study Part A) will be descriptively reported and presented using appropriate measures such as mean ± standard deviation or median and interquartile range depending on distributions and scales of measurement. Additionally, the significance of variable associations (e.g., between physical activity levels and markers of well-being) will be examined using correlation and regression analyses.

To estimate the risk of non-response bias, wave analyses will be conducted according to Lewis et al. (26). Specifically, the responses of the first 10% percent of the participants (early responders) will be compared to those of the last 10% (late responders) by means of inferential statistics. The rationale behind this is that early responders are assumed to be more motivated than late responders which can be compared to non-responders. Hence, if the wave analyses do not provide significant findings, absence of non-response bias is concluded.

For study Parts B and C (randomized, controlled trial/controlled crossover trial), a prospective meta-experiment approach will be applied (27). For each country, the mean pre-post-differences between-groups including 95% confidence intervals (95% CI) will be calculated at the different time points. An a priori sample size calculation using an algorithm specifically designed to account for between-site variance in multi-center trials was performed (28). When achieving a sample size of $n = 544$ with an included drop-out rate of 20%, the trial will have 80.3% power to detect pre-post-differences with a minimal effect size (Cohen's d) of 0.25 at an alpha level of 0.05. To account for potential between-center variance, the data collected in each country will be pooled using a random-effects model (29). This leads to an aggregated effect size (weighted mean differences) demonstrating the overall effectiveness of the intervention while the different countries can still be compared by means of inspecting the 95% CI's. Heterogeneity between countries will be quantified by means of the I^2 index (30). To further explore its potential sources (e.g., country, age, sex, baseline physical activity), a meta-regression with continuous and factorial independent variables will be performed (31).

Data analyses will be performed using standard statistical software packages (e.g., SPSS 22, SPSS Inc., Chicago, Illinois, USA and BiAs statistics, Goethe University, Frankfurt/Main, Germany). The significance level for all analyses will be set to $\alpha = 0.05$.

DISCUSSION

Restricting the opportunities to move outside the own home, while important to control the spread of the novel coronavirus, may limit PA. Our study aims to understand the influence of forced social isolation during the pandemic on movement habits and markers of self-reported mental and physical health.

To date, most research on the novel coronavirus has focused on the crucial topics of detection and treatment, including diagnostic measures, vaccines, and therapeutic pharmaceuticals (32–34). However, it may be argued that the adverse effects of the pandemic extend beyond the direct consequences of infection with SARS-Cov2. Since millennia, the engagement in physical activity and exercise represent significant contributors to human health and compelling evidence has demonstrated its benefits (1–3, 35). As the protective and therapeutic effects, in many cases are similar or superior to pharmaceutic remedies, some have considered exercise to represent a drug which is free of charge while exhibiting a favorable side effect profile (4, 36, 37). The outbreak of the novel coronavirus has both threatened the availability of medical devices and pharmaceutical remedies (38, 39), but also that of exercise medicine: restricting the opportunities to move outside limits the feasibility and availability of physical activity and exercise. Our study, particularly part A (ASAP survey), therefore, will provide relevant data gauging the influence of forced social isolation during the pandemic.

Based on the findings of the cross-sectional questionnaire assessment, the prospective study Parts 2 and 3 will measure the effectiveness of home-based digital exercise programs in addressing limitations in PA and well-being during the pandemic. In first line, they may help counteract the negative bodily effects of inactivity (e.g., musculoskeletal pain, increased risk of cardiovascular diseases, weight gain). In addition, while speculative, participation could also have an indirect effect on the pandemic. An analysis of previous influenza virus infections demonstrated that individuals who rarely or never work out have a reported 6 to 9 percent higher mortality risk (40). This is consistent with studies showing that acute bouts of moderate exercise (65–70% of VO_2 peak) increase the levels of cytokines (i.e., Interleukin-6) needed during immune response (4, 41, 42). In sum, this could suggest that exercise has a protective effect against viral infections although further research is needed to understand the role of exercise in modifying disease from the novel coronavirus.

The planned interventions may also be of relevance from psychological and political perspectives. Social isolation has been demonstrated to have a detrimental influence on a variety of mental health markers. For instance, loneliness leads to mood changes, depression and increased overall mortality (43, 44). Initial evidence for the COVID-19 pandemic shows that life satisfaction decreased in Chinese adults forced to stop working (45). As exercise has positive effects on psychological well-being (3, 35, 46), it may help improve the capacity to deal with the current situation. From a theoretical point of view, the success of governmental restrictions in public life will depend on both their execution and control but also on the compliance of the population. Improving coping by means of sport may thus help governmental goals to maintain restrictions and to control contagion.

Some methodological considerations are needed. As home-exercise may become an important method to maintain PA during future confinements, it will be particularly interesting to study adherence. It has been reported that the feeling of being supported and the possibility to contacting the provider may facilitate compliance (47). As our exercises in study part A will be live-streamed and the participants can interact with the instructors, we believe this can improve training frequency compared to traditional home-exercise programs. Compliance will also be of importance in our CG. As it does not receive an intervention, participants may withdraw from the study. We chose two strategies to counteract this. Firstly, we offer them free database use in study Part B and thus, any participant enrolled will have a PA intervention. Secondly, the CG participants will be actively motivated to express their preferences regarding the video-database and, using their feedback, some workouts will be specifically tailored for them. Besides compliance, another issue relates to outcome assessment. We decided to use questionnaire assessments in both study parts, which is congruent with the objective to measure and improve subjective well-being and allows the achievement of large sample sizes. However, regarding PA assessments, it should also be noted that most persons tend to overestimate the own activity levels and that the recall of moderate-intensity activities is less precise than that of vigorous activities (48).

AUTHOR CONTRIBUTIONS

JW, LM, KH, LV, LH, EV, OV, and AT: conception and design. JW and KH: drafting of the manuscript. JW, LM, KH, LV, LH, EV, OV, and AT: critical revision and proofreading. All authors: contributed to the article and approved the submitted version.

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Publication B

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Article

A Pandemic within the Pandemic? Physical Activity Levels Substantially Decreased in Countries Affected by COVID-19

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Abstract: Governments have restricted public life during the COVID-19 pandemic, inter alia closing sports facilities and gyms. As regular exercise is essential for health, this study examined the effect of pandemic-related confinements on physical activity (PA) levels. A multinational survey was performed in 14 countries. Times spent in moderate-to-vigorous physical activity (MVPA) as well as in vigorous physical activity only (VPA) were assessed using the Nordic Physical Activity Questionnaire (short form). Data were obtained for leisure and occupational PA pre- and during restrictions. Compliance with PA guidelines was calculated based on the recommendations of the World Health Organization (WHO). In total, n = 13,503 respondents (39 ± 15 years, 59% females) were surveyed. Compared to pre-restrictions, overall self-reported PA declined by 41% (MVPA) and 42.2% (VPA). Reductions were higher for occupational vs. leisure time, young and old vs. middle-aged persons, previously more active vs. less active individuals, but similar between men and women. Compared to pre-pandemic, compliance with WHO guidelines decreased from 80.9% (95% CI: 80.3–81.7) to 62.5% (95% CI: 61.6–63.3). Results suggest PA levels have substantially decreased globally during the COVID-19 pandemic. Key stakeholders should consider strategies to mitigate loss in PA in order to preserve health during the pandemic.

Keywords: coronavirus; health; exercise; guidelines

1. Introduction

In March 2020, the World Health Organization (WHO) classified the spread of the novel coronavirus (SARS-CoV2) as a global pandemic. Since this declaration by the WHO, the number of laboratory-confirmed cases has grown from 125,700 (11 March 2020) to 112,205,251 (24 February 2021), while the number of affected countries has increased to 192 [1]. To control the contagion, many governments imposed substantial restrictions on public life. Initial data support the assumption that related measures (e.g., business closures, bans of social gatherings or lockdowns) and the recommendation of social distancing can effectively limit the transmission of the virus [2–4]. However, despite representing a crucial cornerstone to reduce the spread of viral illness, confinement strategies may have detrimental consequences for health. For instance, analyses of quarantines instituted during previous pandemics showed a variety of adverse effects such as post-traumatic stress or symptoms of depression [5].

The specific strategies used by governments to contain COVID-19 have expanded to include the closure of public parks, gyms or sport facilities and clubs. As accessibility to such areas of recreation represents an essential facilitator of physical activity (PA) [6], limitation of spaces and opportunities to move and exercise may foster sedentary behavior. Whereas inactivity has been estimated to cause up to 9% of all premature deaths [7], regular PA is well established in helping to prevent a variety of chronic non-communicable diseases such as hypertonia, metabolic syndrome, type 2 diabetes or cancer [8]. In addition to its benefits on physical health, exercise represents a valuable intervention for psychological disorders, being capable of alleviating symptoms of depression and anxiety [9,10]. In total, large-scale epidemiological studies demonstrate that 150 min/week of moderate-to-vigorous PA reduces all-cause mortality by approximately 31% [11].

Regular PA does not only play a role in general health protection. Although its direct effects on the novel coronavirus are yet to be determined, exercise, along with diet, tackles obesity, which according to initial data, seems to be a risk factor for complications in patients hospitalized for COVID-19 [12]. PA can improve immune function, e.g., via mobilizing lymphocytes and releasing cytokines such as IL-6, IL-7 and IL-15 [13]. Additionally, individuals with high activity levels are less vulnerable to infections from influenza-, rhino- or herpesviruses [13]. Particularly relevant to COVID-19, a primarily respiratory disease, research in exercise immunology has shown that PA can effectively reduce upper respiratory tract infections [14,15]. Collectively, all these data suggest that maintaining regular movement is pivotal during pandemic-related confinements.

To date, the degree to which public life restrictions related to COVID-19 affect PA levels is unknown. Early evidence based on investigations with relatively small sample sizes, however, indicate reductions of PA [16–20]. The present study, therefore, aimed to evaluate changes of self-reported PA in countries with SARS-CoV2 outbreaks on a multinational level.

2. Materials and Methods

2.1. Ethics and Design

Our report summarizes data from the cross-sectional 'Activity and Health during the SARS-CoV2 Pandemic' (ASAP) survey [21]. Ethics approval was obtained in each involved country (Australia, Austria, Argentina, Brazil, Chile, France, Germany, Italy, Netherlands, South Africa, Singapore, Switzerland, Spain, USA). All participants provided digital informed consent.

2.2. Sample

Participant eligibility included residents aged 18 and older from countries with (1) registered cases of SARS-CoV2 and (2) active governmental restrictions limiting movement and activity in public spaces. The recruitment strategy used social media (e.g., Facebook, Twitter, Instagram), mailing lists and health-related multipliers (e.g., national "Exercise is Medicine" chapters).

2.3. Instrument

The PA portion of the ASAP questionnaire assessed self-reported PA levels prior to and during restrictions of public life. To quantify PA, we applied the Nordic Physical Activity Questionnaire-short (NPAQ-short), which is reliable (test–retest reliability: rho = 0.80 to 0.82) and valid for monitoring compliance with the WHO recommendations on PA [22]. With its two questions (Table 1), the instrument retrospectively measures the times (minutes) spent performing (1) moderate-to-vigorous physical activity (MVPA) and vigorous physical activity (VPA) during leisure time. The same categories (MVPA/VPA) were used to address PA during occupational time. The NPAQ-short defines moderate activities as those increasing heartbeat and breath while vigorous activities get the affected person's heart racing, make him/her sweat and leave him/her so short of breath that speaking becomes difficult (Table 1).

In order to achieve comparability with regard to recall periods, the participants were asked to refer (a) to the duration of confinement measures at the time of the survey for restriction PA and (b) to an identical time interval before the imposition of lockdown measures for pre-restriction PA. In addition to the NPAQ-short, we assessed changes in total PA, including light activities, by means of a five-point Likert scale (large decrease, small decrease, no decrease, small increase, large increase).

The ASAP questionnaire was generated using a group consensus process and subsequently forward- and back-translated by native speakers. To increase face validity, focus groups comprising health experts (n = 12; physicians, physiotherapists, sports scientists, movement scientists, public health advisors) and laypersons (n = 18; males and females of varying ages and educational background/socioeconomic backgrounds) within each country reviewed the survey to ensure comprehension. Following minor adjustments based on the provided feedback, the testing persons reported excellent comprehensibility and clarity.

The ASAP survey was administered via the platform SoSci Survey (SoSci Survey GmbH, Munich, Germany) between 3 April and 9 May 2020. During this timeframe, it was available for four weeks in each country.

Table 1. Items of the Nordic Physical Activity Questionnaire (short form) as used in the survey.

<table>
<tr><th colspan="2">Physical Activities in Leisure Time</th></tr>
<tr><td colspan="2">We would like to know, how physically active you have been in your free time (including commuting from and to work). We only ask about moderate and vigorous activities—light activities do not need to be reported here. Moderate activities are those where your heartbeat increases and you breathe faster (e.g., brisk walking, cycling as a means of transport or exercise, heavy gardening, running or recreational sports). Vigorous activities as those that get your heart racing, make you sweat and leave you so short of breath that speaking becomes difficult (e.g., swimming, running, cycling at high speeds, intensive cardio training, weight-lifting or team sports such as football).</td></tr>
<tr><th colspan="2">Physical Activities in the Job</th></tr>
<tr><td colspan="2">While the previous questions addressed free time, the following two focus on work/occupational time. Again, we only ask about moderate and vigorous activities—light activities do not need to be reported here. Remember: Moderate activities are those where your heartbeat increases and you breathe faster (e.g., brisk walking). Vigorous activities are those that get your heart racing, make you sweat and so short of breath that you find it difficult to speak (e.g., repeated lifting of heavy weights).</td></tr>
<tr><th>Moderate and Vigorous Activities</th><th>Vigorous Activities only</th></tr>
<tr><td>On a typical week, how much time in minutes did you spend in total on both moderate and vigorous physical activities?
Please sum all activities with a minimal duration of 10 min.
Enter 0, if there was not at least one activity of more than 10 min.
before lockdown: ___ minutes
during lockdown: ___ minutes</td><td>How much of that time in minutes you indicated above, did you spend in total on vigorous physical activities only?
Please sum all activities with a minimum duration of 10 min.
Enter 0, if there was not at least one activity of more than 10 min.
before lockdown: ___ minutes
during lockdown: ___ minutes</td></tr>
</table>

For the two NPAQ-short questions (white background), applied for free and occupational time, respectively, specific introductions (gray background) were used.

2.4. Outcomes

In addition to computing changes in total leisure and occupational MVPA/VPA (min/week), compliance with the WHO's guidelines was calculated as a dichotomous outcome (fulfilled, not fulfilled). The WHO recommends the accumulation of ≥150 min moderate activity, ≥75 min VPA or an equivalent combination of both. In addition, as the survey was performed in several countries, the Containment and Health Index (CHI [23]) was calculated for the study period. The score uses a variety of criteria to generate a score reflecting the severity of "lockdown" restrictions and measures of health protection.

2.5. Data Processing and Statistics

Data are reported as means including 95% confidence intervals and/or percentages, as appropriate. The normal distribution of data was verified by means of the Shapiro–Wilk test. To estimate the risk of non-response bias, wave analyses were conducted [24]. Specifically, the responses of the first 10% of the participants (early responders) in each recruitment wave were compared to those of the last 10% (late responders) by means of *t*-tests for independent samples. The rationale behind this is that early responders are assumed to be more motivated than late responders, which can be considered equivalent to non-responders. Hence, if the wave analyses do not systematically show significant findings, the absence of non-response bias is assumed. Data analyses were performed using standard statistical software packages (e.g., SPSS 22, SPSS Inc., Chicago, IL, USA and BiAs statistics, Goethe University, Frankfurt/Main, Germany). The significance level was set to $\alpha = 0.05$.

3. Results

Participants totaled n = 13,503 (39 ± 15 years, 59% females). Fifty-four individuals reported having tested positive for SARS-CoV in the past, which is equivalent to 0.40 percent of the sample. Wave analyses yielded no indication of non-response bias ($p > 0.05$).

