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Highlights in physical activity in the prevention and management of disease 2021/22

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Highlights in physical activity in the prevention and management of disease: 2021/22

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Editorial: highlights in physical activity in the prevention and management of disease 2021/22

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COVID-19, health, performance, exercise, workers, lower back pain

Editorial on the Research Topic
Highlights in physical activity in the prevention and management of disease 2021/22

Humans are meant to be active. Or, at the very least, during their evolution they were not able to be inactive and hence many of our underlying adaptations to inactivity can result in metabolic and mental dysfunction. The selection of papers in this special issue (described in brief below) are drawn from a wide variety of sources and seek to understand how physical activity can be used to prevent and manage disease across the lifespan.

A number of the papers in this special issue examined the impact of the COVID-19 pandemic on physical activity and sedentary behaviour. Schmidt and Pawlowski examined the effect of the COVID-19 shutdown on the amount of leisure-time physical activity undertaken by 1,800 Danish citizens aged 15–18, 19–29, 30–59 and 60+ years old, using a cross-sectional survey methodology. They found that, compared to before the shutdown, the proportionate decrease in mean minutes of leisure-time physical activity per week was greatest in the teenage group (−36.6%), followed by the oldest and young adult groups (by −24.9% and −21.3% respectively). The authors noted that although undertaken to prevent disease spread, the shutdown reduced leisure-time physical activity substantially, and ultimately this could have serious public health consequences. In their study, Sugano et al. conducted an internet-based survey of 27,000 Japanese workers during the COVID-19 pandemic, which examined the relationship between their exercise and physical activity habits and their self-assessed, health-related quality of life. Compared to workers who "almost never" undertook any exercise or physical activity, those who took at least some had better self-assessed health. Interestingly, the beneficial effects of exercise were still evident when the outcome was the number of "physically or mentally unhealthy days" in the last 30, but no beneficial effect was evident for physical activity. The authors concluded that even short bouts of daily exercise could have beneficial effects on workers health and work performance, particularly in workers who almost never undertook exercise. Morton et al., using a review of 22 studies based on a systematic search, sought to identify ways in which sedentary behaviour could be reduced in an office environment. Also, given the post COVID-19 culture of increased home working, they sought to examine which of the identified approaches might have utility in the home working environment. In the office, interventions based on environmental restructuring, training, enablement and education, often used in combination, were the most common approaches taken to reduce sedentary behaviours, but not all would be easily transferable to home working situations.

Being sedentary often involves long periods of sitting. The study by Kett et al. showed that neuromuscular stimulation of the lumbar spine during 4.5 h of sitting significantly reduced back muscle stiffness. The authors noted that their research helps explains why long periods of chair sitting without muscular activity may increase the likelihood of lower back pain. Their study also emphasises why consistent muscle activity throughout the day is really important if common but debilitating conditions such as lower back pain are to be attenuated, and perhaps prevented.

The ability to measure and monitor characteristics such as maximal oxygen uptake (cardiorespiratory fitness) and motor competence are really important. "Cardiorespiratory fitness" is associated with life expectancy, mortality and performance, and so it is an important metric in a wide variety of situations and groups. Typically, it is determined using directly measured oxygen uptake during a maximal test. However, in those with clinical dysfunction maximal efforts may not be possible and, even if they are, may be associated with unacceptable risks. Eike et al. evaluated a modified Blake protocol for assessing maximal oxygen consumption and found that the modified protocol was valid compared to directly determined values ($R^2 = 0.78$; SEE = 3.1 ml·kg^{-1}·min^{-1}; $p < 0.001$), and that the modified protocol was feasible for use in individuals at high risk or with chronic health conditions. Drenowatz et al. argue there is linkage between motor competence and physical fitness, a physically active lifestyle and ultimately future public health. In their study they report the preliminary findings from a state wide fitness testing program that examined cardiorespiratory fitness, muscular power, speed, agility, flexibility, object control skills, stature and body mass, and involved 18,000 six- to eleven-year-old Austrian school children. They noted that, while there were expected improvements in fitness and motor competencies as age increased, in those participants designated overweight or obese, physical fitness (except for upper body strength) and motor competence were lower than in normal weight groups. A key issue seemed to be the ability of individuals who were not normal weight to move their own body mass, and while the normal weight group showed improvement in their 6 min run time as they aged, there was no evidence of such improvement in the overweight/obese group.

The importance of involvement in organised sports in childhood and adolescence on future quality of life is also an interesting question. Appelqvist-Schmidlechner et al. examined the association between sports participation and mental and physical components of health-related quality of life using a cross-sectional design, a survey methodology and 777 young adult Finnish males. The study noted that participation in organised sports at age 12 was mainly positively associated with the mental component of their health-related quality of life outcome, rather than the physical component. They also found that a greater involvement in organized sports in childhood increased the likelihood of a higher health related quality of life in young adulthood. The authors noted that their study emphasised the importance of encouraging and facilitating opportunities for organised sports participation in all children and young people.

Other studies in this special issue performed interventions to examine how exercise alone or exercise in combination with nutritional and psychological guidance in middle-aged or adolescent populations influenced markers of cardio-respiratory fitness and health. De Borba Schneiders et al. performed a quasi-experimental study in which seventeen participants (aged 10–17 years-old) were allocated to an intervention group who undertook a 6-month multi-component program comprised of a variety of types of exercise, and nutritional and psychological guidance. Twenty individuals with similar characteristics were allocated to a control group. The study aimed to verify that such a program could positively impact physical fitness, body composition and markers of insulin secretion and resistance in overweight and obese adolescents. While the program improved some body composition outcomes (e.g., body fat percentage) and cardiorespiratory fitness (6 min walking/run test), it had no measurable effect on insulin or HOMA-IR. Collins et al. examined how three different 8-month exercise interventions (aerobic training, resistance training, or aerobic and resistance combined) influenced health-related quality of life (determined by survey responses) in 137 middle-aged women and men (49.0 ± 10.6 years). They found that all of the exercise programmes had some impacts on self-reported health-related quality of life components, but all groups showed significant improvements in peak oxygen uptake, and satisfaction with physical function and appearance scores.

All the studies in this special issue demonstrate the wide variety of important research that is being conducted to understand how physical activity can be used to prevent and manage disease across the lifespan.

Author contributions

All authors contributed to the writing and review of the Editorial. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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BRIEF RESEARCH REPORT
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Physical Activity in Crisis: The Impact of COVID-19 on Danes' Physical Activity Behavior

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Objectives: Because of the COVID-19 pandemic, societies have been shut down, changing the lives of citizens worldwide, including their physical activity (PA) behavior. This cross-sectional study aimed to investigate the impact of the shutdown on Danish citizens' leisure PA throughout different stages of life: 15–18, 19–29, 30–59, and 60+ years.

Methods: Between April 3 and 15, 2020, while Denmark was shut down, a survey was distributed through online platforms. Danish citizens (>15 years) could participate in the study, answering questions about their PA behavior before, and during the shutdown.

Results: The number of total participants was 1,802; 7.9% teens, 21.5% younger adults, 58.7% adults, and 11.9% older adults. Mean minutes of PA decreased 16.1% from before to during the shutdown. Teens had the largest decrease in PA (36.6%) followed by older (24.9%) and younger adults (21.3%). Low educated (31.5%) and those living in rural areas (30.9%) experienced the largest decrease in PA. Main factors for not doing PA during the shutdown were that they missed what they used to do, lacked social support, and did not have access to the right facilities.

Conclusions: During the shutdown, the Danish population struggled even more to comply with national PA guidelines compared with before the shutdown. Although social distancing and shutting down sports facilities are important for preventing the spread of the virus, it can have negative consequences for teens' and younger and older adults' opportunities and motivation for PA, leading to an alarming decrease in PA, and, consequently, will have major public health consequences.

Keywords: coronavirus, leisure physical activity, teens, younger adults, adults, older adults

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INTRODUCTION

On March 11, 2020, the World Health Organization declared the coronavirus disease 2019 (COVID-19) to be a pandemic (World Health Organization, 2020). As of December 11, 2020, Johns Hopkins University reported 101,027 confirmed cases of COVID-19 and 918 deaths in Denmark (University, 2020). Since March 11, 2020, Denmark was shut down as a basic means of limiting people's exposure to the virus, including closures of schools, workplaces, fitness centers, and sport associations, and social gatherings of more than 10 people (Ministry, 2020). These decisions will inevitably affect people's regular leisure physical activity (PA) (Hall et al., 2020). In Denmark, PA plays an important role in many people's everyday life and is often carried out as organized sport in sports associations or fitness centers (Pilgaard and Rask, 2016). The beneficial effects of regular PA on many health outcomes are well-established (Powell et al., 2019). PA has an important role in reducing impact of the COVID-19 pandemic by having a positive effect on immunity (Jones and Davison, 2019), inflammation (Miles et al., 2019), and viral respiratory infections (Nieman and Wentz, 2019). PA can also reduce stress and depression (Powell et al., 2019), which may increase during the pandemic due to health threats, job loss, reduced income, and isolation from social contacts (Douglas et al., 2020). Due to the multiple benefits of PA, it is important to sustain an active lifestyle during the COVID-19 shutdown. Nevertheless, the world has struggled with a physical inactivity pandemic for several years (Kohl et al., 2012), affecting especially those from lower socioeconomic groups (Pilgaard and Rask, 2016) and younger (Rasmussen et al., 2019) and older adults (Bauman et al., 2016). It is argued that the COVID-19 pandemic will increase those struggles and persist long after the world has recovered from the pandemic (Hall et al., 2020).

Several studies from different European, Asian, and American countries have—to some degree—investigated the impact of the COVID-19 shutdown on PA behavior (Cheval et al., 2020; López-Bueno et al., 2020; Maugeri et al., 2020; Ong et al., 2020; Rhodes et al., 2020; Rogers et al., 2020; Smith et al., 2020; Yamada et al., 2020). All reported some form of decrease in PA from before to during the shutdown, whereas three of the studies also reported no change (Rogers et al., 2020; Smith et al., 2020) or an increase in PA (Cheval et al., 2020) for some specific groups. This may be due to poor measures of PA and small sample sizes as two of the studies did not report a specific PA measurement tool used (Rogers et al., 2020; Smith et al., 2020), and one of the studies only included 267 participants (Cheval et al., 2020). Seven of the studies were cross-sectional, using retrospective and self-reported online surveys to measure PA, whereas one was a longitudinal study that used device-based PA monitoring (Ong et al., 2020). Some studies assessed the impact of the shutdown on PA for different age groups (Maugeri et al., 2020; Rogers et al., 2020), whereas one study only focused on older adults (Yamada et al., 2020). None of the studies seem to have included people younger than 18 years old. None of the studies were conducted in Denmark or any other Scandinavian country.

The lack of Scandinavian studies and studies on specific age groups suggest a gap in the literature. This gap is important to fill to understand the worldwide consequences of the pandemic on PA behavior as well as the specific consequences for the Danish population. This supports political leaders in their decision making on COVID-19–related restrictions and helps public health officials to make recommendations for PA during a shutdown. The aim of this study was to investigate the impact of the shutdown on Danish citizens' leisure PA throughout different stages of life. This is done by analyzing retrospective and self-reported data on PA behavior before and during the COVID-19 shutdown among teens, younger adults, adults, and older adults.

METHODS

Study Design and Recruitment

The present paper is a cross-sectional study conducted in Denmark between April 3 and 15, 2020, during the COVID-19 shutdown. April 15 was chosen as the end date for the study because several restrictions from the Danish government were eased from that day.

On April 3, 2020, the study announced a press release, including a link to an online survey to recruit participants. The survey was also distributed through Facebook by posting a link to the survey on the university department's Facebook site and afterward sharing that link in different Facebook groups, on LinkedIn, and through the university's work mail. The Facebook post was boosted 1 time after 1 week to gain further reach. The study was advertised as a survey on people's movement behavior during the COVID-19 shutdown. It was explicitly mentioned that everyone, no matter how much or how little previous or current PA experience they had, could participate in the study. Inclusion criteria were people over the age of 15 years.

Data Collection

The online survey was created in SurveyXact based on a standardized Danish national PA survey repeated every fourth year (Pilgaard and Rask, 2016), which asks citizens about their PA behavior at work/school, during leisure time, and about active transportation. For this study, only questions about leisure PA were assessed. The survey started and ended with a range of background information on age, gender, education, ethnicity, job situation, and living situation (living in a small or large city, alone or with family). This was followed by a range of questions on the participants' general leisure PA behavior before and during the COVID-19 shutdown: "How much time did you usually spend on PA per week before the shutdown?" "How much time per week do you spend during the shutdown on PA (please write the number of minutes in total for 1 week)?" "How often were you physically active before the shutdown?" "How often are you physically active during the shutdown (5 or more times per week, 2–4 times per week, once a week, 2–3 times a month, rarely/never)?" It was clearly stated not to include active transportation, housework, or strenuous work. The participants were also asked, "What types of PA have you done on a regular basis during the last 12 months before the shutdown/during the shutdown?" The survey included examples of leisure PA (e.g., team ball games, outdoor activities, and gymnastics). Other questions were "Where have you primarily been physically active during the last 12 months before the shutdown/during the shutdown (e.g., sport associations, fitness/private center, at home, in public)?" "Who where you the most physically active with before and during the shutdown (alone, with friends, with colleagues, with family, with people I don't know)?" "Have you gained new PA habits during the shutdown?" Last, the participants were asked to identify perceived factors important for whether they are physically active during the shutdown to assess contextual factors that may explain a possible change in PA behavior. All questions came from the original national PA survey and were adapted to the specific COVID-19 shutdown.

The survey took, on average, 10 min to complete. The survey was tested on different age groups prior to its release, to ensure that the adaptions were understandable. The survey was found understandable by all age groups, but feedback from the test respondents resulted in the inclusion of additional response categories to the question on important factors for PA. The survey was only available in Danish.

Ethical Approval

Participants were given information about the study in the introduction to the survey. At the end of the survey, participants were able to read additional information on (1) how data were used and stored, (2) that they accepted that their data would be used for research purposes upon completion of the survey, and (3) that they were able to withdraw from the study at any time. The study and its data-management procedures were ethically approved by the Research & Innovation Organization of the University of Southern Denmark (10.975).

Analysis

Data were downloaded from SurveyXact and uploaded in IBM SPSS Statistics version 25. Paired *t*-tests were performed to test for significant overall changes in weekly minutes of PA between, before, and during the shutdown as well as PA changes for several demographic groups (e.g., gender differences or differences in PA by education) between, before, and during the shutdown (**Table 2**). Pearson Chi-squared tests were performed for specific subgroup analyses on the four age groups: teens (15–18 years), young adults (19–29 years), adults (30–59 years), and older adults (60+ years) to test for independence at a 0.05 significance level between the four age groups before and during the shutdown (**Table 3**).

RESULTS

Overview

A total of 1,347 participants answered the full survey, and an additional 455 partly answered the survey. All 1,802 participants were included in the analysis. Participants' demographics are presented in **Table 1**. The oldest participant was 85 years old, and the youngest was 15 years old. Mainly females (75.8%) and Danish-speaking citizens (98.3%) participated in the survey. Two thirds of all participants (74.5%) lived in large towns and mainly worked at home during the shutdown (43.4%).

Table 2 displays demographic differences in mean minutes of PA per week before and during the shutdown. Overall mean minutes of PA dropped 16.1% ($p < 0.001$) from before to during the shutdown. Of the 215 participants who did not do PA before the shutdown, 51.2% started doing PA during the shutdown, and 7.1% of those doing PA before the shutdown stopped doing PA during the shutdown. Comparing participants' educational level, the highest drop in PA was found among those with the lowest education (−31.5%, $p < 0.001$), whereas the smallest drop was registered among those with the highest education (−1.5%) although it was not significant. Those living in a large city had the smallest decrease in PA (−13.5%, $p < 0.001$) compared with those living in a village or countryside (−30.9%).

Age Specific Differences

Table 3 presents additional analyses made for the four specific age groups.

Teens

Teens experienced the largest decrease in mean minutes of PA per week (36.6%) (**Table 2**). Those who did PA 5 times per week or more increased by 19.1% during the shutdown, whereas those who rarely or never did PA increased by 71.8%. Before the shutdown, more than half of the teens did outdoor activities, and almost a third did street activities and team ball games, primarily in sports associations (53.0%). During the shutdown, more than half still did outdoor activities, but only a fourth did street activities, and only 7.0% did team ball games. Activities during the shutdown were primarily done at home (57.1%) or in public (33.3%). Before the shutdown, PA was mostly done with friends but was during the shutdown mostly done alone or with family. Teens perceived most factors important for whether they are physically active during the shutdown. Only 8.5% identified no factors.

Younger Adults

Younger adults experienced a decrease of 21.3% in mean minutes of PA per week (**Table 2**). Younger adults who did PA 5 times per week or more increased 9.1% during the shutdown, and those who rarely or never did PA increased 22.6% during the shutdown. Primary activities before the shutdown were outdoor activities, street activities, and team ball games. During the shutdown, team ball games dropped to 1.3%, whereas 63.4% did outdoor activities. Before the shutdown, PA was mostly done with friends or alone, in sport associations or fitness centers, whereas, during the shutdown, it was mostly done alone in public and at home. The greatest factors important for whether they were physically active during the shutdown were that they missed what they used to do (42.5%) and felt that they did not have access to the right facilities (41.0%).

Adults

Adults experienced the smallest decrease in mean minutes of PA per week (6.3%) (**Table 2**). Those doing PA 5 times or more per week increased by 44.3%, and those who rarely or never did PA increased by 38.2%. Adults mostly did outdoor PA before and during the shutdown. PA was done in public (34.2%) or fitness centers (31.0%) before the shutdown and was done in public (66.7%) and at home (28.0%) during the shutdown. Most adults did PA alone or with friends before the shutdown. During the shutdown, most adults were still doing PA alone, whereas almost half did PA with their family. Those who lived with their partner and children experienced the smallest decrease in minutes of PA per week (4.8%), whereas those living with their partner (without children) experienced the largest decrease (40.4%) (**Table 2**). Finally, 26.4% of the adults did not identify any factors important for PA, but almost every third respondent missed what they used to do or felt that they did not have access to the right facilities.

Older Adults

Older adults experienced a significant decrease in mean minutes of PA per week (24.9%) (**Table 2**), and over a third were rarely or never physically active during the shutdown. Before the shutdown, older adults primarily did outdoor activities and a third did gymnastics in sports associations (30.5%) and fitness or

TABLE 1 | Descriptive overview of participants' demographics in total and for the four age groups.

		15–18 years old	19–29 years old	30–59 years old	60+ years old	TOTAL
Age total		142 (7.9%)	388 (21.5%)	1,057 (58.7%)	215 (11.9%)	1,802 (100%)
Gender	Male	28 (19.7%)	115 (29.6%)	244 (23.1%)	46 (21.6%)	433 (24.1%)
	Female	113 (79.6%)	273 (70.4%)	810 (76.8%)	167 (78.4%)	1,363 (75.8%)
	Other	1 (0.7%)	0 (0.0%)	1 (0.1%)	0 (0.0%)	2 (0.1%)
Primary language at home	Danish	136 (96.5%)	385 (99.2%)	1,036 (98.2%)	209 (98.1%)	1,766 (98.3%)
	Other languages	5 (3.5%)	3 (0.8%)	19 (1.8%)	4 (1.9%)	31 (1.7%)
Education	Higher education under 3 years (e.g., pharmacist, craftsman)	80 (96.4%)	125 (44.2%)	149 (17.6%)	65 (40.1%)	419 (30.4%)
	Middle higher education 3–4 years (e.g., nurse, schoolteacher)	0 (0.0%)	54 (19.1%)	282 (33.2%)	59 (36.4%)	395 (28.7%)
	Higher education (including any bachelor's degree) over 4 years (e.g., doctor, MSc)	0 (0.0%)	99 (35.0%)	409 (48.2%)	34 (21.0%)	542 (39.4%)
	Other	3 (3.6%)	5 (1.8%)	9 (1.1%)	4 (2.5%)	21 (1.5%)
Region	Large city (>15,000 citizens)	42 (50.6%)	249 (88.0%)	611 (72.1%)	122 (75.3%)	1,024 (74.5%)
	Town (2,000–15,000 citizens)	25 (30.1%)	23 (8.1%)	158 (18.7%)	20 (12.3%)	226 (16.4%)
	Village or countryside (<2,000 citizens)	16 (19.3%)	11 (3.9%)	78 (9.2%)	20 (12.3%)	125 (9.1%)
Living situation	Live alone	0 (0.0%)	62 (22.0%)	95 (11.2%)	46 (28.4%)	203 (14.8%)
	Live with one or more children	0 (0.0%)	4 (1.4%)	85 (10.0%)	3 (1.9%)	92 (6.7%)
	Live with my partner	1 (1.2%)	118 (41.8%)	134 (15.8%)	101 (62.3%)	354 (25.8%)
	Live with my partner and children	0 (0.0%)	16 (5.7%)	513 (60.6%)	8 (4.9%)	537 (39.1%)
	Live with my parents	78 (94.0%)	29 (10.3%)	5 (0.6%)	0 (0.0%)	112 (8.2%)
	Other	4 (4.8%)	53 (18.8%)	14 (1.7%)	4 (2.5%)	75 (5.5%)
Job situation during the COVID-19 shutdown	Work outside of home	5 (3.7%)	24 (6.3%)	161 (15.3%)	20 (9.6%)	210 (11.7%)
	Work at home	5 (3.7%)	77 (20.4%)	657 (62.6%)	43 (20.6%)	782 (43.4%)
	Work partly outside partly at home	4 (3.0%)	4 (1.1%)	20 (1.9%)	2 (1.0%)	30 (1.7%)
	Do not work	6 (4.4%)	55 (14.6%)	135 (12.9%)	134 (64.1%)	330 (18.3%)
	Sent home student	115 (85.2%)	213 (56.3%)	28 (2.7%)	1 (0.5%)	357 (19.8%)
	Other	0 (0.0%)	5 (1.3%)	48 (4.6%)	9 (4.3%)	62 (3.4%)

%, percent.

private centers (20.4%). During the shutdown, most older adults did outdoor activities such as walking in public and gymnastics at home. Before the shutdown, PA was primarily done with friends (40.8%) and alone (28.2%). During the shutdown, more than half of older adults did PA alone, and over a third did PA with family members. Furthermore, a third of the participating older adults stated that they did not gain any new PA habits during the shutdown, 33.0% said that they missed what they used to do, and 27.9% felt that they did not have access to the right facilities.