3.1. Changes in Physical Activity

Mean self-reported MVPA (−41.0%) and VPA (−42.2%) both decreased to a similar degree from pre- to during restrictions (Table 2). More than two-thirds of participants (66.8%; n = 9016) were unable to maintain their previous activity levels. Declines in PA were 10% to 20% higher for occupational than for leisure time (Table 2). While there were no major differences between men and women, participants with higher pre-restriction PA had larger decreases than previously less active individuals (Figure 1). With regard to age, the highest reductions were found in the youngest and oldest participants, resembling a U-shaped distribution. Elderly individuals (70 years and older), furthermore, exhibited the highest VPA decreases (Figure 2). Significant variation was observed between countries with the highest relative reductions in Argentina, Brazil, Chile and South Africa (all > 50% in MVPA; Figure 3). Comparisons against CHI data (Figure 4) suggested a correlation between the severity of public life restrictions/health-related measures and PA reductions in most countries, although both variables seemed independent in some cases (i.e., low CHI values for Brazil, Chile and Spain despite large PA decreases). Participants with past SARS-CoV2 infection had comparable pre-restriction PA, but displayed stronger reductions in vigorous activities (−48.6% vs. −42.2%).

Table 2. Physical activity levels of the investigated sample pre- and during the restrictions.

	Leisure		Work		Total	
	MVPA (min/wk)	**VPA (min/wk)**	**MVPA (min/wk)**	**VPA (min/wk)**	**MVPA (min/wk)**	**VPA (min/wk)**
Pre	296.0 (290.6 to 301.5)	134.7 (131.4 to 138.0)	154.1 (148.0 to 160.2)	54.4 (51.2 to 57.5)	450.1 (440.7 to 459.6)	189.1 (183.6 to 194.5)
During	193.7 (189.6 to 197.7)	81.9 (79.5 to 84.2)	72.1 (68.4 to 75.8)	27.5 (25.5 to 29.5)	265.8 (259.7 to 271.9)	109.4 (105.7 to 113.0)
Δ	−102.4 (−107.2 to −97.6)	−52.8 (−55.4 to −50.2)	−82.0 (−86.8 to −77.2)	−26.9 (−29.3 to −24.4)	−184.4 (−192.3 to −176.5)	−79.7 (−84.0 to −75.4)
% Δ	−34.6	−39.2	−53.2	−49.5	−41.0	−42.2

Table lists means and 95% confidence intervals (CI). MVPA = moderate-to-vigorous physical activity, min = minutes, VPA = vigorous physical activity, wk = week, Δ = difference.

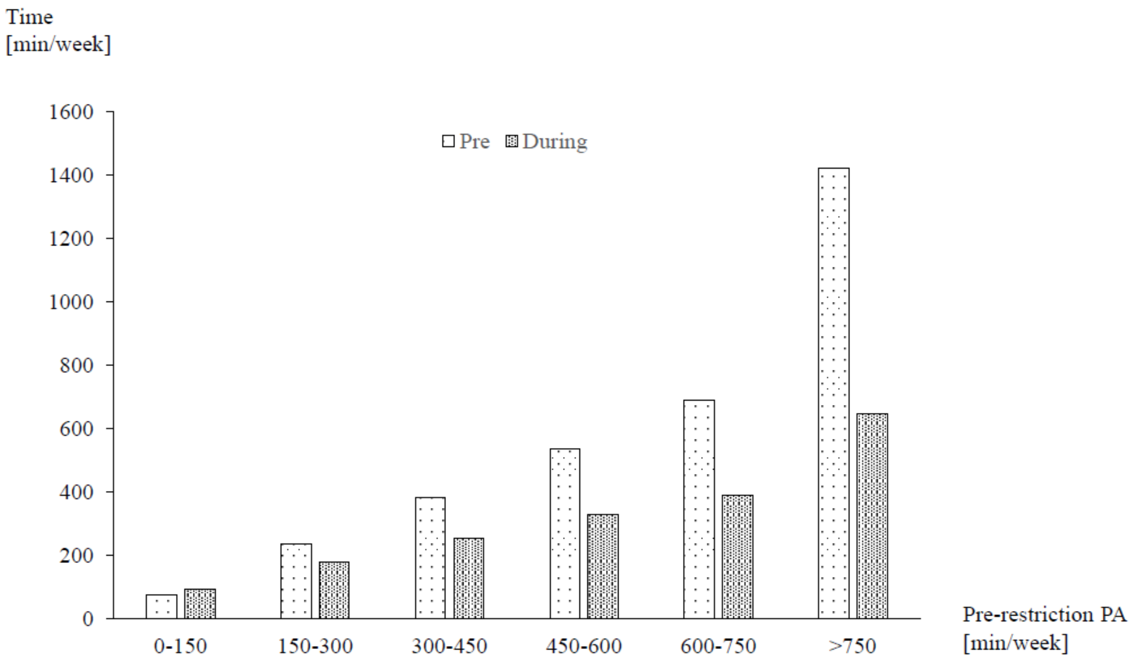

Figure 1. Changes in moderate-to-vigorous physical activity (MVPA) as a function of pre-restriction activity. Figure shows absolute means. PA = physical activity, min = minutes.

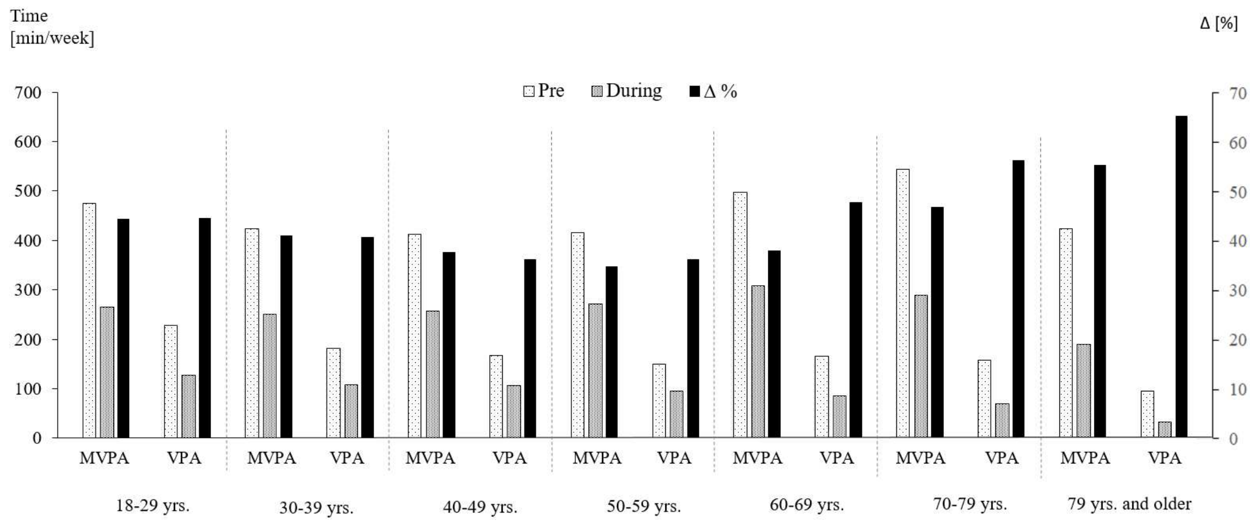

Figure 2. Changes in physical activity levels as a function of age. Figure shows absolute means and relative differences. min = minutes, MVPA = moderate-to-vigorous physical activity, VPA = vigorous physical activity, yrs. = years, Δ = difference.

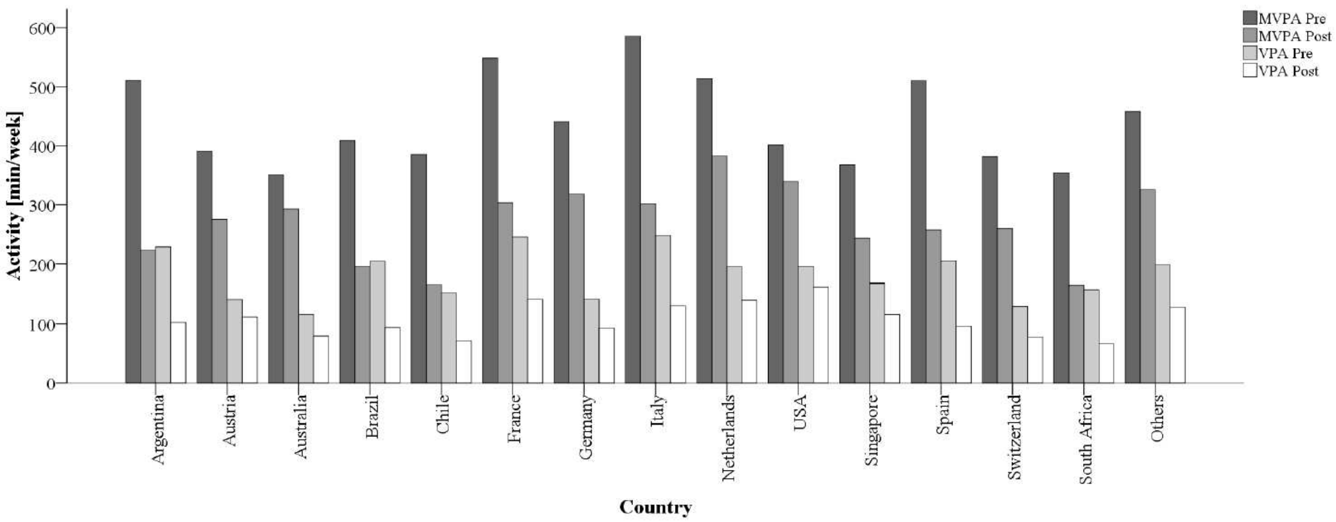

Figure 3. Mean changes in MVPA and VPA levels stratified by countries. min = minutes, MVPA = moderate-to-vigorous physical activity, VPA = vigorous physical activity.

Regarding overall PA, including light activities, most participants (75.5%) reported decreases during restrictions, with 48.7% of them describing a large reduction. Increases from pre-restrictions were indicated in 17.7% of the participants.

3.2. Changes in Physical Activity Guideline Compliance

Pre-restrictions, 80.9% (95% CI: 80.3–81.7) of the sample (n = 10,938) were in compliance with the PA recommendations. Post-restrictions, the overall population fulfilling the guidelines decreased to 62.5% (95% CI: 61.6–63.3; n = 8435). More than one quarter (28.4%, n = 3104) of the participants previously meeting the required cut-offs subsequently fell short during the restrictions. In total, for the individuals who complied with the guidelines pre-restrictions, the average reported MVPA levels were reduced during the restrictions (−43.2%). In contrast, those who fell below guidelines pre-restrictions were able to increase self-reported MVPA (+56.9%), but in most cases (76.6%), this was not sufficient to achieve compliance. Participants with past SARS-CoV2 infection, compared to others, displayed massive declines in guideline compliance (88.9% to 50% vs. 80.9% to 62.5%).

Individuals losing guideline compliance during lockdowns were of similar age as those maintaining it (Table 3). However, persons newly fulfilling the guidelines were three years younger than others. With regard to sex, a slightly higher share of females gained compliance from pre- to during restrictions.

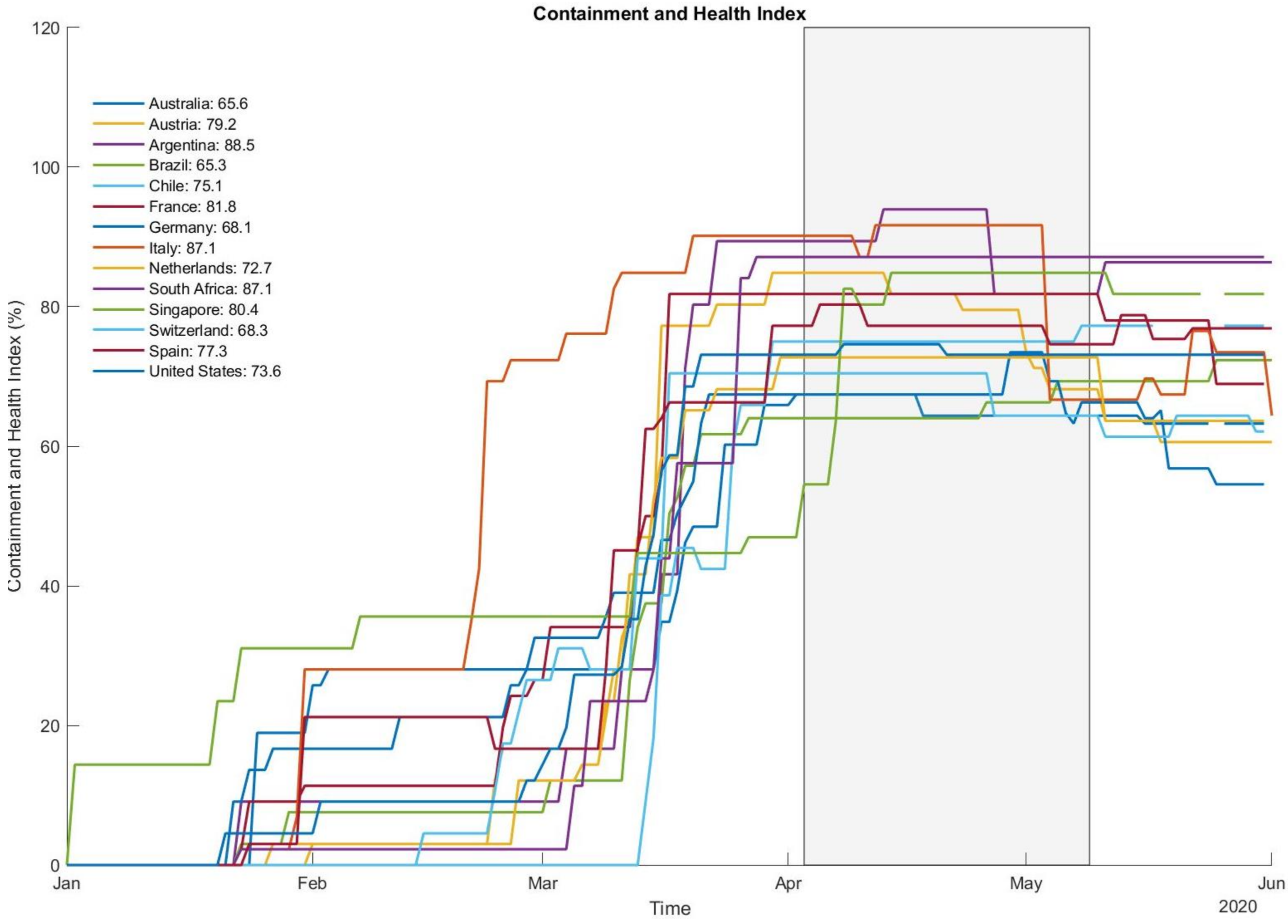

Figure 4. The severity of public life restrictions as measured with the Containment Health Index. Box (right) and individual country values (left) represent the period of data collection.

Table 3. Age and sex as a function of changes in physical activity guideline compliance between pre- and during restrictions.

	Guideline Compliance			
	Pre and During	**Pre but Not During**	**Not Pre but During**	**Neither Pre nor During**
n	7834	3104	601	1964
Age	39 ± 15	38 ± 15	35 ± 13	38 ± 16
Sex	Females: 55.1% Males: 62.4%	Females: 22.8% Males: 23.2%	Females: 5.4% Males: 3.2%	Females: 16.8% Males: 11.3%

4. Discussion

It has been estimated that the spring 2020 public life restrictions related to the COVID-19 pandemic affected up to 3 billion persons worldwide [13]. To the best of our knowledge, this is the first multinational assessment aiming to gauge the effects of the confinements on self-reported PA. Our main finding is that the amount of habitual movement declined by 41% and 42% for MVPA and VPA, respectively. These reductions resulted in a 20% lower compliance with the 2010 WHO guidelines on PA. Taken together, our data support the myriad of calls to maintain PA during confinement [13,25–27] and suggest a large portion of the population may be silently suffering from a less visible impact of the pandemic on public health.