DISCUSSION

The study revealed a decrease in mean minutes of PA by 16.1% from before to during the COVID-19 shutdown. This finding is worrying given the beneficial effects of regular PA on many health outcomes and its important role in reducing the impact of the COVID-19 pandemic (Powell et al., 2019). It is particularly alarming that 7.1% of participants, who did PA before, stopped doing PA during the shutdown. One study by Olsen et al. (2008) finds that only 2 weeks of a marked reduction in PA among healthy individuals had several crucial health consequences. Although it is difficult to predict the long-term health implications due to decreased PA following an pandemic such as COVID-19, previous research on the 2011 earthquake and tsunami devastating East Japan reports a lasting decrease in PA over 3 years following the disaster (Okazaki et al., 2015). This suggests that the COVID-19 shutdown might have long-term consequences for peoples' PA.

Looking at the different subgroups, the drop in PA was even higher. The lower-educated respondents and those living on the countryside significantly decreased their mean minutes of PA per week more than other subgroups. These findings are similar to other studies on PA behavior during the COVID-19 pandemic (López-Bueno et al., 2020; Rhodes et al., 2020). Unfortunately, low-educated individuals and residents living in rural areas are those who already are least likely to meet PA recommendations

TABLE 2 | Changes in mean minutes of physical activity from before to during COVID-19 shutdown.

		Mean minutes of PA per week		
		Before (SD)	During (SD)	Change (percent)
Physical activity		226.7 (313.9)	190.3 (235.6)	−16.1%**
Age	15–18	458.9 (503.5)	290.7 (410.2)	−36.6%**
	19–29	281.7 (230.1)	221.8 (264.5)	−21.3%*
	30–59	205.2 (344.3)	192.4 (213.5)	−6.3%
	60+	180.4 (181.4)	135.4 (194.1)	−24.9%**
Gender	Male	245.8 (264.8)	207.1 (277.5)	−15.7%
	Female	220.1 (328.4)	184.7 (184.7)	−16.1%*
Education	Higher education, under 3 years (e.g., secondary education, craftsman, pharmacist)	276.5 (311.9)	189.4 (291.7)	−31.5%**
	Middle higher education, 3–4 years (e.g., nurse, physio therapist, schoolteacher)	225.7 (461.9)	188.5 (217.8)	−16.5%
	Higher education (including any bachelor's degree) over 4 years (e.g., doctor, MSc)	196.3 (169.2)	193.4 (206.0)	−1.5%
	Other	209.5 (204.6)	182.7 (158.9)	−12.7%
Job situation during the COVID-19 shutdown	Work outside of home	198.2 (196.8)	207.2 (276.2)	+4.3%
	Work at home	194.1 (301.2)	191.5 (197.9)	−1.3%
	Work partly at home partly outside of home	238.9 (187.4)	151.4 (155.6)	−36.6%*
	Do not work	251.9 (411.2)	175.6 (200.7)	−30.3%*
	Sent home student	353.2 (362.0)	247.9 (343.9)	−29.8%**
Region	Large city (>15,000 citizens)	224.9 (256.5)	194.6 (235.8)	−13.5%**
	Town (2,000–15,000 citizens)	227.9 (457.4)	179.2 (178.5)	−21.4%
	Village or countryside (<2,000 citizens)	258.8 (467.4)	178.9 (320.2)	−30.9%
Living situation	Live alone	237.1 (247.2)	218.2 (335.1)	−8.0%
	Live with one or more children	208.7 (249.0)	189.4 (204.9)	−9.3%
	Live with my partner	233.6 (277.0)	179.6 (188.0)	−23.1%**
	Live with my partner and one or more children	180.4 (344.7)	171.7 (170.1)	−4.8%
	Live with my parent(s)	414.4 (419.4)	247.1 (337.4)	−40.4%**

*Paired t-test. Data presented as mean and percentage of change. PA, physical activity; SD, Standard Deviation. **P < 0.001, *P < 0.05.*

both inside (Pilgaard and Rask, 2016) and outside of Denmark (Parks et al., 2003) and, therefore, should be given special priority in public health promotion during and after the COVID-19 shutdown. The study also found a significant disparity in PA behavior among the different age groups, which is supported by previous studies on PA behavior during the COVID-19 pandemic (Cheval et al., 2020; López-Bueno et al., 2020; Maugeri et al., 2020; Ong et al., 2020; Rhodes et al., 2020; Rogers et al., 2020; Yamada et al., 2020) and discussed in the following.

Teens

Teens experienced the largest decrease in mean minutes of PA (36.6%). At the same time, there was a substantial increase in individuals who rarely or never did PA during the shutdown (71.9%). Not doing PA for a longer time in this stage of life is alarming as this is the time when individuals begin to formulate their healthy habits for life (Telama, 2009). A study by Maugeri et al. (2020) finds similar results. They use an adapted version of the IPAQ questionnaire on a sample of 2,524 individuals and find a 34.4% decrease in mean METs min/week for younger participants (<21 years old) (Maugeri et al., 2020). The age range of the <21 age category is, however, not listed in the study, and it is, therefore, unknown whether they included 15–18-year-old adults. The teens were most often active in sports associations together with friends before the shutdown. When these facilities were closed, more than half did PA at home and alone. In fact, a third missed what they used to do, felt that they did not have access to the right facilities, and lacked someone with whom to do PA. For young people, social interactions with friends significantly influences PA behavior (Macdonald-Wallis et al., 2012), a factor that may have been negatively impacted by social distancing mandates as a result of COVID-19.

Younger Adults

Younger adults had a decrease of 21.3% in mean minutes of PA per week from before to during the shutdown. This decrease may be due to their limited abilities to perform their usual PA routines. The younger adults were not able to do their usual PA in sport associations and fitness centers together with friends during the shutdown. Moreover, almost half of the younger adults reported

TABLE 3 | Differences in physical activity for the four age groups before and during shutdown.

		BEFORE				DURING			
		15–18 years	19–29 years	30–59 years	60+ years	15–18 years	18–29 years	30–59 years	60+ years
Are you in general physically active	Yes	88.0%	90.9%	87.3%	83.4%	83.2%	88.2%	87.5%	83.3%
How often where/are you physically active	5 times per week or more	36.3%**	25.0%**	17.5%**	20.5%**	44.9%**	27.5%**	31.4%**	25.9%**
	2–4 times per week	50.4%**	59.4%**	61.4%**	45.3%**	34.6%**	57.0%**	49.2%**	28.0%**
	1 time per week	9.7%**	6.9%**	12.0%**	15.5%**	11.5%**	7.9%**	8.1%**	5.6%**
	2–3 times a month	1.8%**	4.7%**	2.7%**	8.1%**	2.6%**	2.3%**	1.2%**	3.5%**
	Rarely/never	1.8%**	4.1%**	6.3%**	10.6%**	6.4%**	5.3%**	10.2%**	37.1%**
What types of PA have you done on a regular basis during the last 12 months before/during the shutdown	Team ball games (e.g., soccer, handball)	28.9%**	23.5%**	10.6%**	3.7%**	7.0%**	1.3%**	1.8%**	0.0%**
	Individual ball games (e.g., tennis, golf)	19.0%**	10.6%**	7.6%**	7.4%**	4.2%*	0.3%*	2.1%*	1.9%*
	Outdoor activities (e.g., hiking, cycling)	51.4%**	61.9%**	70.9%**	62.8%**	52.1%**	63.4%**	69.3%**	63.7%**
	Water activities (e.g., swimming, kayak)	12.7%*	12.4%*	13.2%*	20.0%*	4.2%	1.8%	1.8%	0.5%
	Street activities (e.g., CrossFit, skateboard)	30.3%**	52.1%**	30.7%**	19.1%**	25.4%**	36.3%**	17.0%**	3.7%**
	Gymnastics etc. (e.g., dance, yoga)	23.9%**	18.3%**	23.6%**	32.6%**	11.3%*	12.4%*	17.5%*	21.4%*
	Other activity (e.g., fishing, scout)	9.2%*	8.8%*	5.5%*	1.9%*	2.1%	4.9%	3.0%	2.3%
Where have you primarily been physically active during the last 12 months before/during the shutdown	Sport associations	53.0%**	31.8%**	23.2%**	30.5%**	4.8%**	0.4%**	0.4%**	0.7%**
	Fitness/private center	21.4%**	42.9%**	31.0%**	20.4%**	0.0%**	1.5%**	0.4%**	0.0%**
	At work/youth club	3.4%**	3.3%**	2.2%**	3.6%**	0.0%**	0.4%**	0.4%**	0.7%**
	At home	7.7%**	2.1%**	4.4%	6.6%	57.1%**	42.2%**	28.0%**	29.2%**
	In public	8.5%**	15.2%**	34.2%**	33.5%**	33.3%**	51.5%**	66.7%**	68.8%**
	Other	6.0%**	4.8%**	4.9%**	5.4%**	4.8%**	4.1%**	4.1%**	0.7%**
Who where you the most physically active with	Alone	10.6%**	29.4%**	37.9%**	28.2%**	57.7%**	61.1%**	46.6%**	56.7%**
	With friends	83.5%**	55.9%**	38.6%**	40.8%**	1.4%**	11.1%**	8.2%**	8.2%**
	With colleagues	1.2%**	4.0%**	3.3%**	3.5%**	0.0%**	0.4%**	0.8%**	0.0%**
	With family	4.7%**	6.3%**	11%**	15%**	40.8%**	27.4%**	44.4%**	35.1%**
	With people I don't know	0.0%**	4.4%**	9.0%**	12.7%**	0.0%**	0.0%**	0.0%**	0.0%**
Have you gained new PA habits during the shutdown	Yes, do other PA					28.9%**	31.2%**	32.5%**	15.8%**
	Yes, do the same PA but in a different way					19.7%*	31.7%*	26.9%*	20.0%*
	No					7.7%**	10.6%**	20.7%**	32.1%**
Which factors are important for whether you are physically active during the shutdown	None					8.5%	10.8%**	26.4%**	27.0%**
	I lack time/use time on something else					12.0%	5.9%**	12.7%**	4.2%**
	I don't feel like it					14.8%	14.2%**	6.8%**	6.0%**
	I don't feel safe going outside my home					4.2%	4.4%**	3.4%**	11.6%**
	I lack someone to do PA with					28.9%	26.0%**	17.7%**	16.3%**
	I don't have access to the right facilities					28.9%	41.0%**	28.9%**	27.9%**
	I miss what I used to do					33.1%	42.5%**	28.0%**	33.0%**
	I have been sick/in quarantine					3.5%	4.4%	2.3%	2.8%
	Other					4.2%	5.7%	7.5%	5.6%

*Pearson Chi-squared test for independence between the four age groups. PA, physical activity; %, percent. **P < 0.001, *P < 0.05.*

that they missed what they used to do and felt that they did not have access to the right facilities. This suggests that restricting younger adults' abilities to perform their usual PA routines has negative consequences for their PA. In line with this, a previous Danish study found it important for younger adults to have fixed appointments and a fixed timetable when doing PA (Pilgaard and Rask, 2016). The study also shows that younger adults to a greater extent seek stability in their everyday life when they experience uncertainties. As such, younger adults might have felt a lack of certainty during the shutdown, making it impossible to do their usual PA routines.

Adults

Adults experienced the smallest decrease in PA (6.3% per week), and the number of adults who did PA 5 or more times per week almost doubled. Being forced to work from home or not work at all may have increased adults' flexibility and ability to do PA at different hours. Previously, adults were found to be the age group that, at most, prefer flexibility to be able to start or continue an active lifestyle (Pilgaard and Rask, 2016). Additionally, adults might not have been forced to make major adaptations to their usual PA habits during the shutdown. Adults primarily did outdoor PA alone before the shutdown, which they continued to do during the shutdown, combined with PA with their family. In fact, those living with their partner and children had the smallest decrease in minutes of PA (4.8%). This is somewhat supported by a study conducted in the UK during the shutdown. Rogers et al. (2020) find that families with school-aged children were associated with doing more intensive PA. Social support from family members and doing PA together is found to positively influence adults PA behavior (Zimmermann et al., 2008), and being "locked up" together may support doing PA in the family.

Older Adults

Globally, half of 80+-year-old and almost a third of 60–79-year-old adults do not reach the PA recommendations (Bauman et al., 2016) and represent the least active population group in Denmark (Jensen et al., 2018). This highlights the severity of the large decrease found in this study (24.9%) and supported by other studies (Maugeri et al., 2020; Yamada et al., 2020). This age group also experienced a 71.4% increase in participants rarely or never being physically active. This suggests that many older adults went from being regularly active during the week to almost no PA. As old age is associated with functional limitations and physical health problems (de Groot et al., 2004), maintaining good physical health is important. The observed decrease in PA may be due to several factors related to older adults. Older adults were the largest group that did not gain any new PA habits during the shutdown (32.1%). This suggests that older adults may have difficulties in adapting their PA habits as they rely more on social support to change and maintain their PA habits (Lindsay Smith et al., 2017). Furthermore, older adults primarily did PA together with friends in public or in sports associations before the shutdown, which, partly, was not possible during the shutdown. This is supported by previous research arguing that social interaction is one of the main motivators for older adults to leave their home and participate in activities (Schmidt et al., 2019) and that social isolation is associated with higher inactivity (Shankar et al., 2011).

Strength and Limitations

This study, conducted in a unique situation during the COVID-19 outbreak, offers important insights into the research field of PA behavior. This study is the first of its kind conducted in Scandinavia and the first to provides contextual data on PA behavior for different age groups. A strength of the study is that the survey is based on a standardized Danish national survey on PA behavior repeated every fourth year (Pilgaard and Rask, 2016). Although the national survey has not been validated, it has been used numerous times in the Danish context throughout the last 20 years, making it highly relevant and comparable for this specific study focusing on PA in a Danish context. It is, therefore, argued that using an international validated questionnaire for this specific study would be less feasible although using a validated questionnaire may limit measurement error (Aggio et al., 2016).

A limitation is the recruitment method, which may have limited the representativeness of the study population as the study found an overrepresentation of highly educated females and adults (30–59 years). Nevertheless, 53% of the Danish population uses Facebook every day with relatively equal distributions of gender (Statistik, 2018), and almost all other similar studies have used online recruitment methods, such as social media (Cheval et al., 2020; López-Bueno et al., 2020; Maugeri et al., 2020; Rogers et al., 2020; Smith et al., 2020). These factors suggest that Facebook may be a reliable recruitment method. On the contrary, because relevance of the survey topic is shown to influence response rates (Groves et al., 2000), using social media platforms may have caused self-selection bias with an overrepresentation of respondents who may find PA important (Lavrakas, 2008). Additionally, the survey was only conducted in Danish and, therefore, excluded a range of ethnic minority groups living in Denmark.

The study builds on retrospective and self-reported data on PA, which is valuable in obtaining people's views of their own PA behavior, but can be threatened by recall bias (Althubaiti, 2016) with great variance in type, frequency, and duration of PA. Although survey questions were on routine PA behavior, which may have minimized the recall bias (Althubaiti, 2016), the length of the recall period was "within the last 12 months," which may be difficult for some to recall. We suggest that future studies should obtain data on citizens' PA behavior collected prior to the COVID-19 shutdown to better compare and assess any consequences of the shutdown on people's PA behavior. More so, objective (device-based) data on PA rather than self-reported data on PA prior to, during, and after the COVID-19 shutdown would be preferable. Last, because this study included Danish citizens over 15 years old, caution should be made when interpreting the results of the low-educated participants. Participants in the age category 15–29 years may not have finished a higher education yet. As such, the low-educated group may not reflect a low socioeconomic group.

CONCLUSIONS AND PERSPECTIVES

This study reveals that different subgroups of the population, already struggling to meet PA guidelines, struggled even more during the shutdown. The shutdown mostly affected teens and younger and older adults negatively as well as those with lower education and those living in rural areas. Although shutting down sports facilities and social distancing are important for preventing the spread of the virus, it can have negative consequences for people's motivation and opportunity for PA, hence exacerbating people's physical and mental health. In conclusion, the shutdown seemed to negatively impact Danish citizens PA behavior, which is concerning if this decrease in PA will persist and become the new societal norm. Efforts should, therefore, be made to help the most vulnerable groups to be physically active during and after the shutdown.

In fact, this study provided relevant information that was used in October 2020 when Denmark had to shut down again because of a second wave of COVID-19. At that time, the Danish government decided not to close fitness and other private sports centers. Organized sports in sport associations were also maintained for children and youth up to the age of 21, whereas adults over the age of 21 were allowed to do organized sports together with a maximum of 10 people. These decisions might especially help teens and younger and older adults to maintain their leisure PA during the COVID-19 pandemic and are beneficial to the health of the Danish population.

Although the study has several limitations, the importance of investigating and learning from this unique situation is argued to outweigh these limitations to spread the knowledge and act more appropriately during future pandemics. More studies are needed using objective PA data collected on all age groups as well as different minority groups, prior, and during the COVID-19 pandemic, to better assess PA change.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, upon request.

ETHICS STATEMENT

The study involving human participants was reviewed and approved by the Research & Innovation Organization (RIO) of University of Southern Denmark (10.975). Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

CP came up with the idea for the study, helped conduct the study, and contributed to writing the paper. TS created the study design and the questionnaire, conducted the data collection and analysis, and was the main author of the paper. Both authors have commented on and approved the final manuscript.

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Aerobic, Resistance, and Combination Training on Health-Related Quality of Life: The STRRIDE-AT/RT Randomized Trial

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Purpose: The main purpose of this study was to determine the differential effects of aerobic training (AT), resistance training (RT), and a combination of aerobic and resistance training (AT/RT) on changes in self-rated HrQoL measures, including the Short-Form 36 (SF-36) survey and Satisfaction with Physical Function and Appearance survey. We also sought to determine if combination training (AT/RT) has a more or less additive effect compared to AT or RT alone on self-rated HrQoL measures.

Materials and Methods: Participants ($n = 137$) completed one of three 8-month exercise interventions: (1) AT: 14 kcal exercise expenditure per kg of body weight per week (KKW; equivalent to roughly 12 miles/week) at 65–80% of peak oxygen consumption; (2) RT: 3 days per week, 8 exercises, 3 sets per exercise, 8–12 repetitions per set; (3) AT/RT: full combination of the AT and RT interventions. The SF-36 survey, Satisfaction with Physical Function and Appearance survey, physical fitness, and anthropometrics were assessed at baseline and post-intervention. Paired *t*-tests determined significant pre- vs. post-intervention scores within groups ($p < 0.05$). Analyses of covariance determined differences in change scores among groups ($p < 0.05$).

Results: On average, participants were 49.0 ± 10.6 years old, obese (BMI: 30.6 ± 3.2 kg/m^2), female (57.7%), and Caucasian (84.7%). Following the 8-month intervention, exercise groups improved peak VO_2 (all groups), strength (RT and AT/RT), and anthropometric measures (AT and AT/RT). For the SF-36, RT ($p = 0.03$) and AT/RT ($p < 0.001$) significantly improved their physical component score; only AT/RT ($p < 0.001$) significantly improved their mental component score. Notably, all groups significantly improved both their satisfaction with physical function and appearance scores (All Groups: $p < 0.001$ for both outcomes).

Conclusions: We found that aerobic, resistance, or combination exercise training improves several components of self-rated HrQoL, including physical function, appearance, and mental well-being.

Clinical Trial Registration: No. NCT00275145.

Keywords: exercise training, self-perception, behavior change, overweight, obese, physical activity, quality of life

INTRODUCTION

Health-related Quality of Life (HrQoL) is a multi-dimensional concept encompassing physical, emotional, and mental well-being. Poor HrQoL is associated with a decreased ability to perform activities of daily living, presence of physical limitations due to pain, loss of energy, limited ability in social activities, and increased depression or nervousness (Posthouwer et al., 2005). As an individual ages, risk for chronic conditions, disability, and comorbidities tend to rise, resulting in reduced HrQoL (White et al., 2009). Further, from adolescence to older adulthood, negative self-perception has damaging effects on HrQoL (Jackson et al., 2014; Manaf et al., 2016). Self-perception—which includes satisfaction with both physical function (SPF) and physical appearance (SPA)—is an influential component of HrQoL (Reboussin et al., 2000; Awick et al., 2015). Poor SPF is associated with low self-efficacy, greater impairment in functional mobility, less fitness, and depressive symptoms (Katula et al., 2004). Poor SPA is associated with low self-esteem, anxiety, depression, and plays a role in eating disorder etiology (Cook and Harman, 2008; Jackson et al., 2014; Seppälä et al., 2014). Consequently, low self-perception of physical function and appearance can lead to a decline in overall HrQoL (Homan and Tylka, 2014; Seppälä et al., 2014; Wang et al., 2018).

Exercise is an effective means for improving HrQoL and body image (Campbell and Hausenblas, 2009). Participation in exercise reduces weight gain, lowers risk for falls, improves physical function, reduces feelings of anxiety and depression, and reduces risk for cardiovascular disease, hypertension, type 2 diabetes, adverse blood lipid profile, and certain cancers (Physical Activity Guidelines Advisory Committee, 2008, 2018). Further, participation in both aerobic and resistance training has been shown to be associated with decreased all-cause mortality (Stamatakis et al., 2017). The 2018 U.S. Physical Activity Guidelines Advisory Committee (Physical Activity Guidelines Advisory Committee, 2018) reported physically active adults were more likely to report better HrQoL compared to sedentary adults (Physical Activity Guidelines Advisory Committee, 2018; DiPietro et al., 2019; Erickson et al., 2019). However, information on the relative effects of different exercise training modes–resistance training, aerobic training or a combination thereof—on self-rated HrQoL is lacking. Further, the U.S. Physical Activity Guidelines call for both aerobic and resistance training modes to be performed for greatest health improvements; however, little literature has examined the impact of combination training on HrQoL (DiPietro et al., 2019; Erickson et al., 2019). The second Studies of a Targeted Risk Reduction Intervention through Defined Exercise randomized trial – STRRIDE AT/RT – investigated the independent and combined effects of aerobic training (AT) and resistance training (RT) on health outcomes. Thus, as a secondary analysis from STRRIDE AT/RT, the main purpose of this study was to determine the differential effects of AT, RT, and a combination of aerobic and resistance training (AT/RT) on changes in self-rated HrQoL measures, including the Short-Form 36 survey and Satisfaction with Physical Function and Appearance survey. This secondary analysis of a prospective exercise training intervention also offered the opportunity to explore whether there is a more or less additive effect of combination training on self-rated HrQoL among overweight or obese adults at risk for cardiometabolic disease.

MATERIALS AND METHODS

Study Design

In the STRRIDE-AT/RT randomized trial (NCT00275145; conducted from 2004–2008), participants completed physical fitness, body composition, and HrQoL assessments prior to and following the end of an 8-month supervised exercise intervention. Participants were recruited continuously between 2004 and 2008. Participants were randomized to either AT, RT, or AT/RT; there was no control group included in this randomized trial. Randomization was performed with a standard computer-based random number generator using a randomized design, blocked by gender, race, and study site. The STRRIDE AT/RT study protocol was approved by the institutional review boards at Duke University (Duke) and ECU.