Our main result of decreases in PA aligns with available data collected in individual countries (e.g., [16,17,19,20]). The same applies to more pronounced reductions in previously active individuals (e.g., [16,17,20]). In contrast, findings are less consistent with regard to sex and age. Notwithstanding, interestingly, the reported magnitude of PA reductions here (41% to 42%) and guideline compliance declines (18.5%) was larger than reported from other surveys [16–20].

Sustained reductions in habitual movement can contribute to a plethora of negative health consequences. According to the World Health Survey, including responses from 237,964 individuals, physical inactivity is associated with an odds ratio of 1.32 for future states of anxiety [10]. A meta-analysis pooling the results from 49 prospective studies found persons with low activity levels to exhibit a higher risk for depression [9]. Lack of PA also results in maladaptive changes to body composition (e.g., increase in body fat), associated with decreased insulin sensitivity, reduced cardiorespiratory fitness and increased dyslipidemia [28]. These changes may occur in as little as 14 days of physical inactivity, and are reversible in young but not in older adults [29]. Considering that pandemic-related restrictions have been in place for weeks to months, the observed PA reductions, besides causing short- and long-term psychological distress, could compound the over-prevalence of non-communicable diseases. Finally, PA can be expected to have a direct beneficial impact on the COVID-19 pandemic due to its positive impact on the immune system and the risk for upper respiratory tract infections [14,15]. Wong et al. [30] analyzed influenza-associated mortality using data from Hong Kong in 1998. A low to moderate exercise frequency reduced the risk of death from influenza by 4.2% to 6.4%, while never or seldom exercising was associated with a 5.8% to 8.5% increased mortality risk. Future research should hence be geared towards investigating similar associations in COVID-19.

Our results suggest that decreases in PA particularly affect those participants who were most active prior to the pandemic. This further enhances concerns of adding to the overall proportion of the world population not meeting WHO guidelines, and, if sustained, this could contribute to rises in medical expenses resulting from disease or inactivity. An economic analysis of US data revealed that the annual healthcare costs per capita are USD 1437 and 713 higher for inactive or insufficiently active vs. active ($\geq$150 min moderate activity per week) individuals, respectively [31]. Extrapolating this to the data of our study, this would roughly mean that only the additional healthcare costs for the 3104 persons who no longer met the PA guidelines during restrictions would translate to between USD 2,172,000 and 4,460,448 per year of continued inactivity.

Older individuals, together with young participants, had the highest reductions in PA. Declines were particularly pronounced for VPA, where adults aged 70 and older showed reductions between 56% and 67%. At matched total energy expenditure, VPA outperforms moderate PA in reducing the risk of cardiovascular disease and associated markers, such as diastolic blood pressure or glucose control [32]. In addition, data collected in middle-aged and older adults demonstrate that the engagement in VPA yields 9% to 13% lower all-cause mortality risks, when compared to identical volumes of moderate activity only [33]. In view of the older persons' large VPA reduction during the pandemic, and given that the elderly generally have the highest risks of chronic diseases and complications following influenza infections, this target group needs special consideration [26].

The novel report on reductions in PA has broad implications for key health-related stakeholders and policymakers. When imposing pandemic-related restrictions on public life, we suggest the development of strategies to proactively counteract the anticipated inactivity. This may be achieved through public education, facilitating PA opportunities at tolerable viral transmission risk and interventions that can be rapidly implemented.

Regarding the latter strategies, home-based exercise programs, offered by certified health and exercise professionals, could represent a low-cost option to maintain PA levels while being restricted to the home.

There are some methodological issues that merit consideration. The WHO has recently updated its guidelines on recommended PA levels. It is now advised to engage in a minimum of 150 to 300 (previously: 150) minutes of moderate activity, a minimum of 75 to 150 (previously: 75) minutes of vigorous activity or an adequate combination of both. Despite these new changes, our classification of individuals complying or not complying with the guidelines, which is based on the 2010 recommendations, is still valid, because the lower margin (150 min of moderate and 75 min of vigorous activity) was maintained in the new version. The absence of non-response bias and large sample size are two major strengths of the present paper, as they improve the generalizability of the findings to understanding changes in PA. Further, our sample was close to the representative pre-restriction PA levels reported: baseline compliance (81%) with WHO recommendations was only slightly higher than the pooled percentage (73%) of 358 previous surveys, including a total of 1.9 million participants [34]. However, it should also be noted that determining response rates is difficult with social media recruitment, and it is possible that persons with low internet affinity or limited access to technology did not participate in our investigation. Another issue relates to the mode of outcome assessment. Like most large-scale studies assessing PA, we used self-reported data instead of objective instruments such as accelerometers. Typically, subjective measures tend to overestimate the actual PA levels, and moderate activities are recalled less precisely than vigorous activities [35]. Although we found substantial PA decreases in both MVPA and VPA, this should be considered when interpreting our results. Finally, our analysis focused on the changes of PA and a few potential moderators, including age, sex, country of origin and baseline physical activity. However, in addition to these, an impact of other factors such as the living environment (urban vs. rural), educational level or socioeconomic status seems highly plausible. Future studies may hence consider jointly assessing these factors in conjunction with the variables presented here.

5. Conclusions

Self-reported PA substantially decreased following public life restrictions associated with the COVID-19 pandemic. In view of the short- and long-term consequences of inactivity, such as impaired mental and physical wellbeing, a possible higher susceptibility to viral infections and increased risk of non-communicable diseases, the implications of our findings warrant careful consideration by governmental and health-related decision-makers.

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Informed Consent Statement: Digital informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data can be made available upon request.

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

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BRIEF RESEARCH REPORT
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Drastic Reductions in Mental Well-Being Observed Globally During the COVID-19 Pandemic: Results From the ASAP Survey

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Most countries affected by the COVID-19 pandemic have repeatedly restricted public life to control the contagion. However, the health impact of confinement measures is hitherto unclear. We performed a multinational survey investigating changes in mental and physical well-being (MWB/PWB) during the first wave of the pandemic. A total of 14,975 individuals from 14 countries provided valid responses. Compared to pre-restrictions, MWB, as measured by the WHO-5 questionnaire, decreased considerably during restrictions (68.1 ± 16.9 to 51.9 ± 21.0 points). Whereas 14.2% of the participants met the cutoff for depression screening pre-restrictions, this share tripled to 45.2% during restrictions. Factors associated with clinically relevant decreases in MWB were female sex (odds ratio/OR = 1.20, 95% CI: 1.11–1.29), high physical activity levels pre-restrictions (OR = 1.29, 95% CI 1.16–1.42), decreased vigorous physical activity during restrictions (OR = 1.14, 95% CI: 1.05–1.23), and working (partially) outside the home vs. working remotely (OR = 1.29, 95% CI: 1.16–1.44/OR = 1.35, 95% CI: 1.23–1.47). Reductions, although smaller, were also seen for PWB. Scores in the SF-36 bodily pain subscale decreased from 85.8 ± 18.7% pre-restrictions to 81.3 ± 21.9% during restrictions.

Clinically relevant decrements of PWB were associated with female sex (OR = 1.62, 95% CI: 1.50–1.75), high levels of public life restrictions (OR = 1.26, 95% CI: 1.18–1.36), and young age (OR = 1.10, 95% CI: 1.03–1.19). Study findings suggest lockdowns instituted during the COVID-19 pandemic may have had substantial adverse public health effects. The development of interventions mitigating losses in MWB and PWB is, thus, paramount when preparing for forthcoming waves of COVID-19 or future public life restrictions.

Keywords: coronavirus, WHO-5, SF-36, psychological health, pain, lockdowns

INTRODUCTION

The pandemic associated with the novel coronavirus SARS-CoV2 (commonly referred to as COVID-19) has been managed using a variety of containment strategies. States with known cases instituted restrictions in public travel, school and business closures, stay-at-home orders, and quarantines. Despite their effectiveness in limiting virus transmission (1), lockdowns may have detrimental consequences for health. Even with no restrictions in place, social isolation results in a 29% higher mortality risk (2). Investigations of quarantine effects for previous pandemics (e.g., Ebola, MERS, and SARS) identified the occurrence of post-traumatic stress syndromes, confusion, anger, or symptoms of depression (3). In addition to reducing interpersonal contact, confinements rendered gyms, sports clubs, and public spaces inaccessible. This is of relevance because regular movement is associated with positive affect and life satisfaction (4). Furthermore, active individuals exhibit better nociceptive inhibition and have a lower risk of suffering from musculoskeletal disorders when compared with sedentary persons (5). In sum, it could be speculated that lockdowns cause decreases in both physical and mental well-being.

So far, the health impact of public life restrictions related to COVID-19 has mostly been examined in individual countries. For instance, reports from China (6, 7), Italy (8), and Greece (9) suggest considerable increases in anxiety and depression. As confinement measures affect an estimated minimum of 4 billion people worldwide (10), exploring changes in mental well-being on a multinational scale is an urgent need. The same applies to physical well-being. To the best of our knowledge, changes in the prevalence of musculoskeletal pain and related disability have not been studied. The present study, therefore, investigated the hypothesis that restricting public life to address the COVID-19 pandemic is globally associated with decreases in markers of psychological and physical health.

MATERIALS AND METHODS

Ethics and Design

We report data from the Activity and Health during the SArs-CoV2 Pandemic (ASAP) survey (11), which was performed in April and May 2020. Ethics approval was obtained in each of the involved 14 countries (Australia, Austria, Argentina, Brazil, Chile, France, Germany, Italy, Netherlands, South Africa, Singapore, Switzerland, Spain, and the United States). Participants were 18 and older from countries with (1) official cases of SARS-CoV2 and (2) confinement measures limiting movement in public spaces. Recruitment strategies included social media promotion, mailing lists, and health-related organizations.

Assessment

The well-being section of the ASAP questionnaire consisted of three parts. The first used a Likert scale to gauge the overall impact of public life restrictions on (a) mental and (b) physical well-being. In the second part, mental well-being was assessed by means of the World Health Organization Well-Being Index (WHO-5) questionnaire. It retrospectively measures agreement with five statements (feeling cheerful and in good spirits, feeling calm and relaxed, feeling active and vigorous, waking up feeling fresh and relaxed, having a daily life being filled with things of interest). Each item is answered on a Likert scale (0 = at no time, 1 = some of the time, 2 = less than half of the time, 3 = more than half of the time, 4 = most of the time, 5 = all of the time). A total score is calculated by multiplying the sum of all item values by four. The instrument is available in multiple languages and has high reliability and validity as a screening tool for depression (12): A sum score of $\leq$50 has been shown to exhibit 86% sensitivity and 81% specificity for a "screening diagnosis" of depression (12). The WHO-5 was answered twice, once referring to a typical period before public life restrictions and once referring to the time during restrictions.

In the third part, physical well-being was measured using the bodily pain subscale of the SF-36 questionnaire (SF-36 BPS). The instrument asks two questions assessing musculoskeletal pain (6-point Likert scale from "none" to "very severe") and the resulting disability (5-point Likert scale from "not at all" to "extreme"). For the composite score, the average of both items is calculated and translated to a 0–100 scale. The SF-36 BPS is cross-culturally adapted and has both high internal consistency and reliability (13). To complement the results from the SF-36 BPS, we examined locations of musculoskeletal pain by adapting a checklist from a consensus statement on the reporting of epidemiological injury data (14). Also, the SF-36 BPS and the pain location checklist were completed twice: once for the time period preceding and once for the period during public life restrictions.

In addition to the background variables assessed in the ASAP questionnaire (sex, age, physical activity, work mode, and work volume), the level of national public life restrictions during the assessment period was quantified by means of the Containment and Health Index (15). The instrument systematically evaluates the governmental measures taken to contain viral spread (e.g., business closures, contact restrictions/tracing). The resulting score ranges between 1 and 100 with higher values representing stronger restrictions.

Data Processing and Statistics

We conducted wave analyses to estimate the risk of nonresponse bias (16). Then, first, well-being changes from pre- to during restrictions were examined using Wilcoxon tests (Likert ratings of physical/mental well-being, subdimensions of the WHO-5 index) and paired t-tests for dependent samples (WHO-5 and SF-36 BPS scores), respectively. For the WHO-5, in addition to the sum score, the portion of participants below the cutoff for depression screening ($\leq$50) pre- and during restrictions was determined.

In a second step, binary logistic regression (dependent variables: clinically relevant WHO-5 decrease of $\geq$10 (12) or minimally important SF-36 BPS decrease of $\geq$10 [13]) was used to calculate adjusted odds ratios (OR) including 95% confidence intervals for variables potentially moderating reductions in well-being. All data analyses were performed using SPSS 22 (SPSS Inc., Armonk, NY, USA). The significance level was set to $\alpha = 0.05$.

RESULTS

Our sample consisted of 14,975 participants (38 ± 15 years, 58.1% females) from 14 countries. Levels of national public life restrictions were highest in Argentina, South Africa, and France and lowest in Brazil, Australia, and Switzerland (**Table 1**). Wave analyses yielded no indication of nonresponse bias ($p < 0.05$).

Changes in Mental Well-Being

On the Likert scale, 73.0% (n = 10,916) of the participants reported a reduction in overall mental well-being although an improvement was indicated by 14.2% (n = 2130). Like the global rating ($p < 0.001$), also the WHO-5 score declined significantly from 68.1 ± 16.9 to 51.9 ± 21.0 during restrictions ($p < 0.001$, **Figure 1**). In the vast majority of cases (80.6%), the observed reductions were clinically relevant. Decreases were found on all items of the WHO-5 with highest reductions in "feeling active and vigorous" and "having a life filled with interesting things" ($p < 0.001$, **Table 2**). Pre-restrictions, 14.2% (n = 2,133) of participants met the cutoff for depression screening. This portion increased to 45.2% (n = 6,765) during restrictions.

Clinically relevant reductions of the WHO-5 score were associated with high physical activity levels pre-restrictions (OR = 1.29, 95% CI: 1.16–1.42), decreased vigorous physical activity during restrictions (OR = 1.14, 95% CI: 1.05–1.23), female sex (OR = 1.20, 95% CI: 1.11–1.29), working outside the home vs. working remotely (OR = 1.29, 95% CI: 1.16–1.44), and the combination of both vs. working remotely (OR = 1.35, 95% CI: 1.23–1.47). No associations were found for work volume (p = 0.42), age (p = 0.27), level of national public restrictions (p = 0.54), and changes in total physical activity during restrictions (p = 0.77).

TABLE 1 | Strength of governmental public life restrictions in the included countries as measured with the Containment and Health Index.

Country	Containment and Health Index
Australia	65.6 ± 1.5
Austria	79.2 ± 6
Argentina	88.5 ± 5.3
Brazil	63.3 ± 1.9
Chile	75.1 ± 0.5
France	81.8 ± 0
Germany	68.1 ± 2.4
Italy	87.1 ± 9.2
Netherlands	72.7 ± 0
South Africa	87.1 ± 0
Singapore	80.4 ± 9.8
Switzerland	68.3 ± 2.9
Spain	77.3 ± 1.6
United States	73.6 ± 0.7

The table lists mean percentage values and standard deviation of changes during the study period. Higher values represent more restrictive measures.

Changes in Physical Well-Being

Almost two thirds (64.2%; n = 9,594) of the participants reported a reduction in overall physical well-being although an improvement was indicated by 20.0% (n = 2,985) of the surveyed individuals. Values on the SF-36 BPS decreased from 85.8 ± 18.7 to 81.3 ± 21.9% ($p < 0.001$). Regarding individual items, score reductions were higher for musculoskeletal pain (−7.1%) than for resulting disability (−3.8%). Prevalence of pain (**Figure 2**) increased in all body locations with the highest increments in the lower back (+8.4%), neck (+8.1%), and thoracic spine (+5.3%).