Participants

Potential participants (n = 3,145) responded to local advertisements and were screened by phone. Of these, 234 met inclusion criteria and were recruited into the study, 75% were recruited at Duke and the remaining 25% at ECU. Inclusion criteria were as follows: age 18–70 years, sedentary (dedicated leisure time physical activity <1 day per week), body mass index (BMI) 26–35 kg/m^2, and mild to moderate dyslipidemia (low density lipoprotein cholesterol 130–190 mg/dL and/or high density lipoprotein cholesterol <40 mg/dL for men or <45 mg/dL for women). Participants were non-smokers without a history of diabetes, hypertension, or coronary artery disease. The use of statin drugs was an exclusion criterion. After informed, written consent, participants were asked to maintain their current lifestyle during a 4-month run-in period, followed by randomization into one of three exercise training groups. The purpose of the run-in period was to discourage individuals who were not serious about the study commitment and thus reduce the dropout rate that may occur after randomization.

Participants were compensated for participation in the study. Of the 234 recruited, 38 participants dropped out during the run-in period, leaving 196 participants for randomization. Of the participants who were randomized, 73.5% ($n = 144$) completed the trial, 133 participants completed the Short-Form 36 (SF-36) survey, and 126 completed the Satisfaction with Physical Function and Appearance Survey. Demographic data were collected prior to the 4-month run-in period. All other measures in this analysis – HrQoL surveys, anthropometrics, and physical fitness – were assessed at baseline (pre-intervention) and post-intervention (16–24 h following the final exercise bout).

Exercise Training

The exercise groups were as follows: (1) AT: 14 kcal exercise expenditure per kg of body weight per week (KKW; equivalent to roughly 12 miles/week) at 65–80% of peak oxygen consumption; (2) RT: 3 days per week, 8 exercises, 3 sets per exercise, 8–12 repetitions per set; (3) AT/RT: full combination of the AT and RT interventions (Bateman et al., 2011).

Aerobic Training

For participants in the AT and AT/RT groups, a ramp period of 8–10 weeks was designed to gradually increase the amount of aerobic exercise to the prescribed amount. Once achieved, the prescribed amount of aerobic exercise was maintained for the remainder of the 8-month training period. Details about the prescribed and actual exercise training amounts, intensity, and frequency are provided in **Table 1**. The aerobic exercise modalities included treadmill, elliptical trainers, cycle ergometers, or a combination. All aerobic exercise sessions were verified either by direct supervision from fitness staff and/or use of a heart rate monitor that provided recorded, downloadable data (Polar Electro, Inc; Woodbury, NY). Intensity of the AT program was based on and maintained by using heart rate zones; therefore, participants in AT/RT performed the AT exercise first, followed by RT. The total amount of aerobic exercise minutes was determined with a cardiorespiratory fitness test, as all participants were prescribed a specific amount of exercise per unit body weight [i.e., KKW]. Individuals with greater fitness required less time to expend the prescribed number of calories per week. Exercise frequency was not prescribed for aerobic training; however, participants were encouraged not to exceed 60 min/day. Participants were encouraged to exercise at least three times per week. Aerobic compliance percentages were calculated each week as a percentage, equal to the number of minutes completed within the prescribed heart rate range, divided by the number of total weekly minutes prescribed.

Resistance Training

For participants randomized to RT or AT/RT, the ramp period began with one set during *weeks 1–2*, two sets during *weeks 3–4*, and built up to the prescribed three set amount on *week 5,* which was maintained throughout the remainder of the 8-month training period. The groups were prescribed three sessions per week (on non-consecutive days), three sets each of 8–12 repetitions of upper body (bench press, military (or overhead) press, lat pull, seated row, back extension (or bicep flexion and triceps extension), and lower body (leg extension, leg flexion, and leg press) exercises. Throughout the intervention, the amount of weight lifted was increased by 5 pounds each the time participant performed 12 repetitions with proper form on all three sets on two consecutive workout sessions to ensure a progressive RT stimulus.

All training sessions at Duke were verified by direct supervision of fitness staff and/or the FitLinxx Strength Training Partner (FitLinxx; Norwalk, CT). Throughout each workout, the "training partner" captured and stored information including total amount of weight lifted, verified by infrared laser, and the number of repetitions and sets completed within the pre-programed speed and range of motion limits. At the ECU site, sessions were confirmed via direct supervision by fitness staff. To accommodate those individuals who were randomized to AT/RT, aerobic and resistance training sessions were combined into one session to obviate the need to make twice the number of visits to the center.

TABLE 1 | Exercise prescription and adherence by group.

	Aerobic training ($n = 44$)	Resistance training ($n = 48$)	Aerobic + Resistance training ($n = 45$)
Resistance Rx			
Intensity	-	Progressive	Progressive
Rx amount, sets/wk	-	72	72
Adherence %	-	83.0 (12.8)	81.4 (14.0)
Average frequency		2.5	2.5
Aerobic Rx			
Intensity, % peak VO_2	65–80%	-	65–80%
Prescription amount			
kcal/kg/wk	14	-	14
miles/wk	12		12
min/wk	131.2 (24.8)	-	133.4 (25.0)
Adherence %	89.7 (10.0)	-	82.2 (17.2)
Average frequency	3.0		2.8

Values are means (SD). Rx = exercise prescription for AT and RT groups. Rx amount = (kcal/kg/wk) = kcal exercise expenditure per kg of body weight per week. Average frequency refers to the group average number of sessions attended per week.

Short Form—36 Survey

The SF-36 survey was used to measure self-perceived physical and mental health over that past 4 weeks before and following the intervention period. This is a 36-item survey scored into eight domains: (1) physical functioning, (2) role-physical, (3) bodily pain, (4) general health, (5) vitality, (6) social functioning, (7) role-emotional, and (8) mental health. Physical Component Score is comprised of the following 4 domains: physical functioning, role-physical, bodily pain, and general health. Mental Component Score is measured with the following 4 domains: role-emotional, social functioning, vitality, and mental health. The validity and reliability of the SF-36 have been established, and there are standardized norms available for comparative purposes (Ware and Sherbourne, 1992; Ware et al., 2000). Participants' raw scores were converted into scale scores ranging from 0 to 100, with higher scores representing better HrQoL or higher functioning for all scales (Ware et al., 1996). The SF-36 was scored by blinded assessors.

Satisfaction With Physical Function and Appearance Survey

The Satisfaction with Physical Function and Appearance survey was used to measure participant-perceived satisfaction with physical function and appearance before and following the intervention period. This survey was developed by Ray et al. and has been validated in several randomized controlled trials to pinpoint the satisfaction with HrQoL and physical activity participation (Ray et al., 1996; Reboussin et al., 2000). This nine-question survey contained five questions regarding physical function and four questions on physical appearance. Participants answered the following questions regarding physical function: "Over the past 4 weeks, how satisfied have you been with (1) your overall level of physical fitness? (2) the muscle strength in your legs? (3) your level of endurance or stamina? (5) your overall level of energy? (6) your physical ability to do what you want or need to do?" The following questions were asked regarding physical appearance: "Over the past 4 weeks, how satisfied have you been with (4) your muscle tone? (7) your weight? (8) your shape? (9) your overall physical appearance?" Each item was rated on a 7-point Likert scale ranging from −3 to 3 with the following terms: (−3) very dissatisfied, (−2) somewhat dissatisfied, (−1) a little dissatisfied, (0) neither, (+1) a little satisfied, (+2) somewhat satisfied, and (+3) very satisfied. Questions 1, 2, 3, 5, and 6 were averaged together to generate SPF score. Similarly, questions 4, 7, 8, and 9 were averaged together to generate SPA score. Greater scores indicate greater satisfaction with physical function and/or appearance. The Satisfaction with Physical Function and Appearance survey was scored by blinded assessors.

Anthropometric Measures

All anthropometric measurements were performed by trained study staff. At the Duke University clinical site, body composition was assessed using the BOD POD air displacement plethysmography method (Life Measurement, Concord, CA) on all participants before and following the intervention period. At ECU, body composition was assessed using dual-energy x-ray absorptiometry (DXA). As previously reported, measurements with BOD POD and DXA are highly correlated (0.94) with one another (Ball and Altena, 2004). Further, with the focus of this analysis being pre- to post-intervention change scores, any differences between the study sites due to techniques used to assess body composition would not affect the data interpretation. Height and body weight were assessed with the participant in light weight clothing and shoes removed. Body weight was assessed using a calibrated digital scale to the nearest 0.1 kg, with the average of three weights taken over 2 weeks, on different days, being used for each time point. Body weight was measured three times (before each intravenous glucose tolerance test, cardiopulmonary exercise test, and body composition testing), therefore we averaged these together to produce the most stable weight outcome. Height was assessed using a stadiometer to the nearest 0.25 cm, measured one time. Body mass index (BMI) was calculated from height and weight measurements. Waist circumference was measured at the minimal waist (the lowest circumference measurement above the umbilicus and below the xiphoid). Our laboratory has previously shown the minimal waist measure to be highly correlated to metabolic health, compared to the umbilicus waist measurement (Willis et al., 2007).

Physical Fitness Measures

All physical fitness measures were performed by trained study staff. Peak VO_2 was determined via maximal cardiopulmonary exercise tests with a 12-lead ECG and expired gas analysis on a treadmill using a TrueMax 2400 Metabolic Cart (ParvoMedics, Sandy, UT) before and after the exercise intervention, as described previously (Duscha et al., 2005). Exercise tests were performed under medical supervision and were conducted by exercise physiologists. The two highest, consecutive, 15 second readings from each test were averages to determine absolute peak VO_2 (L/min). In RT and AT/RT participants, the upper and lower body total amounts of weight lifted (TWL) from a single session during week 5 were used as the baseline measure of overall strength. The same measurements from a single session at week 32 were used as the end of training measure of overall strength. The difference in these two amounts constituted the overall strength gains expressed in pounds lifted/session. TWL was recorded each week either by a supervising exercise professional at East Carolina University site or electronically by the FitLinxx Strength Training Partner system (FitLinxx, Norwalk, CT) at the Duke University site.

Statistical Analyses

Data in this secondary analysis were analyzed using Statview (SAS Institute, Cary, NC) or JMP (SAS Institute, Cary, NC). Two-tailed, paired *t*-tests were used to determine whether the pre- vs. post-intervention score for changes within each group were significant (**Table 3**). A *p*-value of <0.05 was considered significant. To determine between group differences, analysis of covariance (ANCOVA), with baseline values used as a covariate was conducted. When the analysis was impressionable ($p < 0.10$), Tukey-Kramer *post-hoc* analysis was performed to determine the differences between the groups (**Table 4**, **Figures 2**, **3**). *P*-values <0.05 were considered significant in *post-hoc* testing. Prior to data analysis, assumptions for conducting a paired *t*-test and ANCOVA were assessed, with data meeting all necessary assumptions. There were no a priori power calculations because the variables in the present article were not primary outcome variables for the STRRIDE AT/RT study. The analyses present were performed "per protocol."

RESULTS

Of the 196 participants randomized, 137 participants had data for either the SF-36 ($n = 133$) or Satisfaction with Physical Function and Appearance ($n = 126$) surveys. **Figure 1** describes the flow of participants from recruitment to post-intervention testing. The baseline demographics are presented for each group in **Table 2**. Participants were on average 49.0 ± 10.6 years

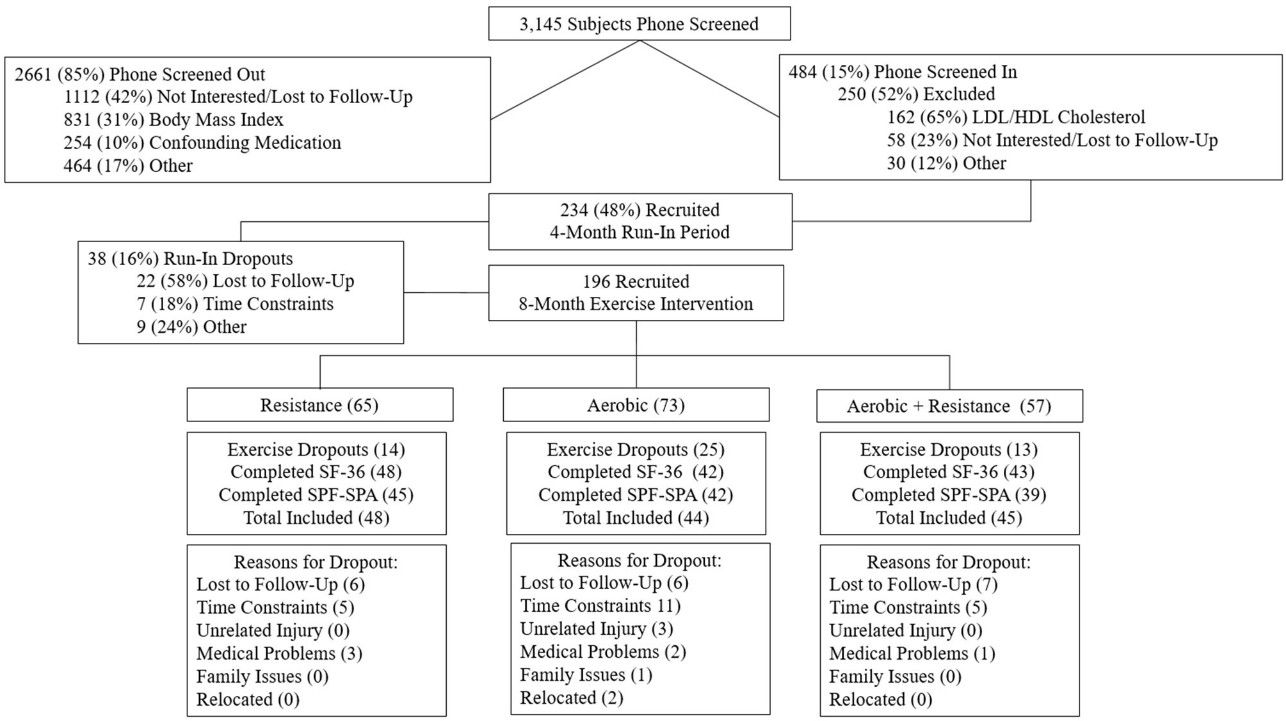

FIGURE 1 | Flowchart of screening and randomization inclusion and exclusion.

TABLE 2 | Baseline characteristics by exercise groups.

	Aerobic training (*n* = 44)	Resistance training (*n* = 48)	Aerobic + Resistance training (*n* = 45)
Age, yr	50.1 (9.9)	50.2 (11.6)	46.8 (9.9)
Sex, % Female	54.5	60.4	57.8
Race, %			
Caucasian	86.4	83.3	84.5
African American	13.6	14.6	13.3
Asian	-	2.1	-
Indian	-	-	2.2
Body weight, kg	88.5 (10.5)	88.5 (15.7)	90.4 (12.1)
Body mass index, kg/m^2	30.6 (3.0)	30.6 (3.4)	30.7 (3.4)

Values are means (SD).

old, obese (BMI: 30.6 ± 3.2 kg/m^2), female (57.7%), and Caucasian (84.7%). The exercise prescription and adherence are described in **Table 1**. Participants in AT were more adherent to the prescribed aerobic exercise intervention compared to participants in the AT/RT (89.7 vs. 82.2%, respectively; $p = 0.016$ for difference among groups). The main HrQoL outcomes of physical component score, mental component score, SPF, and SPA were not significantly different at baseline among groups.

Baseline and change scores for SF-36 individual domains, physical component score, mental component score, SPF, SPA, physical fitness, and anthropometric variables are presented for each group in **Table 3**. Following the 8-month intervention, all groups significantly improved peak VO_2, ranging from 1.1 ± 2.3 to 4.0 ± 3.2 mL/kg/min ($p < 0.001$ for all groups). Both RT and AT/RT significantly improved the TWL from baseline by 9073.0 ± 5561.2 and 7699.3 ± 5521.7 lb., respectively ($p < 0.001$ for both groups). For anthropometric variables, both AT and AT/RT reduced their minimal waist circumference by −1.0 ± 2.7 and −2.1 ± 2.9 cm, respectively ($p < 0.05$ for both groups). Only AT/RT experienced reductions in fat mass (−2.3 ± 3.1 kg; $p < 0.001$) and hip circumference (−2.1 ± 2.6 cm; $p < 0.001$). Differences among groups are presented in **Table 4**, with Tukey's *post-hoc* analysis performed only when there was an impressionable *p*-value.

At baseline, all three exercise groups began with average SF-36 scores comparable to the general US population for the physical component score, mental component score, and individual domain scores (McDowell, 2006). Following the intervention period, both RT ($p = 0.03$) and AT/RT ($p < 0.001$) significantly increased their physical component score by 1.7 ± 5.2 and 3.8 ± 5.4 points, respectively (**Figure 2**, **Panel A**). After adjusting for baseline values, there were no significant differences among groups for change in physical component scores ($F = 2.10$, $p = 0.127$). For change in mental component scores following the intervention, only AT/RT significantly experienced an increased score (3.3 ± 5.9 points; $p < 0.001$; **Figure 2**, **Panel B**). There was an impressionable *p*-value among groups for change in mental component score ($F = 2.51$, $p = 0.085$). Tukey's HSD *post-hoc* testing revealed only a trending toward significant difference between AT and AT/RT

TABLE 3 | Baseline and change values for satisfaction with physical function and appearance, SF-36, anthropometric, and fitness variables.

		Aerobic training		Resistance training		Aerobic + Resistance training	
		Baseline$^{\alpha}$	Δ	Baseline$^{\alpha}$	Δ	Baseline$^{\alpha}$	Δ
Satisfaction with		$n = 42$		$n = 45$		$n = 39$	
	Physical function	−0.4 (1.6)	**2.1 (1.6)****	−0.5 (1.6)	**2.0 (1.9)****	−0.7 (1.7)	**2.6 (2.0)****
	Physical appearance	−1.6 (1.3)	**1.3 (1.3)****	−1.5 (1.7)	**1.3 (1.7)****	−1.2 (1.8)	**1.8 (2.3)****
SF-36		$n = 42$		$n = 48$		$n = 43$	
	Physical component score	76.5 (5.1)	**1.6 (5.7)**†	76.1 (6.8)	**1.7 (5.2)***	75.4 (6.2)	**3.8 (5.4)****
	Physical functioning	78.2 (10.3)	**4.3 (9.9)***	78.9 (10.2)	**3.4 (7.7)***	76.0 (20.9)	**2.9 (11.5)****
	Role-physical	90.2 (14.1)	3.6 (16.9)	85.4 (21.4)	3.8 (19.8)	90.3 (13.6)	2.3 (14.4)
	Bodily pain	81.6 (19.4)	−1.9 (25.1)	82.3 (18.5)	−2.7 (17.5)	74.0 (16.1)	**4.7 (16.1)**†
	General health	63.3 (14.1)	3.4 (14.6)	63.1 (23.1)	**5.5 (19.2)**†	63.3 (20.0)	**10.6 (19.3)****
	Mental component score	58.5 (5.5)	−0.1 (6.6)	57.6 (7.4)	1.0 (6.5)	56.8 (8.0)	**3.3 (5.9)****
	Vitality	57.9 (16.5)	**4.7 (13.4)***	60.3 (18.0)	**3.9 (15.7)**†	56.6 (20.4)	**9.7 (18.7)***
	Social functioning	82.0 (11.9)	−0.3 (12.3)	79.4 (12.7)	−0.3 (17.0)	78.2 (16.8)	1.7 (12.4)
	Role-emotional	92.0 (13.3)	0.5 (15.8)	86.0 (20.0)	0.2 (20.6)	85.8 (19.5)	**6.7 (16.7)***
	Mental health	75.0 (13.9)	−1.1 (12.5)	72.3 (20.1)	2.7 (17.5)	71.8 (19.7)	**6.1 (15.8) ***
Anthropometric and fitness		$n = 44$		$n = 48$		$n = 45$	
	Fat mass (kg)	33.9 (8.1)	−0.7 (3.8)	34.3 (8.8)	0.1 (2.6)	34.9 (8.9)	**−2.3 (3.1)****
	Minimal waist circumference (cm)	97.0 (9.5)	**−1.0 (2.7)***	95.4 (9.6)	0.01 (2.0)	96.8 (10.0)	**−2.1 (2.9)****
	Hip circumference (cm)	111.0 (6.5)	−0.6 (2.8)	112.0 (8.4)	0.03 (2.9)	113.6 (8.9)	**−2.1 (2.6)****
	Total weight lifted (lbs)	-	-	19273.4 (7954.8)	**9073.0 (5561.2)****	18906.7 (5873.8)	**7699.3 (5521.7)****
	Peak VO_2 (ml/kg/min)	28.0 (6.0)	**3.4 (3.5)****	26.0 (6.0)	**1.1 (2.3)****	27.2 (5.9)	**4.0 (3.2)****

Values are means (SD). Δ represents the change from baseline to post-intervention.
[α]A higher score indicates a better health state.
*†p-value < 0.1; *p-value < 0.05; **p-value < 0.001. Bold values indicate significant or trending toward significant values.*

TABLE 4 | ANCOVA and *post-hoc* comparison values for SF-36 domains, physical fitness, and anthropometric variables.