Clinically relevant decrements in physical well-being were associated with female sex (OR = 1.62, 95% CI: 1.50–1.75), high levels of national public life restrictions (OR = 1.26, 95% CI: 1.18–1.36), and young age (OR = 1.10, 95% CI: 1.03–1.19). No associations were found for work mode (p = 0.76), work volume (p = 0.10), pre-restriction physical activity level (p = 0.23), or moderate (p = 0.90) and vigorous physical activity (p = 0.22) during restrictions.

DISCUSSION

To the best of our knowledge, this is the first large-scale multinational investigation of physical and mental well-being during the first wave of the COVID-19 pandemic. Although confinement strategies seem effective in curbing the spread of the virus, they may entail a series of adverse health consequences. Most notably, the number of individuals at risk for depression has tripled during lockdowns. With almost half of our sample then falling below the screening cutoff, the reductions in mental well-being, observed across 14 countries, validate and expand available data from other pandemics (3) and early COVID-19 reports [e.g., (6–10)].

Impairments were smaller for physical than for mental well-being. In the first place, this may mean that interventions aiming to mitigate negative health consequences associated

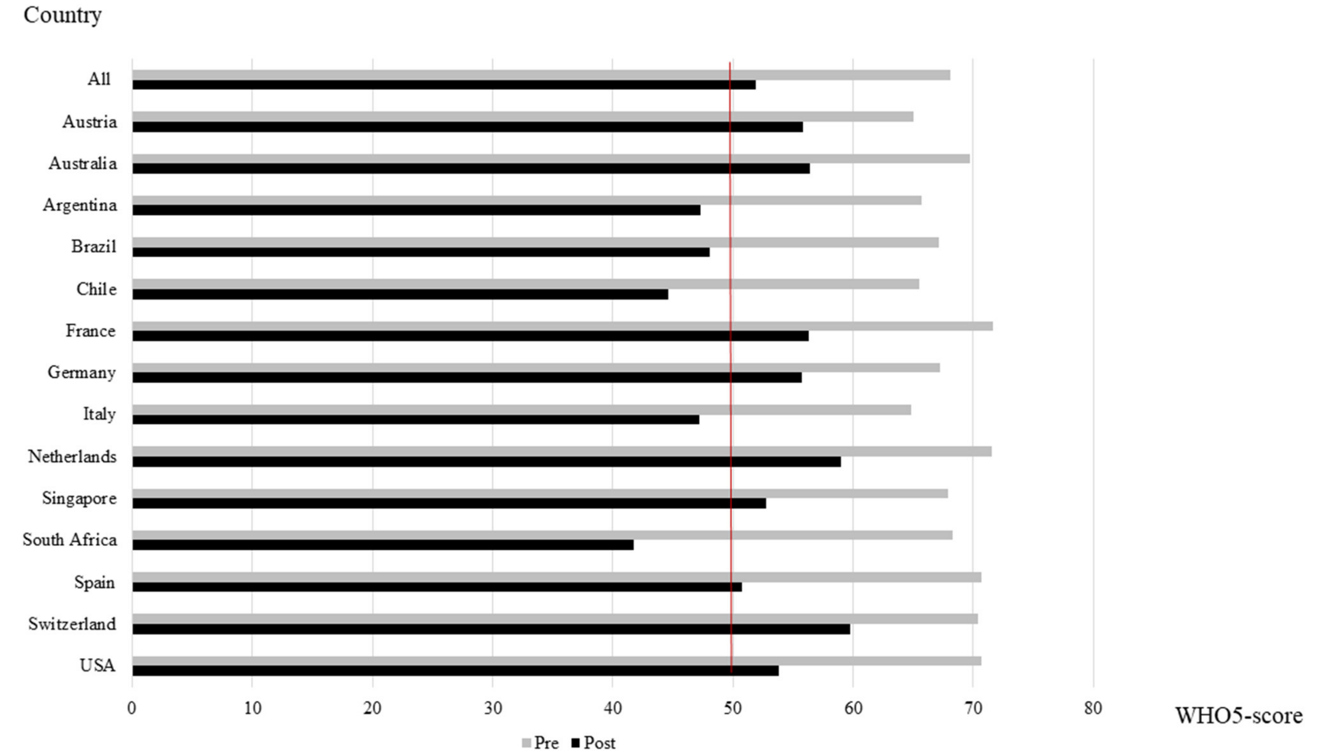

FIGURE 1 | Mental well-being (mean WHO-5 sum score) pre- and during public life restrictions in all included countries. The red line indicates the cutoff score for depression screening (50%).

TABLE 2 | Subdimensions of the WHO-5 index before and during public life restrictions (median and interquartile range).

WHO-5 item	Pre-restrictions	During restrictions	Wilcoxon test of difference
I have felt cheerful in good spirits	4 (1)	3 (2)	$p < 0.0001, r = -0.61$
I have felt calm and relaxed	4 (1)	3 (2)	$p < 0.0001, r = -0.32$
I have felt active and vigorous	4 (1)	2 (2)	$p < 0.0001, r = -0.56$
I woke up feeling fresh and rested	3 (2)	3 (3)	$p < 0.0001, r = -0.25$
My life has been filled with things that interest me	4 (1)	2 (2)	$p < 0.0001, r = -0.59$

The 6-point Likert scale has the following values: 0 = at no time, 1 = some of the time, 2 = less than half of the time, 3 = more than half of the time, 4 = most of the time, 5 = all of the time.

with lockdowns should particularly emphasize psychological aspects. However, careful consideration is still needed when aiming to interpret the seemingly low decreases in physical health. The SF-36 BPS combines ratings on musculoskeletal pain and disability. Most theoretical models assume that pain needs to be maintained for a certain period of time until disability manifests (17). Moreover, disability is significantly moderated by psychological distress and fear (17). As the survey referred to a period of a few weeks and as impairments in mental well-being were strong, a more pronounced increase in pain and dysfunction would be plausible at a later point in time.

Our results represent a call to action for health providers and policy makers. Impaired psychological well-being increases not only the odds of depression but also mortality risk (18). This highlights the importance of recognizing the negative mental health consequences during pandemic-related confinements. Newly developed interventions should specifically address the needs of women, who had higher odds for clinically relevant reductions in both the WHO-5 and the SF-36 BPS. Regarding psychological well-being, the present study's findings align with a wealth of evidence demonstrating a gender gap with a higher depression susceptibility of females (19). In summary, health stakeholders need to be aware that restrictions in public life may be associated with substantial decrements in mental and physical well-being. Interestingly, we found only a modest relationship between the restriction level and lower SF-36 values and no relationship between the restriction level and the WHO-5 scores. This may be because the Containment and Health Index contains several elements that are not directly related to individual well-being (e.g., contact tracing and testing paradigm).

Two strategies seem of value to mitigate losses in physical and, particularly, mental well-being. Existing literature suggests

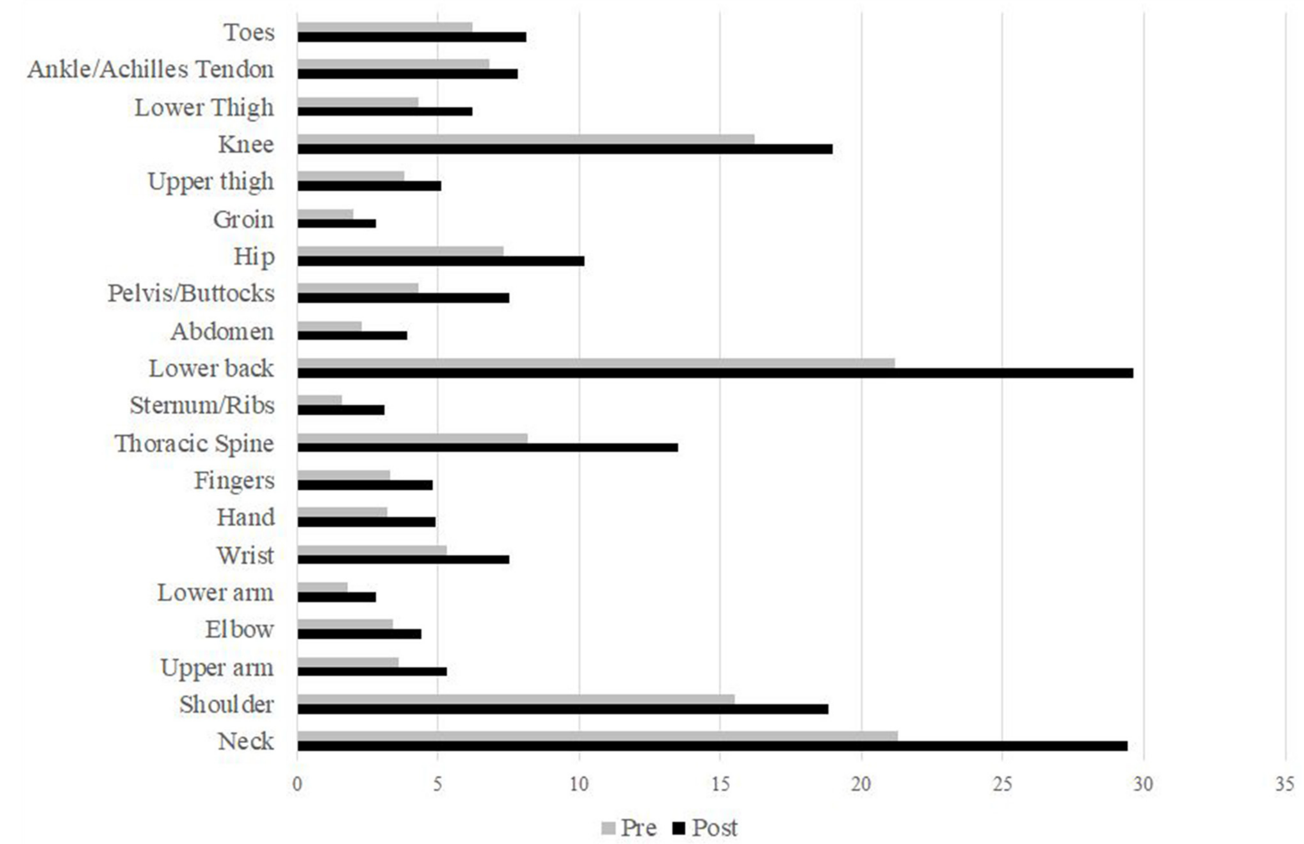

FIGURE 2 | Prevalence [%] of musculoskeletal pain pre- and during public life restrictions stratified by body locations.

working remotely is associated with lower stress levels and decreased risk of depression (20, 21). Also, our survey revealed smaller odds for mental well-being reductions in persons working from home. Besides encouraging and allowing employees to change the workplace, the promotion of regular physical activity could be helpful. Reductions in vigorous activity during restrictions and a high baseline activity prior to restrictions were both related to declines in WHO-5 scores. This means that (a) having been active prepandemic is not protective against well-being decrements and (b) that the development of strategies aiming to maintain the previous movement habits is urgently needed.

Our survey provides strong indications of a subjective well-being decrease in the vast majority of participants. However, it is of interest that a substantial proportion also displayed improvements: One in seven individuals reported increased mental health, and one in five reported improved physical health. Possible reasons for this may include a variety of factors, such as higher amounts of time spent with family, higher task autonomy, reduced work-related travel, or reevaluation of personal health priorities.

Finally, some methodological aspects merit consideration. Our cross-sectional study used retrospective questions. It has been shown that self-reports of health outcomes may be affected by recall bias if relating to the past (22). Although we used relatively short time periods (days to weeks), this phenomenon cannot be ruled out entirely in the examined sample. Another issue relates to the influence and control of background variables: Although we assessed many factors, including age, sex, physical activity levels, work mode, and work volume, it would, inter alia, have been valuable to collect additional sociodemographic data, such as education, profession, and income.

CONCLUSIONS

Confinements in countries affected by the novel coronavirus may have caused major reductions in subjective well-being. Strategies promoting telecommuting and maintenance of physical activity may help prevent similar losses in future pandemics or forthcoming waves of COVID-19.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because only aggregated data can be shared as per ethics approval. Requests to access the datasets should be directed to Jan Wilke, wilke@sport.uni-frankfurt.de.

ETHICS STATEMENT

The study was approved by the Ethics committee of the Faculty of Psychology and Sports Sciences, Goethe University. The participants provided informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JW: concept/design, data collection, analysis, interpretation, writing, and critical revision. KH, LM, and AT: concept/design, data collection, analysis, interpretation, and critical revision. PE, CF, MG-G, CS, FL, BT, JP, FP, DJ-P, MS, JJ, MZ, MP, CH, SW, LV, EV, and LH: data collection, interpretation, writing, and critical revision. All authors contributed to the article and approved the submitted version.

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Brief Report

Restrictercise! Preferences Regarding Digital Home Training Programs during Confinements Associated with the COVID-19 Pandemic

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Abstract: Confinement measures during the COVID-19 pandemic have caused substantial reductions in global physical activity (PA) levels. In view of the manifold health benefits of PA, the development of interventions counteracting this trend is paramount. Our survey with 15,261 participants (38 ± 15 years, 58.5% females) examined preferences towards digital home exercise programs in 14 countries affected by COVID-19. More than two-thirds of the sample (68.4%, n = 10,433) indicated being interested in home exercise, and most participants were willing to work out at least three times per week (89.3%, n = 9328). Binary logistic regression revealed that female sex, working part-time, younger age, and being registered in a gym were associated with willingness to exercise. Flexibility (71.1%, n = 7377), resistance (68.6%, n = 7116), and endurance training (62.4%, n = 6478) were the most preferred types of exercise. Our results may guide health providers in developing individually tailored PA interventions during the current and future pandemics.

Keywords: physical activity; COVID-19; coronavirus; telemedicine; e-Health

1. Introduction

The spread of the novel coronavirus, also referred to as COVID-19, has prompted countries worldwide to restrict public life over weeks to months. Investigations into the effectiveness of related measures demonstrate that confinement strategies effectively curbed the pandemic [1,2]. However, controlling the contagion by means of lockdowns could have negative implications for health. A recent population-based survey recruiting 13,503 participants from five continents revealed a 41% decline in physical activity (PA) compared to pre-restrictions [3]. On the basis of data collected in China, it was estimated that the portion of insufficiently active individuals in China tripled during the early phase of the pandemic [4].

According to the literature, inactivity causes 9% of premature mortality, and reducing it by only 10% could avert more than 500,000 deaths per year [5]. The impact of the current PA decreases may, therefore, have detrimental consequences. With gyms, sports clubs, and other public activity spaces rendered inaccessible, the development of alternative movement opportunities is paramount. Tele-exercise represents a cost-effective and easy-to-distribute option for individuals mandated to stay at home [6]. Previous research demonstrated that meeting the individual preferences of the target population represents a key aspect to consider in the design of new PA offers. For instance, older adults' adherence to fall prevention programs is related to the inclusion of specific components (e.g., balance exercise) rather than to the general effectiveness of the interventions [7]. In a similar way, back and neck pain patients are more compliant with home exercise when positively evaluating the program characteristics [8]. Against this background, the present study examined the preferences towards digital home exercise programs in individuals affected by the COVID-19 pandemic.

2. Materials and Methods

2.1. Ethical Standard and Study Design

The cross-sectional ASAP (Activity and health during the SARS-CoV-2 pandemic) survey [9] was performed in 14 countries (Argentina, Australia, Austria, Brazil, Chile, France, Germany, Italy, the Netherlands, Singapore, South Africa, Spain, Switzerland, and the United States of America (USA)). Approval was obtained from the study center's ethics committee (Local Ethics Committee of the Faculty of Sports Sciences and Psychology, ref. 2020-13) and the ethics committees of the other collaborating partners. All participants provided informed consent.

2.2. Participants

Individuals aged 18 and older from countries with (1) official cases of COVID-19 and (2) governmental restrictions limiting movement in public spaces were eligible. Recruitment included social media promotions (e.g., Facebook), mailing lists, and health-related multipliers (e.g., national "Exercise is Medicine" chapters).