	Model (*F* Ratio)	Model (*p*-value)	Group effect (*F* Ratio)	Group effect (*p*-value)	*Post-Hoc* within group Δ (*SD*)		
					AT vs. RT	AT vs. AT/RT	RT vs. AT/RT
SF-36 domains							
Physical functioning	36.92	**<0.001****	1.88	0.157	-	-	-
Role-physical	30.91	**<0.001****	0.56	0.573	-	-	-
Bodily pain	1.83	0.146	1.57	0.212	-	-	-
General health	24.47	**<0.001****	3.14	**0.047***	3.4 (14.6) vs. 5.5 (19.2)	**3.4 (14.6) vs. 10.6 (19.3)***	5.5 (19.2) vs. 10.6 (19.3)
Vitality	19.36	**<0.001****	1.67	0.193	-	-	-
Social functioning	13.15	**<0.001****	0.21	0.812	-	-	-
Role-emotional	11.86	**<0.001****	1.83	0.164	-	-	-
Mental health	17.85	**<0.001****	2.51	**0.085**†	−1.1 (12.5) vs. 2.7 (17.5)	**−1.1 (12.5) vs. 6.1 (15.8)**†	2.7 (17.5) vs. 6.1 (15.8)
Physical fitness and anthropometrics							
Fat mass	7.23	**<0.001****	6.77	**0.002****	−0.7 (3.8) vs. 0.1 (2.6)	−0.7 (3.8) vs.−2.3 (3.1)	**0.1 (2.6) vs.−2.3 (3.1)****
Minimal waist circumference	4.99	**0.003****	8.34	**<0.001****	−1.0 (2.7) vs. 0.01 (2.0)	**−1.0 (2.7) vs.−2.1(2.9)**†	**0.01 (2.0) vs.−2.1(2.9)****
Hip circumference	6.56	**<0.001****	6.12	**0.003****	−0.6 (2.8) vs. 0.03 (2.9)	**−0.6 (2.8) vs.−2.1 (2.6)**†	**0.03 (2.9) vs.−2.1 (2.6)****
Total weight lifted	15.46	**<0.001****	1.28	0.262	-	**-**	-
Peak VO_2	8.14	**<0.001****	12.15	**<0.001****	**3.4 (3.5) vs. 1.1 (2.3)****	3.4 (3.5) vs. 4.0 (3.2)	**1.1 (2.3) vs. 4.0 (3.2)****

*Tukey's HSD was performed only if the ANCOVA group effect was impressionable (p < 0.1). †p-value < 0.1; *p-value < 0.05; **p-value < 0.001. Bold values indicate significant or trending toward significant values.*

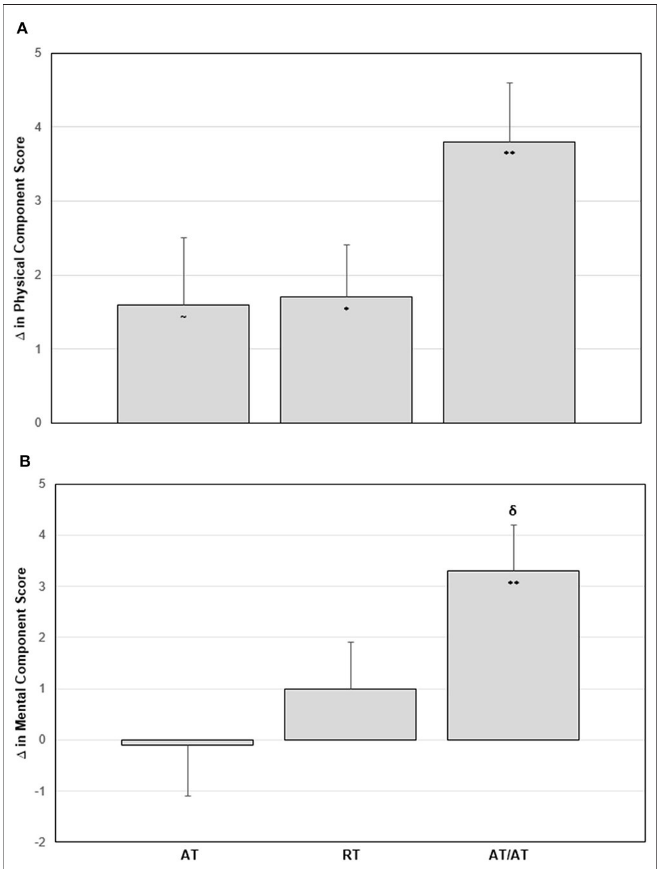

FIGURE 2 | Panel A: Change in physical component score by group. **Panel B**: Change in mental component score by group. Error bars indicate SE. Significant within group change: ~*p*-value < 0.1; **p*-value < 0.05; ***p*-value < 0.001. $^{\delta}$*p*-value < 0.1 Tukey's *Post-Hoc* Test compared with aerobic training.

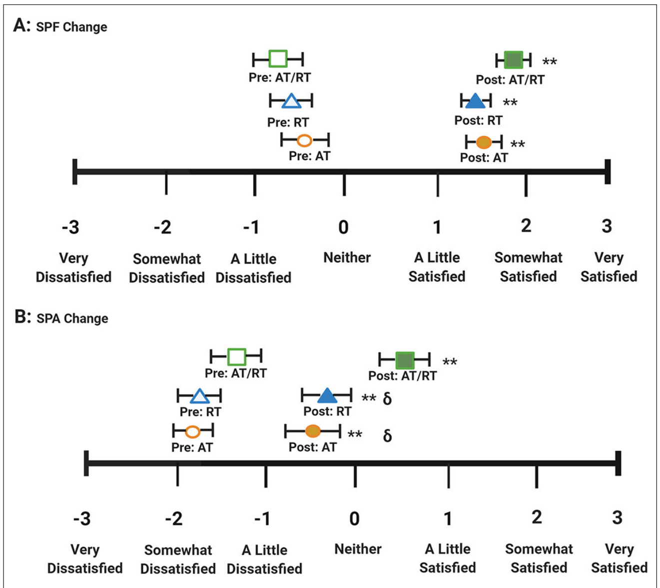

FIGURE 3 | □ AT/RT pre-intervention score. ■ AT/RT post-intervention score. △ RT pre-intervention score. ▲ RT post-intervention score. ○ AT pre-intervention score. ● AT post-intervention score. **Panel A**: Satisfaction with physical function pre/post scores by intervention group. **Panel B**: Satisfaction with physical appearance pre/post scores by intervention group. Error bars indicate SE. Significant within group change: ***p*-value < 0.001. $^{\delta}$*p*-value < 0.01 Tukey's *Post-Hoc* Test compared with aerobic + resistance training.

($p = 0.08$; **Figure 2**, **Panel B**). When evaluating changes in each of the domain scores, AT/RT significantly improved "physical functioning" ($p < 0.001$), "general health" ($p < 0.001$), "vitality" ($p = 0.001$), "role-emotional" ($p = 0.012$), and "mental health" ($p = 0.015$) domain scores. RT only experienced a significant improvement in "physical functioning" ($p = 0.003$). Finally, AT experienced a significant improvement "physical functioning" ($p < 0.001$) and "vitality" ($p = 0.03$). **Table 4** contains significant differences among groups for each SF-36 domain, after adjusting for baseline values.

At baseline, all three groups had overall negative average SPF and SPA scores, indicating overall dissatisfaction with both physical function and physical appearance. **Figure 3** displays the average pre- and post-intervention scores for SPF and SPA by group. Following the intervention period, all exercise groups significantly increased both SPF ($p < 0.001$ for all groups; **Figure 3**, **Panel A**) and SPA ($p < 0.001$ for all groups; **Figure 3**, **Panel B**) scores. After adjusting for baseline values, there were no significant differences between groups for change in SPF score ($F = 1.80$; $p = 0.169$). There was an impressionable p-value among groups for change in SPA score ($F = 4.78$; $p = 0.010$). Tukey's HSD *post-hoc* testing revealed a significant difference between RT and AT/RT ($p = 0.018$; **Figure 3**, **Panel B**), as well as, between AT and AT/RT ($p = 0.025$; **Figure 3**, **Panel B**). The changes in SPF score following the intervention resulted in overall positive ratings for each exercise group (AT = 1.7 ± 1.2; RT = 1.5 ± 1.0; AT/RT = 1.9 ± 1.0). However, changes in SPA score following the intervention resulted in a positive rating only for AT/RT (0.7 ± 1.4). AT and RT maintained an overall negative rating of SPA (AT: -0.3 ± 1.4; RT: -0.2 ± 1.4) even though a statistically significant change was found, indicating overall dissatisfaction with appearance following the exercise intervention.

DISCUSSION

Participation in exercise has been shown to improve measures of HrQoL (Martin et al., 2009; Reid et al., 2010; Pucci et al., 2012). However, little research has been done comparing the effects of AT, RT, and the combination there-of on self-rated HrQoL. The STRRIDE AT/RT study provided a unique opportunity to determine if an 8-month combination AT/RT exercise intervention had a more or less additive effect on measures of self-rated HrQoL compared to AT and RT alone using a secondary analysis. In our study design, AT/RT performed an additive combination of the AT and RT interventions, almost doubling the amount of exercise compared to

AT or RT. Therefore, we had the unique opportunity to determine if AT/RT resulted in a more or less additive change in physical component score, mental component score, SPF score, and SPA score compared to AT or RT alone.

The primary findings of the parent STRRIDE-AT/RT study were as follows: (1) the RT program significantly improved peak VO_2 and strength, with all other cardiometabolic outcomes not effected, (2) the AT program resulted in significant improvements in body mass, peak VO_2, and triglycerides, and (3) the full combination of AT/RT resulted in significant improvements in body mass, peak VO_2, strength, triglycerides, waist circumference, diastolic blood pressure, mean arterial blood pressure, ATP III score, and Metabolic Syndrome *z*-score (Bateman et al., 2011). The results of this secondary analysis on changes in anthropometric and physical fitness outcomes mirror those previously published. We found AT/RT exercise resulted in significantly improved objective measures of health—cardiorespiratory fitness, strength, and anthropometrics. RT exercise resulted in significant improvement in measures of strength, AT exercise resulted in significant improvement in anthropometrics, and both significantly improved cardiorespiratory fitness.

In this secondary analysis, we found all exercise groups experienced significant improvements in self-rated HrQoL measures. In the SF-36, AT/RT had the greatest improvement in physical component score, mental component score, and individual domain scores. When comparing the effects of AT and RT alone to AT/RT, we found an additive effect for change in physical component score in AT/RT following the intervention (**Figure 2**, **Panel A**). Interestingly, we observed a more than additive effect of AT/RT on mental component score (**Figure 2**, **Panel B**). In the Satisfaction with Physical Function and Appearance survey, we found significant improvements in all exercise interventions for both SPF and SPA scores. When comparing the effects of AT and RT alone to AT/RT, we found there was a less than additive effect observed in AT/RT for both SPF and SPA score compared to AT and RT alone (**Table 3**); However, change in SPF and SPA in AT/RT resulted in a numerically greater change compared to either AT or RT alone, following the intervention.

Although the SF-36 is a well-known and broadly used questionnaire, depending on the population, the survey can lack the sensitivity needed to detect a significant change in self-rated HrQoL. In the U.S., mean scores for individual domains range from 70.9 to 84.3 on a scale of 0–100 (excluding vitality which has a lower mean of 58.3), with physical component domain scores typically greater than mental component domain scores (McDowell, 2006). Our average baseline scores for physical component domains ranged from 63.1 ("general health") to 90.3 ("role-physical"); average baseline scores for mental component domains ranged from 56.8 ("vitality") to 92.0 ("role-emotional"). Though the domain scores in our cohort of previously sedentary adults at risk for cardiometabolic disease were comparable to U.S. general population scores, they were high on a scale from 0 to 100, potentially limiting the ability to detect large changes in self-rated HrQoL (McDowell, 2006). Further, the SF-36 questions around physical function and mental health (e.g., "Does your health now limit you in these activities? Lifting or carrying groceries, climbing one flight of stairs," etc.) may be too specific or inappropriate to detect a change in our cohort, comprised of highly functioning, relatively healthy adults who performed an intense exercise intervention.

On the other hand, the Satisfaction with Physical Function and Appearance survey utilizes a 7-point Likert scale, conferring more sensitivity to change in our cohort. Therefore, inclusion of the Satisfaction with Physical Function and Appearance survey in this study provided an additional lens by which to evaluate changes in self-rated HrQoL following an exercise intervention. Moreover, using a single Likert scale for all response choices in the Satisfaction with Physical Function and Appearance survey may limit bias from the respondents. Various arrangements of response choices and change of response scales throughout the SF-36 survey may cause bias in how the participants answer each set of questions, therefore diminishing potential sensitivity to the measure (Choi and Pak, 2005). The participants in our study reported overall dissatisfaction with their physical function and appearance at baseline. By the end of the intervention, all three exercise groups experienced significant improvements in both SPF and SPA scores; this illustrates the utility of this survey to assess components of self-rated HrQoL in a population at risk for cardiometabolic disease development.