2.3. Questionnaire

The herein reported part of the ASAP survey measured the participants' preferences regarding digital home exercise programs delivered via internet. In addition to ascertaining the general willingness to participate in related programs (yes/no), the optimal duration (free entry, min/week), training frequency (workouts per week; 1–2, 3–4, 4–6 or daily), and exercise types (flexibility, resistance, endurance, balance/stability, cognition, relaxation) were assessed. Additional information obtained from other sections of the ASAP survey included age, sex, work mode (home office/office/both), and volume (part-time/full-time), as well as physical activity guideline compliance (yes/no; ≥150 min moderate, ≥75 min vigorous PA or an adequate combination of both as per the World Health Organization (WHO), assessed using the Nordic Physical Activity Questionnaire, short version [10]).

2.4. Data Processing and Statistics

Data are presented as mean and standard deviation (SD), median and interquartile range (IQR), or absolute and relative frequency, as appropriate. Factors influencing (a) the willingness to exercise and (b) the preference of specific components (e.g., resistance or endurance exercise) were investigated using multiple binary logistic regression. The results were presented as adjusted odds ratios (OR) and 95% confidence intervals (CI). Calculations were made with SPSS 22 (SPSS Inc., Chicago, IL, USA).

3. Results

A total of n = 15,261 responses (Argentina: n = 1021, Australia: n = 325, Austria: n = 806, Brazil: n = 1800, Chile: n = 1364, France: n = 2433, Germany: n = 2294, Italy: n = 903, Netherlands: n = 203, Singapore: n = 941, South Africa: n = 658, Spain: n = 632, Switzerland: n = 429, USA: n = 1193, others: n = 259) were obtained. Mean age was 38 (SD 15) years and 58.9% (n = 8935) were females.

3.1. Exercise Preferences

Over two-thirds of the participants (68.4%, n = 10,433) indicated readiness to engage in digital home exercise. Among these, the chosen duration (median) was 40 (IQR: 30–60) minutes per session. The majority of the participants preferred working out at least three times weekly (89.3%, n = 9328). The most popular contents were flexibility (71.1%, n = 7377), resistance (68.6%, n = 7116), and endurance exercise (62.4%, n = 6478), while relaxation (42.6%, n = 4416) and cognitive training (24.2%, n = 2514) were selected less frequently.

3.2. Variable Associations

Logistic regression revealed four factors associated with interest in digital home exercise: female sex, working part-time, younger age, and having exercised in a gym pre-restrictions (Table 1).

Table 1. Variables associated with willingness to participate in online home exercise programs.

Variable	Descriptive Statistics	OR (95% CI)
Age, % (*n*)		
<40 years	62.2 (9488)	Reference
≥40 years	37.8 (5773)	0.707 (0.619 to 0.808) *
Sex, % (*n*)		
Male	41.1 (6237)	Reference
Female	58.9 (8935)	1.747 (1.577 to 1.936) *
Physical Activity Level, % (*n*)		
Not meeting guidelines	18.5 (2423)	Reference
Meeting guidelines	81.5 (10,681)	0.924 (0.831 to 1.027)
Exercising in a Gym, % (*n*)		
No	61.1 (9323)	Reference
Yes	38.9 (5938)	1.324 (1.188 to 1.476) *
Exercising in a Sports Club, % (*n*)		
No	70.9 (10,821)	Reference
Yes	29.1 (4440)	1.093 (0.972 to 1.229)
Exercising Self-Organized, Indoor, % (*n*)		
No	74.4 (11,360)	Reference
Yes	25.6 (3901)	0.954 (0.847 to 1.074)
Exercising Self-Organized, Outdoor, % (*n*)		
No	40.4 (6164)	Reference
Yes	59.6 (9097)	0.973 (0.873 to 1.084)
Work Mode, % (*n*)		
Office	16.3 (2439)	Reference
Home office	44.2 (6600)	1.024 (0.917 to 1.143)
Home office and office	11.5 (1714)	1.073 (0.927 to 1.241)
No formal employment	28.0 (4185)	0.942 (0.836 to 1.061)
Working Volume, % (*n*)		
Full-time	66.8 (5600)	Reference
Part-time	33.2 (2781)	1.249 (1.118 to 1.394) *

The adjusted ORs were estimated by the multiple binary logistic regression model. SD: standard deviation. OR: adjusted odds ratio for all independent variables included in the model; CI: confidence interval. * Statistically significant.

With regard to exercise types (Table 2), older participants (≥40 years) were more likely to select flexibility and less likely to choose resistance, endurance, and cognitive training. Marked differences also occurred between men and women. Female sex was associated with a more frequent choice of flexibility and relaxation exercises and a less frequent selection of resistance, cognitive, and endurance exercise. Participants with high physical activity levels (meeting WHO PA recommendations) more often preferred resistance, endurance, and balance/stability training, but not other forms of exercise. Type of employment (full-time/part-time) was weakly/not associated with exercise preference. In most cases, individuals working remotely (home office) had comparable odds to participants working outside the home (in the office). However, individuals who combined working at home and in the office had a higher preference of most exercise types than persons working outside the home only. Not having a formal employment was associated with a less frequent choice of resistance and endurance training but more frequent choice of balance/stability, cognitive, flexibility, and relaxation exercise.

Table 2. Associations between preferred workout contents and sample characteristics.

Independent Variables	Dependent Variables					
	Resistance OR (95% CI)	**Endurance OR (95% CI)**	**Balance/Stability OR (95% CI)**	**Cognition OR (95% CI)**	**Flexibility OR (95% CI)**	**Relaxation OR (95% CI)**
Age						
<40 years	Reference	Reference	Reference	Reference	Reference	Reference
≥40 years	0.470 (0.414 to 0.533) *	0.619 (0.550 to 0.696) *	1.075 (0.960 to 1.203)	0.822 (0.718 to 0.940) *	1.375 (1.213 to 1.559) *	0.960 (0.855 to 1.077)
Sex						
Male	Reference	Reference	Reference	Reference	Reference	Reference
Female	0.650 (0.568 to 0.742) *	0.789 (0.697 to 0.893) *	1.070 (0.951 to 1.205)	0.822 (0.715 to 0.945) *	1.445 (1.270 to 1.645) *	1.610 (1.425 to 1.819) *
Physical Activity Level						
Not meeting guidelines	Reference	Reference	Reference	Reference	Reference	Reference
Meeting guidelines	2.104 (1.810 to 2.447) *	1.486 (1.282 to 1.722) *	1.347 (1.165 to 1.558) *	1.004 (0.843 to 1.195)	1.101 (0.937 to 1.294)	0.655 (0.566 to 0.759) *
Work Mode						
Office	Reference	Reference	Reference	Reference	Reference	Reference
Home office	0.934 (0.815 to 1.070)	0.871 (0.766 to 0.990) *	1.037 (0.918 to 1.171)	1.152 (0.994 to 1.335)	1.113 (0.973 to 1.273)	1.225 (1.081 to 1.388) *
Home office and office	1.228 (1.023 to 1.475) *	1.026 (0.866 to 1.217)	1.209 (1.028 to 1.422) *	1.221 (1.008 to 1.479) *	1.095 (0.916 to 1.311)	1.243 (1.055 to 1.466) *
No formal employment	0.752 (0.649 to 0.871) *	0.771 (0.671 to 0.886) *	1.145 (1.003 to 1.307) *	1.366 (1.168 to 1.597) *	1.178 (1.018 to 1.363) *	1.260 (1.110 to 1.443) *
Work Volume						
Full-time	Reference	Reference	Reference	Reference	Reference	Reference
Part-time	0.992 (0.870 to 1.129)	1.124 (0.994 to 1.271)	1.099 (0.976 to 1.236)	1.261 (1.098 to 1.449) *	0.923 (0.810 to 1.052)	1.127 (1.000 to 1.271) *

The adjusted ORs were estimated by the multiple binary logistic regression model. OR: adjusted odds ratio for all independent variables included in the models; CI: confidence interval. * Statistically significant.

4. Discussion

A wealth of evidence supports the manifold health benefits of sufficient and regular engagement in physical activity [11]. Not only because of these general effects, but also because exercise can have a positive impact on immune function and reduce upper respiratory tract infections [12], researchers have underlined the need to maintain or improve PA habits during mandated lockdowns [13,14]. To the best of our knowledge, the present study is the first to describe the exercise preferences of individuals affected by the COVID-19 pandemic. More than two in three participants indicated willingness to engage in digital home exercise programs. This particularly applied to women whose odds of being interested were 1.7 times higher than those of men. On the whole, our data suggest that tele-health interventions could be well received, thereby helping to stem any reduced PA during confinements [3]. Reports from China indicate that public life restrictions caused considerable increases in anxiety and depression [15]. As exercise is effective in addressing both, supporting the maintenance of regular PA may be crucial not only for physical health, but also for mental well-being.

Although abundant evidence underlines the relevance of matching program design and participant preferences in special populations such as patients, the elderly, or postmenopausal women [8,9], there is a paucity of studies investigating the preferences of asymptomatic individuals. This report provides significant information toward supporting tailored programs on the basis of specific needs of different target groups during the COVID-19 pandemic. For example, new programs should have a minimum frequency of three sessions per week. This is in line with statements of the American College of Sports Medicine [16] recommending resistance, flexibility, and neuromotor training 2–3 times weekly and cardiorespiratory training 3–5 times weekly.

Flexibility training was the most preferred exercise type, followed by resistance and endurance training. Benefits of flexibility exercise include the promotion of well-being and relaxation [17].

Therefore, its choice could be an attempt to minimize the psychological impact caused by public life restrictions. Furthermore, flexibility exercise does not require extensive space or equipment, making it easy to perform at home and potentially more attractive than other forms of training. However, exercise preference varied considerably as a function of sex and age. Whereas women presented a stronger orientation to flexibility and relaxation, men were more interested in endurance, resistance, and cognition. The latter three were also more popular among younger vs. older participants who rather seemed to require flexibility. The observed patterns might be explained by the belief that resistance and endurance exercise could be more "vigorous" than flexibility and/or relaxation exercises. The perceived "safety" (e.g., in terms of injuries during training) might, hence, influence exercise preference. This particularly applies to women/older participants who display a higher health perception and are more conservative with regard to healthy behaviors than men and younger individuals [18,19]. While future studies should test this hypothesis, we suggest calibrating the exercise modality and intensity to the risk appetite of each group, in order to encourage compliance.

Finally, another remarkable finding was that active participants had more than twice the odds of preferring resistance exercises and about 1.5 the odds of preferring endurance training. Seeking to improve performance, they may prefer vigorous exercises, while less active individuals may select less vigorous exercises aiming to acquire health benefits with the lowest possible risk of adverse events.

Some limitations have to be discussed. Firstly, this was an internet survey, and promotion was mainly based on social media promotion. Persons with limited or no internet access and individuals with small affinity for digital content may, therefore, have had a lower chance to participate. Another issue relates to the items included. Although the questions were mostly self-explanatory, a few contents could be interpreted differently. For instance, some participants may have assigned yoga and light stretching/mobility training to "relaxation exercise". while others may have understood the term as only describing specific techniques such as progressive muscle relaxation. Finally, while we examined important program characteristics such as the exercise type, training frequency, and session duration, we did not include preferred intensity, which would have been interesting as it may moderate the protective effect of exercise against viral infections.

5. Conclusions

In summary, a large portion of individuals affected by confinements related to the COVID-19 pandemic are interested in digital home exercise. Interventions meeting their needs should consider factors such as the frequency (minimum: three times a week), duration (40 min), and type (flexibility, resistance, endurance) of program. Additionally, carefully balancing the different needs of individuals, such as old versus young, male versus female, and active versus inactive, is recommended.

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Publication E

Train at home, but not alone: a randomised controlled multicentre trial assessing the effects of live-streamed tele-exercise during COVID-19-related lockdowns

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ABSTRACT

Objective Public life restrictions associated with the COVID-19 pandemic caused reductions in physical activity (PA) and decreases in mental and somatic health. Considering the interplay between these factors, we investigated the effects of digital home exercise (DHE) during government-enforced lockdowns.

Methods A multicentre randomised controlled trial was performed allocating healthy individuals from nine countries (N=763; 523 female) to a DHE or an inactive control group. During the 4-week main intervention, DHE members engaged in live-streamed multicomponent home exercise. Subsequently, both groups had access to prerecorded workouts for an additional 4 weeks. Outcomes, assessed weekly, included PA level (Nordic Physical Activity Questionnaire-Short), anxiety (Generalized Anxiety Disorder Scale-7), mental well-being (WHO-5 Questionnaire), sleep quality (Medical Outcome Study Sleep Scale), pain/disability (Chronic Pain Grade Scale) and exercise motivation (Self-Concordance Scale). Mixed models were used for analysis.

Results Live-streamed DHE consistently increased moderate PA (eg, week 1: 1.65 times more minutes per week, 95% CI 1.40 to 1.94) and vigorous PA (eg, week 1: 1.31 times more minutes per week, 95% CI 1.08 to 1.61), although the effects decreased over time. In addition, exercise motivation, sleep quality and anxiety were slightly improved for DHE in the 4-week live streaming period. The same applied to mental well-being (mean difference at week 4: +0.99, 95% CI 0.13 to 1.86), but an inverted trend was observed after live streaming was substituted by prerecorded exercise.

Conclusions Live-streamed DHE represents an efficacious method to enhance PA and selected markers of health during pandemic-related public life restrictions. However, research on implementation is warranted to reduce dropout rates.

Trial Registration number DRKS00021273.

INTRODUCTION

In March 2020, the WHO classified the global spread of the novel coronavirus (SARS-CoV-2) as a pandemic. To control the contagion, governments used a variety of strategies, inter alia including stay-at-home orders, social distancing, business closures and banning of mass events.[1] Although related measures have proven effective in reducing viral transmission,[1] restricted access to sports clubs, gyms and parks caused massive declines in physical activity (PA). According to a multinational survey with 13 503 participants from 14 countries, individual movement at both moderate and vigorous intensity decreased by more than 40% during lockdowns[2] and the portion of individuals achieving recommended PA levels (ie, 150 min of moderate PA or 75 min of vigorous PA per week) dropped by 19%.[2] These self-reported findings align with objectively measured data. Tison *et al*[3] analysed daily step counts measured with smartphone applications before and during the pandemic. One month after the WHO declaration, step counts (averaged for 187 countries) had decreased by more than a quarter.

Physical inactivity causes 8%–9% of all premature deaths[4 5] and furthermore is associated with the occurrence of coronary heart disease and type 2 diabetes, as well as different forms of cancer.[4] Being physically active, on the other hand, entails a myriad of somatic benefits, such as reducing mortality[6] as well as decreasing the risk of musculoskeletal[6 7] and non-communicable[6] diseases. In addition to the general importance of PA in health, it seems to confer some protection against COVID-19.[8] Sallis *et al*[9] analysed health data from 48 440 adults diagnosed with COVID-19. Inactive individuals had a higher risk of hospitalisation (OR 2.3), intensive care unit admission (OR 1.7) and death (OR 2.5) compared with persons meeting the PA guidelines.

Public life restrictions may also compromise mental well-being. According to survey data, the share of general population members meeting cut-off screening scores for depression tripled when compared with prerestriction periods.[10] A systematic review of other self-reports, furthermore, identified high rates of stress (up to 82%), post-traumatic stress (up to 54%), anxiety (up to 51%) and psychological distress (up to 38%) in countries affected by COVID-19.[11] Generally, regular PA is known to avert and improve anxiety and symptoms of depression[12–14] while being significantly associated with positive affect and life satisfaction.[15]

In view of the paramount importance of movement for both somatic and mental health, researchers have called for the development of specifically tailored programmes aimed at maintaining PA during public life restrictions.[16–20] Digital home exercise represents an opportunity to be physically active while still supporting viral containment efforts by means of social distancing. According to multinational data, 7 out of 10 persons would be willing to participate in related programmes.[16] Against this background, the present study investigated the efficacy of a 'virtual gym' providing digital live-streamed home exercise on PA and markers of mental and somatic health during the COVID-19 pandemic.

METHODS

Study design

This article reports data from the 'Move ASAP' (*A*ctivity and health during the *S*ARS-CoV-2 *P*andemic) project.[21] A two-armed randomised controlled multicentre trial was performed in nine countries with active public life restrictions (Argentina, Austria, Brazil, Chile, Germany, Italy, Ireland, South Africa and Spain). In the main 4-week study phase, all involved centres assigned healthy adults to either a live-streamed digital home exercise group (DHE) or an inactive control group (CON). After the actual 4-week intervention, both groups had access to an online archive with prerecorded workouts for an additional 4 weeks. Proxies of somatic and mental health, as well as PA, were assessed using online questionnaires weekly. All enrolled individuals provided digital informed consent.

Public involvement

Feedback of target population members (healthy adults, see the Sample section) was used during the planning of the study. The formulation of the research question and the choice of assessed outcomes were based on previous surveys.[2 10] The questionnaires used were additionally pilot-tested for clarity and comprehension by non-academic volunteers. With regard to the design of the intervention, we draw on reported preferences for DHE.[16]

Sample

Participants were recruited by means of online and newspaper advertising as well as via social media promotion. To verify the absence of contraindications to exercise, each participant completed the Physical Activity Readiness Questionnaire[22] and only healthy adults without reported complaints were enrolled. Exclusion criteria encompassed severe orthopaedic, neurological, cardiovascular, metabolic, endocrine or psychiatric diseases, intake of drugs modifying pain perception, and pregnancy.

Randomisation

We used stratified (strata variable: centre) urn randomisation for group assignment.[23] To allow concealed allocation and to prevent selection bias, randomisation was automatically performed by means of the software for survey delivery (Soscisurvey, Soscisurvey, Munich, Germany). In detail, after having completed the outcome assessments of the baseline questionnaire, the digital algorithm assigned the participants to the two groups, in the end generating balanced group sizes for each centre stratum.

Intervention

Individuals randomised to DHE participated in a 4-week tele-exercise programme provided via video live streaming (ie, synchronous approach). A 'virtual gym' schedule (example in online supplemental figure 1) was created, offering multicomponent workouts with different focuses, such as strength, endurance, flexibility, stability, balance, relaxation and cognition. The intensity of most sessions was moderate, although a few workouts also included vigorous exercise activities. Using camera and microphone, the instructors carefully monitored the participants, and if necessary provided advice regarding correct exercise execution or adjustments of training intensity. Participants could participate in the workouts *ad libitum* and without prior registration. While each country developed its own schedule depending on the availability of instructors (see also online supplemental table 1), the following criteria were uniform to ensure standardisation: training sessions were offered for a minimum of 5 days per week; individual workout durations ranged between 30 and 60 min; and instructors held, as a minimum requirement, a bachelor's degree in sports science, movement science or a related discipline. Instructors received standardised training, modifiable demonstration workouts and a video archive containing a large pool of sample exercises. During the workouts, both the instructors and the participants could activate a camera and microphone to receive feedback on exercise execution, ask questions or interact with the group (online supplemental figure 2). The software used for video transmission (VidyoConnect, Vidyo, Hackensack, USA; Zoom, Zoom Video Communications, San Jose, California, USA; Skype, Microsoft Corporation, Redmond, USA; Microsoft Teams, Microsoft Corporation, Redmond, USA; BlackBoard, Blackboard, Washington, DC, USA) varied between centres, depending on local licensing and requirements thereof. The CON members did not receive an intervention and completed only outcome assessments (see the Outcomes section) during the main intervention period. However, to create an incentive for participation, members of both groups (DHE and CON) received unlimited access to an online archive with prerecorded workouts for an additional 4 weeks after the end of the main study phase.

Outcomes

Blinded assessment of health markers and PA was performed each 7 days using digital questionnaires. The study thus had nine measurements: at baseline and weekly during the two 4-week part periods (T1–T8). The applied scales were selected based on psychometric validation and, where possible, the availability of translations and cross-cultural adaptations for each centre. Instruments employed included the Nordic Physical Activity Questionnaire-Short (NPAQ-Short[24]) for PA, WHO-5 Scale for Mental Well-Being,[25] Generalized Anxiety Disorder Scale-7 (GAD-7[26]) for impulsiveness and anxiety levels, the Medical Outcome Study (MOS) Sleep Scale (12-item version) for sleep quality,[27] the Self-Concordance Scale (SKK)[28] for exercise motivation, and the Chronic Pain Grade Scale (CPGS) for pain and disability levels.[29] In addition to the intervention effects, adherence to exercise was checked by documenting attendance at each workout session offered.

Data processing and analysis

We performed an a priori sample size calculation using an algorithm to account for between-site variance in multicentre trials aimed to be analysed with linear mixed models.[30] As a result, 544 participants had to be included in the present study (dropout rate: 20%, power: 80.3%, $\alpha=0.05$, d=0.25). All analyses were performed using standard statistical software packages (eg, R and SPSS V.22). The two-sided significance level for all analyses was set to $\alpha=0.05$.

We conducted three types of analysis in this study[31 32]: (1) intention-to-treat (ITT), which was the main analysis; (2) complier average causal effect (CACE); and (3) dose–response analysis. The

ITT analysis was aimed at estimating the population average causal effect by considering the randomised allocation regardless of whether the participants in each group complied or not with their allocation condition (ie, intervention or control[32 33]). The CACE analysis was aimed at estimating the local average causal effect within the compliers. 'Compliers' were considered those randomly allocated to the DHE group who adhered to at least two workouts per week throughout the study and those randomly allocated to CON who did not receive the live-streamed DHE during the 4-week main period and who adhered to at least two workouts per week during the additional 4 weeks when access to an online archive with prerecorded workouts was granted. For each analysis and outcome, a three-level mixed model with restricted maximum likelihood estimation was implemented. Initially, a linear mixed model was fit. An exponential (log-linear) mixed model was considered in case of evidence for violations of assumptions, although linear mixed models are rather robust in regard to this.[34] The results of the linear models were presented as mean difference (MD), while ratios of means (RoM) were presented for exponential models. Uncertainty around the average estimates was expressed as 95% CI.[35 36]

The fixed effect term of the mixed models was composed of dummy variables indicating the follow-up time points 1–8, and the interaction terms were composed of group and time (ie, 'group × time', where 0 is for CON and 1 is for DHE, and weeks 1–8). This strategy was implemented in order to adjust for possible differences between groups at baseline and in turn to correct the analyses for possible bias related to regression to the mean.[37] Two random effect terms were included in the mixed models in order to adjust the analysis for centres and for repeated measurements: (1) a correlated random intercept and slope varying the intercept for the respective centres and varying the slope for the time points; and (2) a correlated random intercept and slope varying the intercept for the repeated measurements within each centre and varying the slope for the time points. Both random effect terms were assumed to follow a multivariate normal distribution with the following hyperparameters: a k-dimensional mean vector composed of zeros and a '$k \times k$' covariance matrix composed of random intercept, slope and intercept–slope covariances. The models were adjusted for the following observed prognostic variables at baseline that could possibly affect missing outcome data in our data set: age, sex, living environment, employment and university degree.

We used instrumental variable (IV) analysis to estimate CACE. The IV was considered the randomised allocation assignment. We assumed the exclusion restriction and monotonicity assumptions for the IV analysis.[31 32 38] The IV analysis was conducted in two stages. In stage 1, we regressed a binary variable indicating the compliers on the IV using a logistic mixed model. Time and the interaction term composed of the IV and time were also included in the fixed effect term of the model. From this model, we estimated the predicted probabilities of performing at least two workouts per week for each participant. In stage 2, CACE was estimated using mixed models regressing the outcomes of the study on the predicted probabilities estimated in stage 1. The random terms and the prognostic variables at baseline previously described were also included in stage 1 and 2 models.

A dose–response relationship analysis was performed using mixed models to investigate the influence of exercise dose (adherence) on the possible effects of the DHE programme. The dose–response models were adjusted for age, sex, living environment, employment, university degree and study part (ie, part 1: first 4 weeks; part 2: last 4 weeks). The random effect terms were the same as previously described.

RESULTS

A total of 763 individuals volunteered to participate (online supplemental figure 3). Both groups (CON: n=377, DHE: n=386) were comparable with regard to age, sex, educational level, living environment and employment status (table 1). The main 4-week study part (live-streamed DHE vs CON) was completed by 350 participants, corresponding to a dropout rate of 54%. Slightly more dropouts were recorded in the CON (CON: 57% vs DHE: 51%). From the 350 participants, 228 finished the second 4-week study part (prerecorded workouts), which further increased the total dropout to 70% (CON: 71% vs DHE: 68%) at the end of the 8-week period. No adverse or serious adverse events were reported.

The evaluation of the linear mixed model assumptions revealed violations in the models including the following five outcome variables: GAD-7, NPAQ (moderate PA), NPAQ (vigorous PA), CPGS (pain) and CPGS (disability). Therefore, exponential (log-linear) mixed models were implemented for these five outcome variables. Linear mixed models were implemented for the remaining three outcome variables: exercise motivation (SKK), sleep quality (MOS) and WHO-5 Scale for Mental Well-Being.

ITT analysis

Overall, the ITT analysis (table 2) revealed small to moderate MDs or RoMs for DHE versus CON (figures 1–4). DHE consistently increased moderate PA (eg, week 1: 1.65 times more minutes per week, 95% CI 1.40 to 1.94) and vigorous PA (eg, week 1: 1.31 times more minutes per week, 95% CI 1.08 to 1.61) during the main study part using live streaming (figure 1). These effects, however, became smaller over time and comparisons did no longer include the null value after replacing live exercise by prerecorded workouts (now offered in both groups).

Although with lower consistence, mental well-being (WHO-5) was slightly higher for DHE during the live streaming period (ie, week 4: MD 0.99, 95% CI 0.13 to 1.86) and showed an inverted (ie, lower compared with CON) trend during the additional 4 weeks when live streaming was interrupted and both groups had access to prerecorded workouts (figure 2). However, the 95% CI of the group comparisons contained the null value during these additional 4 weeks. Also, sleep problems (MOS) were initially reduced for the DHE group (week 1: MD −2.30, 95% CI −4.43 to −0.17; figure 3). Similarly, in week 2, anxiety was lower (RoM 0.87, 95% CI 0.77 to 0.98; figure 2) and exercise motivation was higher (MD 0.50, 95% CI 0.02 to 0.97; figure 3) for the DHE group compared with CON.

CACE analysis

The results of the CACE analysis (table 2) were largely similar to the ITT results. However, the uncertainty around the CACE estimates was higher with wider 95% CIs and more frequent inclusions of the null value. Only two exceptions were found: sleep problems (MOS) were higher for the DHE group at the end of the prerecorded workout phase (week 8: MD 7.69, 95% CI 1.30 to 14.08) and pain (CPGS) was up to 1.48 times higher (95% CI 1.10 to 2.01) for the DHE group during the 4-week live-streamed period compared with CON.

Table 1 Sample characteristics at baseline

	Total sample (N=763)	CON (n=377)	DHE (n=386)
Age	32.8±12.6	32.6±12.1	32.9±13.1
Sex, n (%)			
Male	237 (31.1)	122 (32.4)	115 (29.8)
Female	523 (68.5)	253 (67.1)	270 (69.9)
Diverse	2 (0.3)	2 (0.5)	0
No entry	1 (0.1)	0	1 (0.3)
Living environment, n (%)			
Rural	111 (14.5)	55 (14.6)	56 (14.5)
Urban	652 (85.5)	322 (85.4)	330 (85.5)
Origin, n (%)			
Argentina	43 (5.6)	20 (5.3)	23 (6.0)
Austria	20 (2.6)	10 (2.7)	10 (2.6)
Brazil	177 (23.2)	88 (23.3)	89 (23.0)
Chile	229 (30.0)	115 (30.5)	114 (29.5)
Germany	126 (16.5)	62 (16.4)	64 (16.6)
Ireland	46 (6.0)	20 (5.3)	26 (6.7)
Italy	23 (3.0)	12 (3.2)	11 (2.8)
South Africa	73 (9.6)	37 (9.8)	36 (9.3)
Spain	26 (3.4)	13 (3.4)	13 (3.4)
Employment, n (%)			
Yes	516 (67.6)	252 (66.8)	264 (68.4)
No	234 (30.7)	121 (32.1)	113 (29.3)
No entry	13 (1.7)	4 (1.1)	9 (2.3)
University degree, n (%)			
Yes	454 (59.5)	226 (59.9)	228 (59.1)
No	309 (40.5)	151 (40.1)	158 (40.9)

CON, control group; DHE, digital home exercise.

Dose–response analysis

The number of workout participations per week did not affect exercise motivation (SKK), sleep quality (MOS), anxiety (GAD-7), pain intensity and pain-related disability (CPGS). However, the exercise dose was predictive of changes in mental well-being (a 1-point increase in workout participation per week was associated with a 0.10 absolute increase in WHO-5 Scale; 95% CI 0.02 to 0.18), moderate PA (a 1-point increase in workout participation per week was associated with 1.07 times higher minutes of moderate PA per week; 95% CI 1.05 to 1.08) and vigorous PA (a 1-point increase in workout participation per week was associated with 1.04 times higher minutes of vigorous PA per week; 95% CI 1.02 to 1.06).

DISCUSSION

Public life restrictions instituted during the COVID-19 pandemic substantially reduced the opportunities to engage in health-enhancing PA[2 3] and there have been several calls to action requesting the development of novel ways to exercise.[39 40] To the best of our knowledge, the present multicentre trial with participants from nine countries and four continents was the first to examine the effects of live-streamed home exercise conforming to the demand for social distancing.

From a population average causal effect perspective (ie, ITT), two key findings were made. First, DHE substantively enhanced PA, with population means markedly and consistently exceeding the WHO recommendation of at least 150 min of moderate PA or 75 min of vigorous PA per week. This is of particular importance because the worldwide confinements caused an almost 20% drop in PA guideline compliance[2] and because sufficient activity is not only related to reduced mortality in general but also to a lower risk of hospitalisation, intensive care unit admission and death due to COVID-19.[9] Second, live-streamed DHE had small beneficial effects on mental well-being, anxiety, sleep quality and exercise motivation. The positive impact of DHE on well-being was initially observed during all 4 weeks of the main intervention part. However, interestingly, this effect was not sustained during the subsequent 4 weeks, when the live streaming was interrupted and prerecorded workouts were available to both groups. This finding may be explained by the fact that the formerly inactive control group now received an intervention too and because the prerecorded workouts could have been less attractive to the DHE group.

Since the sample of our study was composed of healthy individuals, we did not expect large effects on physical and mental health indicators. However, even small changes as those observed could be relevant for several reasons. Effect sizes of previously tested interventions aiming to improve markers of mental well-being were small or moderate at best,[41–44] meaning that our intervention performed at least similar. Additionally, exercise was offered during a pandemic with concomitant restrictions to public life. As these may be expected to adversely affect health, maintaining the status quo could already be seen as a success. Finally, if achieved changes, even if small, could be maintained over time, they could still result in an increased quality of life and/or cumulative and latent preventive effects regarding undesired health conditions. DHE, executed regularly, could thus be a promising option to protect health both during and in the absence of a pandemic. The challenge, however, would be to maintain adherence to tele-exercise as our study showed that the

Table 2 Results of the causal effects (efficacy) analyses

		DHE								CG								Crude	ITT	CACE
	Time	n	Mean	SD	Min	Q1	Median	Q3	Max	n	Mean	SD	Min	Q1	Median	Q3	Max	Unadjusted MD* or RoM† (95% CI)	Adjusted MD* or RoM† (95% CI)	Adjusted MD* or RoM† (95% CI)
WHO-5*	Baseline	386	13.1	5.1	0.0	9.0	13.0	17.0	25.0	377	12.6	5.3	0.0	9.0	13.0	17.0	25.0	0.43 (−0.31 to 1.17)	Reference	Reference
	Week 1	246	14.6	5.3	0.0	10.0	15.0	19.0	25.0	227	14.0	5.6	2.0	9.0	14.0	18.5	25.0	0.60 (−0.38 to 1.58)	0.42 (−0.43 to 1.27)	0.11 (−1.15 to 1.37)
	Week 2	219	15.0	5.5	1.0	11.0	15.0	20.0	25.0	206	14.1	5.3	1.0	11.0	14.5	18.8	25.0	0.91 (−0.13 to 1.94)	0.73 (−0.10 to 1.56)	0.28 (−1.03 to 1.58)
	Week 3	198	15.4	5.7	0.0	11.0	16.0	20.0	25.0	176	14.7	5.5	1.0	11.0	15.0	19.0	25.0	0.68 (−0.46 to 1.81)	0.68 (−0.17 to 1.52)	0.81 (−0.61 to 2.22)
	Week 4	186	16.2	5.5	0.0	12.0	17.0	20.0	25.0	157	15.1	5.5	2.0	11.0	16.0	20.0	25.0	1.02 (−0.16 to 2.19)	0.99 (0.13 to 1.86)‡	0.07 (−1.43 to 1.56)
	Week 5	156	13.6	5.6	5.0	10.0	13.0	17.0	30.0	145	14.4	5.3	5.0	10.0	14.0	19.0	26.0	−0.75 (−1.98 to 0.48)	−0.66 (−1.59 to 0.27)	−0.04 (−1.75 to 1.67)
	Week 6	140	13.8	5.6	5.0	10.0	13.0	16.3	29.0	126	14.1	5.2	5.0	10.0	13.0	17.8	28.0	−0.29 (−1.60 to 1.01)	−0.22 (−1.24 to 0.81)	−0.24 (−2.20 to 1.71)
	Week 7	129	13.5	5.8	5.0	10.0	12.0	16.0	29.0	115	13.7	5.4	5.0	10.0	13.0	17.0	27.0	−0.20 (−1.62 to 1.22)	−0.14 (−1.27 to 0.99)	−0.23 (−2.40 to 1.93)
	Week 8	120	13.1	5.4	5.0	10.0	11.5	16.0	29.0	108	13.5	5.7	5.0	10.0	12.5	17.3	27.0	−0.49 (−1.95 to 0.97)	−0.24 (−1.49 to 1.01)	−0.34 (−2.75 to 2.06)
GAD-7†	Baseline	386	7.2	5.4	0.0	3.0	6.0	11.0	21.0	377	6.9	4.9	0.0	3.0	6.0	10.0	21.0	1.05 (0.94 to 1.16)	Reference	Reference
	Week 1	249	6.4	5.3	0.0	2.0	5.0	9.0	22.0	230	6.7	5.2	0.0	3.0	6.0	9.0	27.0	0.95 (0.82 to 1.10)	0.93 (0.83 to 1.04)	0.99 (0.84 to 1.17)
	Week 2	221	5.6	5.2	0.0	2.0	4.0	8.0	21.0	208	6.3	4.5	0.0	3.0	6.0	9.0	20.0	0.88 (0.75 to 1.03)	0.87 (0.77 to 0.98)‡	0.90 (0.74 to 1.09)
	Week 3	201	5.4	5.0	0.0	2.0	4.0	8.0	21.0	177	5.5	4.7	0.0	2.0	5.0	8.0	21.0	0.98 (0.82 to 1.17)	0.95 (0.83 to 1.08)	0.96 (0.77 to 1.20)
	Week 4	189	5.5	5.5	0.0	1.0	4.0	8.0	21.0	161	5.2	4.4	0.0	2.0	4.0	7.0	21.0	1.05 (0.86 to 1.27)	0.96 (0.84 to 1.11)	0.87 (0.68 to 1.11)
	Week 5	158	5.2	5.4	0.0	1.0	4.0	7.0	21.0	146	4.8	4.3	0.0	2.0	4.0	6.0	21.0	1.08 (0.86 to 1.34)	0.98 (0.84 to 1.15)	1.00 (0.75 to 1.32)
	Week 6	141	4.8	5.2	0.0	1.0	3.0	7.0	21.0	127	4.7	4.2	0.0	1.0	4.0	7.0	20.0	1.03 (0.81 to 1.30)	0.98 (0.82 to 1.16)	0.88 (0.64 to 1.22)
	Week 7	129	4.6	4.9	0.0	1.0	3.0	7.0	20.0	116	4.6	4.5	0.0	1.0	3.0	6.0	21.0	1.01 (0.78 to 1.31)	0.93 (0.77 to 1.13)	0.97 (0.68 to 1.38)
	Week 8	118	4.6	5.1	0.0	0.0	3.0	7.0	21.0	110	4.9	4.4	0.0	2.0	4.0	7.0	20.0	0.94 (0.72 to 1.22)	0.87 (0.71 to 1.07)	0.86 (0.58 to 1.28)
SKK*	Baseline	386	4.2	2.7	−8.3	2.3	4.3	6.0	10.0	377	4.5	2.7	−5.3	3.0	4.7	6.3	10.0	−0.27 (−0.65 to 0.12)	Reference	Reference
	Week 1	249	4.3	2.6	−3.7	2.7	4.7	6.0	10.0	229	4.5	2.6	−4.7	3.0	4.7	6.3	10.0	−0.17 (−0.64 to 0.30)	−0.06 (−0.51 to 0.39)	−0.33 (−0.98 to 0.33)
	Week 2	220	5.9	5.5	−4.3	3.0	5.0	7.0	30.0	208	5.5	4.9	−4.0	2.7	4.7	6.7	30.0	0.44 (−0.55 to 1.43)	0.50 (0.02 to 0.97)‡	0.80 (0.06 to 1.54)‡
	Week 3	200	4.4	3.1	−10.0	2.7	4.7	6.3	21.0	177	4.3	2.8	−4.0	2.3	4.3	6.0	10.0	0.09 (−0.51 to 0.70)	0.01 (−0.49 to 0.51)	0.29 (−0.54 to 1.12)
	Week 4	188	4.5	2.8	−3.3	2.7	4.7	6.3	10.0	160	4.4	2.9	−4.3	2.6	4.3	6.0	11.0	0.13 (−0.47 to 0.73)	0.02 (−0.50 to 0.55)	0.42 (−0.46 to 1.31)
	Week 5	158	4.6	2.8	−4.7	2.8	4.7	6.3	10.0	146	4.2	2.8	−4.7	2.4	4.0	6.0	10.0	0.39 (−0.24 to 1.02)	0.12 (−0.44 to 0.67)	0.21 (−0.78 to 1.20)
	Week 6	141	4.5	3.1	−10.0	2.3	4.7	6.3	10.0	127	4.1	2.9	−4.7	2.2	4.7	6.0	10.0	0.34 (−0.38 to 1.07)	0.06 (−0.53 to 0.64)	0.09 (−0.98 to 1.17)
	Week 7	129	4.5	2.8	−2.3	2.3	4.7	6.0	10.0	116	4.3	3.0	−4.7	2.3	4.5	6.1	10.0	0.23 (−0.49 to 0.95)	0.05 (−0.56 to 0.66)	0.12 (−1.02 to 1.25)
	Week 8	118	4.7	2.7	−3.7	3.0	5.0	6.3	10.0	110	4.1	3.3	−10.0	2.3	4.7	6.0	10.0	0.55 (−0.24 to 1.34)	0.30 (−0.34 to 0.93)	0.56 (−0.63 to 1.75)
NPAQ (moderate)†	Baseline	386	179.3	275.3	0.0	0.0	90.0	240.0	2880.0	377	171.7	229.8	0.0	0.0	90.0	230.0	1440.0	1.04 (0.85 to 1.28)	Reference	Reference
	Week 1	249	290.0	354.2	0.0	60.0	200.0	400.0	3325.0	228	170.7	235.5	0.0	0.0	75.0	242.5	1440.0	1.70 (1.34 to 2.15)‡	1.65 (1.40 to 1.94)‡	1.38 (1.08 to 1.76)‡
	Week 2	220	232.1	452.4	0.0	0.0	95.0	300.0	4550.0	206	127.5	315.0	0.0	0.0	0.0	163.8	3780.0	1.82 (1.19 to 2.79)‡	1.54 (1.26 to 1.87)‡	1.03 (0.72 to 1.46)
	Week 3	197	322.4	622.0	0.0	60.0	180.0	375.0	6450.0	177	187.1	453.1	0.0	0.0	110.0	240.0	5280.0	1.72 (1.10 to 2.70)‡	1.29 (1.08 to 1.54)‡	1.01 (0.74 to 1.37)
	Week 4	187	247.7	276.3	0.0	60.0	180.0	347.5	1680.0	156	193.7	277.2	0.0	0.0	120.0	242.5	2400.0	1.28 (0.97 to 1.69)	1.25 (1.04 to 1.51)‡	1.07 (0.77 to 1.48)
	Week 5	158	304.2	499.0	0.0	60.0	190.0	395.0	4530.0	146	192.1	308.1	0.0	22.5	120.0	240.0	3000.0	1.58 (1.10 to 2.28)‡	1.17 (0.96 to 1.42)	1.05 (0.73 to 1.50)
	Week 6	140	310.1	377.5	0.0	80.0	200.0	400.0	2520.0	126	205.9	313.0	0.0	30.0	120.0	270.0	2760.0	1.51 (1.08 to 2.11)‡	1.19 (0.96 to 1.47)	1.10 (0.73 to 1.66)
	Week 7	129	311.4	362.5	0.0	60.0	200.0	380.0	2140.0	114	210.9	379.5	0.0	40.0	125.0	240.0	3600.0	1.48 (1.00 to 2.18)‡	1.37 (1.09 to 1.72)‡	1.14 (0.73 to 1.76)
	Week 8	118	336.1	433.4	0.0	60.0	200.0	390.0	2790.0	109	234.2	383.1	0.0	30.0	120.0	250.0	3000.0	1.44 (0.97 to 2.12)	1.23 (0.96 to 1.57)	1.30 (0.81 to 2.08)
NPAQ (vigorous)†	Baseline	386	91.3	231.3	0.0	0.0	0.0	90.0	2880.0	377	71.1	133.6	0.0	0.0	0.0	80.0	960.0	1.28 (0.94 to 1.76)	Reference	Reference

Continued

Table 2 Continued

		DHE								CG								Crude	ITT	CACE
	Time	n	Mean	SD	Min	Q1	Median	Q3	Max	n	Mean	SD	Min	Q1	Median	Q3	Max	Unadjusted MD* or RoM† (95% CI)	Adjusted MD* or RoM† (95% CI)	Adjusted MD* or RoM† (95% CI)
	Week 1	249	131.1	245.2	0.0	0.0	50.0	165.0	2200.0	228	63.5	134.2	0.0	0.0	0.0	60.0	1200.0	2.06 (1.44 to 2.96)‡	1.31 (1.08 to 1.61)‡	1.09 (0.81 to 1.46)
	Week 2	220	91.7	202.7	0.0	0.0	0.0	120.0	1920.0	206	42.5	97.3	0.0	0.0	0.0	50.0	840.0	2.15 (1.40 to 3.31)‡	1.23 (0.97 to 1.54)	1.24 (0.82 to 1.88)
	Week 3	197	160.7	518.3	0.0	0.0	60.0	160.0	5000.0	177	51.9	90.5	0.0	0.0	10.0	60.0	600.0	3.09 (1.84 to 5.21)‡	1.30 (1.04 to 1.61)‡	1.18 (0.82 to 1.70)
	Week 4	187	127.2	216.2	0.0	0.0	60.0	160.0	1680.0	156	71.4	115.6	0.0	0.0	17.5	105.0	700.0	1.78 (1.25 to 2.54)‡	1.19 (0.95 to 1.50)	1.01 (0.68 to 1.49)
	Week 5	158	143.2	280.9	0.0	0.0	55.0	180.0	2670.0	146	66.3	107.6	0.0	0.0	20.0	97.5	750.0	2.16 (1.44 to 3.24)‡	1.17 (0.92 to 1.49)	1.23 (0.80 to 1.92)
	Week 6	140	162.8	299.4	0.0	7.5	60.0	200.0	2520.0	126	60.2	87.2	0.0	0.0	22.0	94.5	420.0	2.71 (1.82 to 4.03)‡	1.14 (0.87 to 1.48)	1.25 (0.77 to 2.04)
	Week 7	129	147.2	229.4	0.0	0.0	50.0	200.0	1320.0	114	81.2	130.4	0.0	0.0	30.0	120.0	800.0	1.81 (1.21 to 2.70)‡	1.11 (0.84 to 1.48)	1.33 (0.79 to 2.26)
	Week 8	118	167.0	283.1	0.0	0.0	60.0	200.0	1860.0	109	80.1	156.1	0.0	0.0	20.0	120.0	1300.0	2.09 (1.29 to 3.37)‡	1.11 (0.81 to 1.50)	1.42 (0.80 to 2.50)
MOS Sleep Scale*	Baseline	386	69.7	18.3	13.3	56.7	70.0	83.3	100.0	377	69.1	17.8	10.0	56.7	70.0	83.3	100.0	0.63 (−1.94 to 3.19)	Reference	Reference
	Week 1	248	66.8	12.0	16.7	60.0	66.7	73.3	96.7	230	68.5	12.2	6.7	60.8	70.0	76.7	100.0	−1.69 (−3.88 to 0.49)	−2.30 (−4.43 to −0.17)‡	−3.66 (−6.77 to −0.56)‡
	Week 2	221	69.3	10.5	36.7	63.3	70.0	76.7	100.0	208	68.3	11.0	23.3	60.0	70.0	73.3	100.0	0.97 (−1.06 to 3.01)	0.14 (−2.05 to 2.33)	0.23 (−3.18 to 3.63)
	Week 3	201	68.1	11.1	26.7	63.3	66.7	73.3	100.0	177	68.1	11.9	20.0	63.3	66.7	76.7	100.0	0.03 (−2.31 to 2.36)	−0.42 (−2.72 to 1.89)	−0.79 (−4.60 to 3.03)
	Week 4	189	68.7	10.1	33.3	63.3	70.0	73.3	100.0	161	68.8	10.2	20.0	63.3	66.7	73.3	93.3	−0.08 (−2.22 to 2.06)	−0.26 (−2.67 to 2.14)	−0.13 (−4.23 to 3.98)
	Week 5	158	67.4	12.6	0.0	63.3	66.7	73.3	100.0	146	68.5	9.9	30.0	63.3	70.0	73.3	90.0	−1.09 (−3.66 to 1.48)	−1.01 (−3.62 to 1.60)	−1.37 (−6.11 to 3.37)
	Week 6	141	66.1	13.1	20.0	63.3	66.7	73.3	96.7	127	67.3	11.9	13.3	61.7	66.7	73.3	100.0	−1.17 (−4.19 to 1.85)	−1.13 (−3.98 to 1.72)	−0.55 (−5.89 to 4.80)
	Week 7	129	68.9	11.4	20.0	63.3	70.0	73.3	100.0	116	69.1	9.7	50.0	63.3	66.7	76.7	93.3	−0.19 (−2.87 to 2.49)	−0.04 (−3.13 to 3.05)	−1.11 (−6.97 to 4.75)
	Week 8	118	70.0	11.2	30.0	63.3	70.0	73.3	100.0	110	68.0	11.1	26.7	63.3	66.7	73.3	93.3	2.06 (−0.86 to 4.97)	2.26 (−1.07 to 5.60)	7.69 (1.30 to 14.08)‡
CPGS (pain)†	Baseline	386	18.9	18.5	0.0	3.3	13.3	30.0	93.3	377	16.2	18.0	0.0	0.0	10.0	26.7	80.0	1.17 (1.01 to 1.36)‡	Reference	Reference
	Week 1	249	22.6	20.4	0.0	6.7	20.0	36.7	93.3	230	18.4	20.8	0.0	0.0	10.0	30.0	90.0	1.23 (1.02 to 1.48)‡	1.02 (0.89 to 1.17)	1.03 (0.85 to 1.26)
	Week 2	221	19.5	20.4	0.0	0.0	13.3	30.0	93.3	208	15.7	19.0	0.0	0.0	10.0	26.7	80.0	1.24 (1.00 to 1.54)‡	1.06 (0.91 to 1.23)	1.27 (1.01 to 1.60)‡
	Week 3	201	17.5	20.4	0.0	0.0	10.0	26.7	93.3	177	15.2	18.4	0.0	0.0	10.0	26.7	76.7	1.15 (0.90 to 1.46)	1.05 (0.89 to 1.23)	1.31 (1.00 to 1.71)‡
	Week 4	189	15.0	18.9	0.0	0.0	6.7	23.3	86.7	161	14.2	18.4	0.0	0.0	6.7	23.3	80.0	1.06 (0.81 to 1.39)	1.18 (0.98 to 1.41)	1.48 (1.10 to 2.01)‡
	Week 5	158	15.8	19.8	0.0	0.0	6.7	30.0	90.0	146	12.8	17.3	0.0	0.0	6.7	20.0	80.0	1.24 (0.92 to 1.66)	1.18 (0.97 to 1.44)	1.32 (0.92 to 1.88)
	Week 6	141	13.9	18.2	0.0	0.0	6.7	23.3	86.7	127	13.5	17.3	0.0	0.0	10.0	23.3	93.3	1.03 (0.75 to 1.40)	1.04 (0.83 to 1.30)	1.03 (0.68 to 1.54)
	Week 7	129	12.8	17.1	0.0	0.0	6.7	20.0	90.0	116	13.2	17.4	0.0	0.0	6.7	20.0	80.0	0.97 (0.69 to 1.36)	1.05 (0.82 to 1.34)	1.23 (0.78 to 1.95)
	Week 8	118	12.6	16.3	0.0	0.0	8.3	20.0	93.3	110	10.4	14.2	0.0	0.0	3.3	16.7	70.0	1.21 (0.85 to 1.71)	1.18 (0.90 to 1.54)	1.39 (0.83 to 2.31)
CPGS (disability)†	Baseline	386	9.0	16.1	0.0	0.0	0.0	10.0	90.0	377	7.3	13.7	0.0	0.0	0.0	10.0	83.3	1.23 (0.95 to 1.59)	Reference	Reference
	Week 1	249	8.9	15.0	0.0	0.0	0.0	10.0	80.0	230	8.7	15.7	0.0	0.0	0.0	10.0	86.7	1.03 (0.75 to 1.41)	1.00 (0.81 to 1.24)	1.11 (0.82 to 1.50)
	Week 2	221	8.1	15.6	0.0	0.0	0.0	10.0	83.3	208	6.5	14.3	0.0	0.0	0.0	6.7	80.0	1.24 (0.84 to 1.83)	1.00 (0.78 to 1.28)	0.97 (0.66 to 1.43)
	Week 3	201	8.0	15.6	0.0	0.0	0.0	10.0	83.3	177	5.0	11.3	0.0	0.0	0.0	3.3	56.7	1.58 (1.03 to 2.43)‡	1.15 (0.87 to 1.53)	1.24 (0.80 to 1.95)
	Week 4	189	5.8	14.1	0.0	0.0	0.0	6.7	76.7	161	5.0	11.0	0.0	0.0	0.0	3.3	63.3	1.17 (0.72 to 1.89)	0.96 (0.70 to 1.30)	0.78 (0.46 to 1.32)
	Week 5	158	7.3	16.5	0.0	0.0	0.0	6.7	100.0	146	5.6	12.8	0.0	0.0	0.0	3.3	60.0	1.29 (0.77 to 2.16)	1.12 (0.81 to 1.56)	1.51 (0.79 to 2.86)
	Week 6	141	5.2	13.6	0.0	0.0	0.0	0.0	80.0	127	5.9	13.3	0.0	0.0	0.0	3.3	66.7	0.88 (0.49 to 1.58)	0.98 (0.67 to 1.43)	0.99 (0.46 to 2.11)
	Week 7	129	6.7	17.4	0.0	0.0	0.0	3.3	100.0	116	5.6	13.2	0.0	0.0	0.0	3.3	70.0	1.20 (0.65 to 2.24)	1.30 (0.87 to 1.95)	1.31 (0.60 to 2.88)
	Week 8	118	4.0	9.6	0.0	0.0	0.0	3.3	73.3	110	3.6	8.9	0.0	0.0	0.0	0.0	56.7	1.11 (0.59 to 2.09)	0.88 (0.57 to 1.37)	0.76 (0.33 to 1.76)

Adjusted values were estimated with mixed models corrected for differences between groups at baseline, repeated measurements, centres (ie, countries), and the following prognostic variables at baseline that could possibly affect missing outcome data in our data set: age, sex, living environment, employment and university degree. Estimates for each time point were obtained from mixed models by including dummy variables indicating the follow-up time points 1–8 and the interaction terms composed of group and time (ie, 'group × time', where 0 is for CG and 1 is for DHE, and weeks 1–8) as fixed effects.

*Estimates reported as MD from the results of the linear models.

†Estimates reported as RoM from exponentiating the results of the exponential (log-linear) models.

‡CI not containing the null value.

CACE, complier average causal effect; CG, control group; CPGS, Chronic Pain Grade Scale; DHE, digital home exercise; GAD-7, Generalized Anxiety Disorder Scale-7; ITT, intention-to-treat effect; MD, mean difference; MOS, Medical Outcome Study; NPAQ, Nordic Physical Activity Questionnaire; RoM, ratio of means; SKK, Self-Concordance Scale.

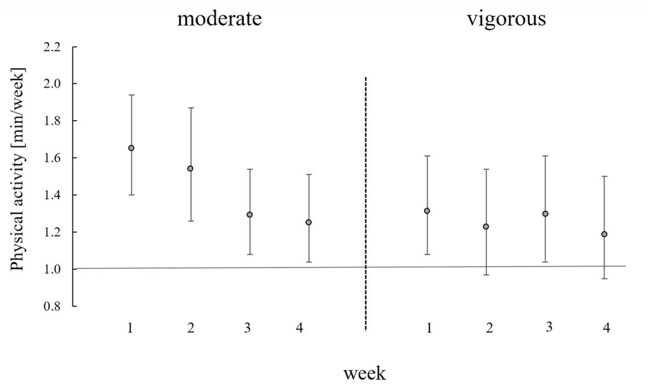

Figure 1 Differences between the control and digital home exercise group in moderate (left) and vigorous (right) physical activity. The figure shows the ratios of means and 95% CI.

effects (ie, on mental well-being) ceased with the switch from live-streamed to prerecorded exercise.

Our CACE (ie, local average causal effect) analysis of the DHE programme was consistent with the ITT results, although the uncertainty around the estimates was higher. Of note, the DHE participants reported higher pain (CPGS) levels especially during the first 4-week period of live-streamed exercise intervention, although they did not report adverse events. Two non-mutually exclusive explanations are plausible. First, CPGS pain was higher in DHE than in CON at baseline. Although group allocation was randomised preventing selection bias, randomisation does not guarantee that groups are equivalent at baseline.[33] This is why we adjusted the analyses for possible between-group differences at baseline. Second, there is an increased probability of delayed onset muscle soreness (DOMS) in individuals who increase exercise levels or those who initiate the practice of a new exercise type or regimen, and pain is one of the most common symptoms of DOMS.[45 46]

Prior to study initiation, in a very similar sample, we found that more than two-thirds of the respondents were ready to engage in DHE.[16] This and the fact that individuals complying with the live-streamed exercise programme achieved potentially relevant improvements in PA levels and mental well-being are promising. However, despite meeting our predetermined sample size at baseline, only 46% (main study, part 1) or 30% respectively (unlimited database access, part 2) of the participants completed the study and a considerable share completed the questionnaires without attending workouts. Due to the substantial missing outcome data and possible violations of the 'missing at random' assumption of mixed models, the main ITT analyses in this study may be considered pseudo-ITT restricted to participants with complete data, although we adjusted the analyses for possible prognostic factors at baseline that could possibly affect missing data in our study.[38]

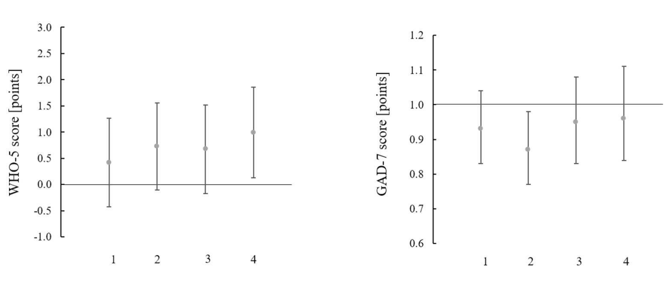

Figure 2 Differences between the control and digital home exercise group in well-being (left) and anxiety (right). The figure shows adjusted means (WHO-5) or ratios of means (GAD-7) and 95% CI. GAD-7, Generalized Anxiety Disorder Scale-7; WHO-5, WHO-5 Questionnaire.

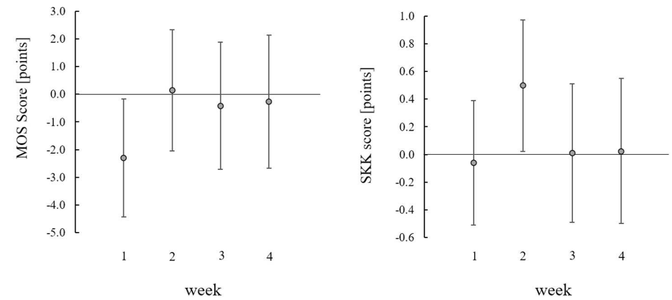

Figure 3 Differences between the control and digital home exercise group in sleep quality (left) and exercise motivation (right). The figure shows adjusted means and 95% CI. MOS, Medical Outcome Study; SKK, Self-Concordance Scale.

Dropout is a general problem in many longitudinal trials involving exercise interventions. Pooling data from 37 studies in patients with cancer, Czosnek *et al*[47] reported a mean attrition rate of 38% with a range of 22%–56%. Joseph *et al*[48] systematically reviewed internet-based PA interventions, reporting a mean attrition rate of 22.3% with a range between 0% and 69%. Comparing these data with our trial, it needs to be acknowledged that our dropout rate is rather at the upper margin. Three issues may particularly explain this finding. First, to obtain as much data as possible despite the rapidly changing situation related to the pandemic (eg, end of local restrictions and subsequent dropouts before terminal outcome measurements), we used weekly questionnaires. Possibly, this rather high frequency represented an obstacle for a share of the sample. Second, we removed participants from the study as soon as they did not complete the weekly assessments. However, some individuals who failed to answer the questionnaires initially may have continued to participate in the study later, if they would have been allowed to. Third, the duration and severity of public life restrictions varied, depending on many factors, inter alia local incidence, mortality and intensive care availability. While restrictions were still in place in all countries during the study, local relaxing of some measures (eg, partial opening of gyms) could have prompted participants to drop out. Irrespective, our study reinforces the

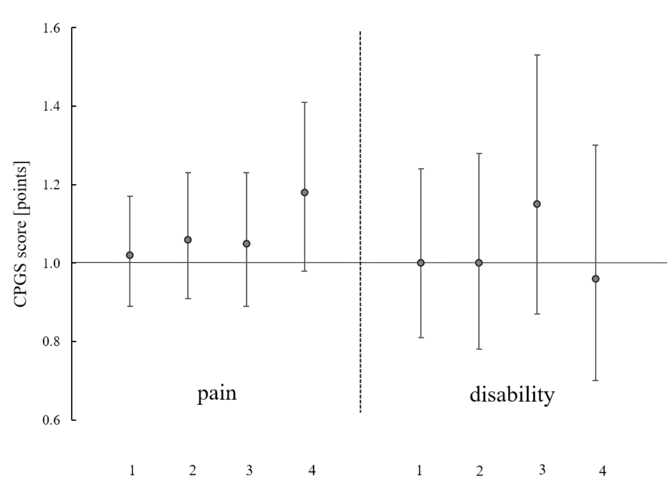

Figure 4 Differences between the control and digital home exercise group in pain (left) and disability (right). The figure shows ratios of means and 95% CI. CPGS, Chronic Pain Grade Scale.

importance of successful implementation. It is known that exercising in a group,[49] being supervised by a healthcare professional[50] and having a choice of contents[51] represent important features ensuring adherence to exercise interventions. Using a virtual gym schedule and the live streaming format helped to satisfy these needs. Future studies, however, should aim to identify other decisive barriers and facilitators for participation.

As mentioned, the participants of our study were classified as healthy. Compelling evidence shows that, even in this group, mental and physical well-being were substantially decreased during social restrictions.[10] The development of newly tailored interventions is hence paramount to prevent long-term increases of disease prevalence in most of the population. Notwithstanding, no assumptions can be made as to how the investigated exercise programme can be of help to individuals with chronic diseases. As PA and sports may improve not only general health parameters such as well-being, but also disease-specific outcomes (eg, insulin sensitivity in persons with diabetes), patients may be substantially more affected by the pandemic. It would therefore be intriguing to elucidate the potential as well as the risks of live-streamed exercise in related populations.

CONCLUSIONS

Live-streamed DHE is efficacious in consistently enhancing PA and, to a smaller degree, in improving mental well-being, anxiety, sleep quality and exercise motivation during pandemic-related public life restrictions. A dose–response relationship seems to exist, with a higher number of workouts per week being predictive of increases in mental well-being and PA levels. However, observed dropout rates, reaching about 50% after the 4-week main intervention, are worrisome. Future research should hence be geared towards refining and enhancing implementation.

What is already known on this topic?

⇒ Public life restrictions issued to contain the COVID-19 pandemic have caused significant reductions in physical activity levels and mental well-being.

What are the findings?

⇒ Live-streamed digital home exercise (DHE) increases physical activity and, to a minor degree, improves mental well-being, anxiety, sleep quality and exercise motivation.

⇒ The use of prerecorded workouts may not be associated with such health benefits.

⇒ Dropout proportion in DHE is high, making it a challenge for implementation.

How might it impact on clinical practice in the future?

⇒ If barriers to participation are reduced, live-streamed DHE can help counteract the mental and somatic adverse effects of social distancing and stay-at-home regulations during a pandemic.

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Ethics approval This study involves human participants and was approved by the Ethics Committee of the Faculty of Psychology and Sports Sciences of Goethe University Frankfurt (protocol no 2020-25); Ethics Committee of Karl Franzens University Graz (no 39/66/63 ex 2019/20); Comitato di Ateneo per la Ricerca, Università degli Studi di Roma "Foro Italico" (no CAR 45/2020); Research Ethics Committee of the Universidade Cidade de São Paulo (no 31216720.2.000.0064); Institutional Research Ethics Committee of Durban University of Technology (no IREC 090/20); Institutional Ethics Committee of the University of Santiago of Chile (no 207/2020); Research Ethics Committee of Fundación Instituto Superior de Ciencias de la Salud (no DEPINV12/20); Research Ethics Committee of Waterford Institute of Technology (no WIT2020REC100); and Ethics Committee of Universidad Politécnica de Madrid. Participants gave informed consent to participate in the study before taking part.

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Own contribution to publications

The following table lists the authors' contribution to the papers included into the dissertation as defined by the International Committee of Medical Journal Editors (ICMJE).

	Publication				
Criterion	**A**	**B**	**C**	**D**	**E**
Conception/Design	✓	✓	✓	✓	✓
Data acquisition	✓	✓	✓	✓	✓
Data analysis	✓	✓	✓	✓	✓
Data interpretation	✓	✓	✓	✓	✓
Drafting of the article	✓	✓	✓	✓	✓
Critical revision of the article	✓	✓	✓	✓	✓
Final approval of the article	✓	✓	✓	✓	✓
Author's responsibility	✓	✓	✓	✓	✓

Tab.1. Author contributions to the included papers (A-E) according to the ICMJE criteria (shown in first column).

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