Few large randomized controlled trials have examined the effects of AT and RT on overweight or obese adults. In the DREW (Dose Response to Exercise in Women) study (Martin et al., 2009), sedentary, post-menopausal women were randomized to either a control group or one of three aerobic exercise interventions. A significant, positive dose-response relationship was found between amount of aerobic exercise performed and improvements in physical and mental QoL components (Martin et al., 2009). Among individuals with type 2 diabetes in the HART-D study, AT, RT, and combined AT/RT exercise training improved physical component score; however, the effects on mental component score were limited, with improvements favoring AT/RT and RT (Myers et al., 2013). Moreover, in our study of sedentary adults at risk for cardiometabolic disease, we found greater changes in the physical component and mental component scores with AT/RT compared with AT or RT alone.

An 8-week AT vs. RT randomized exercise intervention assessing changes in body image among college-aged women with pre-existing body image concerns found both AT and RT significantly improved body image satisfaction scores in three body image measures (Ginis et al., 2005). Further, when comparing change in body image among groups, AT had significantly greater improvements in body image satisfaction scores compared to RT (Ginis et al., 2005). We found a significant group difference between AT and AT/RT for SPF change, and no group differences for SPA change. These differences may be attributed to study design and population. More evidence is needed to determine whether AT, RT, or a combination AT/RT program is the most effective for improving self-perception of appearance and function.

To the best of our knowledge, this is one of the first studies to explore the differential effects of exercise modes separately and in full combination on changes in self-rated HrQoL. Further, the 8-month duration of the intervention resulted in significant changes among objective measures of cardiorespiratory fitness and anthropometrics; therefore, this may be a sufficient duration to see significant changes in self-rated HrQoL. In addition, our study employed two different measures of self-rated HrQoL, allowing us to assess the effects of our exercise interventions on different dimensions of HrQoL.

We recognize the limitations of our study, which includes the recruited population contained men and women motivated to perform exercise in a semi-supervised setting; this may limit the generalizability of our findings to other populations. Using questionnaires to capture perceived HrQoL measures can result in inclusion of false answers, differences in understanding and interpretation of questions, lack of personalization, and unanswered questions. Another limitation is this study was designed as an efficacy study, not an intention to treat study. Further, the data collected in this study were collected between 2004–2008, therefore it is unclear if the outcomes measured here would be the same if the data had been collected more recently today as obesity continues to become visually normalized. Last, this study lacks the ability to detect if the changes seen with AT/RT are due to the addition of RT, or if greater amounts of either AT or RT would have produced a similar effect.

CONCLUSION

We found that aerobic and/or resistance exercise training can positively influence self-rated HrQoL measures, with the combination of both modes having the greatest impact. To the best of our knowledge this is one of the first studies to provide evidence that individuals should include both aerobic and resistance training modes in physical activity regiments in order to improve self-rated HrQoL, supporting the U.S. Physical Activity Guidelines.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors upon request, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Duke University Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

WK, JH, and CS contributed to the study conception and design. Data collection was performed by LW, LP, LB, and CS. Data analysis and manuscript conception was conducted by KC, LF, LR, PD, and CS. The first draft of the manuscript was written by KC and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Physical Fitness and Motor Competence in Upper Austrian Elementary School Children—Study Protocol and Preliminary Findings of a State-Wide Fitness Testing Program

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Motor competence and physical fitness are key components for the promotion of an active and healthy lifestyle. Poor motor competence and low physical fitness in children, therefore, are a major threat to future public health. Even though the assessment of physical fitness and motor competence *per se* does not enhance these entities, fitness tests can provide important information for intervention strategies. Fitness tests may also motivate children to become more active in order to increase their physical abilities. In the school-year 2016/17 the Upper Austrian government initiated the state-wide testing program "wie fit bist du" (how fit are you) in elementary schools, that examined cardiorespiratory fitness, muscular power, speed, agility, flexibility and object control skills along with the assessment of height and weight. Since the beginning of the program more than 18,000 children between 6 and 11 years of age participated in the school-based tests. The results show a significant increase in the prevalence of overweight/obesity with increasing age ($p > 0.01$). Overweight/obese children displayed lower motor competence and physical fitness, except for upper body strength. Further, the improvement in test performance with increasing age was less pronounced in overweight/obese children compared to their normal weight peers. In fact, distance covered during the 6-min run did not improve throughout the elementary school years in overweight/obese children. Given the importance of motor competence and physical fitness for general development and well-being, physical education should be considered a viable setting for the promotion of these entities as a majority of children can be reached independent of their socio-economic background. In order to provide adequate movement experiences that enhance motor competence and physical fitness while ensuring a motivating environment, objective information on current ability levels are required. The implementation of fitness monitoring at young ages, therefore, can be an important contributor for the promotion of an active and healthy lifestyle.

Keywords: cardiorespiratory endurance, muscular strength, motor skills, motor competence, body weight, youth

INTRODUCTION

Physical fitness and motor competence are considered key components for the development and general health in children and adolescents (Dwyer et al., 2009; Ruiz et al., 2009; Robinson et al., 2015; Hamer et al., 2020; Raghuveer et al., 2020). There is considerable evidence for beneficial associations of physical fitness with body weight (Ortega et al., 2008; Rauner et al., 2013), chronic disease risk (Ortega et al., 2008; Ruiz et al., 2009; Grøntved et al., 2015; Lang et al., 2018), cognitive development and academic performance (Ortega et al., 2008; Santana et al., 2017; Marques et al., 2018; Mintjens et al., 2018) as well as mental health (Ortega et al., 2008; Lubans et al., 2016). Similarly, motor competence has been associated with body weight (Lopes et al., 2012; Robinson et al., 2015; Barnett et al., 2016) in addition to self-efficacy and general well-being (Robinson et al., 2015). Further, motor competence is directly associated with physical fitness as it reflects the ability to perform goal-directed movements that involve large muscle groups or the whole body (Robinson et al., 2015; Barnett et al., 2016). Accordingly, motor competence provides the foundation for various sport-specific skills, particularly during middle and late childhood (Clark and Metcalf, 2002; Stodden et al., 2008), which will influence physical fitness (Robinson et al., 2015; Barnett et al., 2016) and subsequent physical activity (PA) (Barnett et al., 2009; Lopes et al., 2011; Lloyd et al., 2014). Physical fitness is also an important component in the promotion of active leisure time choices as it has been defined as the ability to complete daily activities without undue fatigue that provides sufficient energy reserves to engage in active recreational pursuits (Malina and Katzmarzyk, 2006). In addition, high motor competence and physical fitness have been suggested to induce relatively permanent behavioral choices that transfer into adulthood (Barnett et al., 2009; Lai et al., 2014; Telama et al., 2014; Robinson et al., 2015; García-Hermoso et al., 2019) and are considered key components in the promotion of an active lifestyle (Stodden et al., 2008). Nevertheless, physical fitness and motor competence have declined in children and adolescents over the last several decades (Moraes Ferrari et al., 2013; Brian et al., 2018; Tomkinson et al., 2019). Available data indicates "below normal" muscular fitness in 74% of Czech children (Müllerova et al., 2015) and less than half of US adolescents are believed to achieve healthy fitness levels (Gahche et al., 2014). At the same time the prevalence of overweight and obesity in children increased, which also has significant impact on current and future health (Llewellyn et al., 2016; NCD Risk Factor Collaboration, 2017). Given these trends in body weight and physical fitness, additional efforts to promote an active and healthy lifestyle are needed.

The elementary school years appear to be a particularly critical period for the development of physical fitness and motor competence (Augste and Jaitner, 2010). Motor competence and physical fitness, however, do not develop naturally (Robinson et al., 2015); rather, motor development is described as a learning process that is driven by structural and functional changes of the body and the environment (Clark, 1995), which requires nurturing experiences (Robinson et al., 2015). Changes in the social and built environment, however, have led to a decline in PA at young ages, which hinders motor development (Dordel, 2000; Sygusch, 2006; Bös et al., 2008). The detrimental association of insufficient PA, low physical fitness, poor motor competence and associated health outcomes is also referred to as pediatric inactivity triad, which is a considerable risk for future public health (Faigenbaum et al., 2018). In order to reach a large number of children, independent of their socio-economic background, schools are a prime setting for the promotion of PA and health in children and adolescents (Peralta et al., 2020). There is also evidence on beneficial effects of structured school-based interventions on physical fitness and motor competence (García-Hermoso et al., 2020).

Even though the assessment of motor competence and physical fitness does not improve these entities *per se*, it does provide information on current abilities, which is crucial for the selection of adequate movement experiences that facilitate motor development. Further, repeated assessments provide valuable insights into the efficacy of various intervention strategies and potentially serve as motivation to engage in activities that promote motor competence and physical fitness (Wiersma and Sherman, 2008; Jaakkola et al., 2013). Harris and Cale (2019), therefore, argue that appropriately performed and well-incorporated fitness monitoring should be part of the curriculum due to its viable role in supporting an active and healthy lifestyle. The German Olympic Sports Association also recommends regular assessments of motor competence and physical fitness starting from the elementary school years beyond its use for talent identification (Deutscher Olympischer Sportbund, 2013). Given these recommendations the Upper Austrian government initiated the project "wie fit bist du?" (how fit are you?), which provides a large-scale assessment of motor competence and physical fitness in Upper Austrian elementary school children. The purpose of this article is to provide a description of the study protocol and individual fitness assessments. Further, preliminary cross-sectional results addressing differences in physical fitness by age and weight status are shown.

MATERIALS AND METHODS

The project started in the school-year 2016/17. All elementary schools in the federal state of Upper Austria were informed about the project. During the first year of data collection only elementary students in grades 2 and 3 were eligible for participation. In subsequent years, grade 4 students were included as part of follow-up measurements and first grade students were included as this was requested by participating schools. Study procedures have been approved by the Upper Austrian School Board and are in accordance with the 2008 declaration of Helsinki. Written informed consent was obtained from participating schools (school board and classroom teacher) and parents. Children provided oral assent at the time of measurement.

Test Items

Anthropometric Measurements

Anthropometric measurements were taken according to standard procedures with children in gym clothes and barefoot.

A portable stadiometer (SECA 2013, Seca, Hamburg, Germany) was used to measure body height to the nearest 0.5 cm. Body weight was measured with an electronic scale (Seca 878 dr, Seca, Hamburg, Germany) to the nearest 0.1 kg. Subsequently body max index (BMI) was calculated (kg/m^2) and converted to BMI percentiles (BMIPCT) using German reference values (Kromeyer-Hauschild et al., 2001). Children with a BMIPCT above the 90th percentile were classified as overweight and children above the 97th percentile were classified as obese. Children with a BMIPCT of <10 were considered underweight.

The participants completed a total of eight tests that assessed various components of physical fitness (cardiorespiratory endurance, muscular strength, muscular power, speed, and flexibility) as well as motor competence (agility and object control).

Cardiorespiratory Endurance

Distance covered during a 6-min run was used as indicator for cardiorespiratory endurance. The running track was marked in the school's gymnasium with four cones that were set up 2.5 m from each corner of the gymnasium. The distance of one lap was measured with a measuring wheel in duplicate to assure accuracy. Total distance covered was determined to the nearest meter [Distance (m) = lap (m) × number of laps + distance of last partial lap]. In order avoid congestion during the run no more than 4 participants were starting in each corner per trial. Prior to the beginning of the test participants were instructed to complete as many laps as possible within 6 min—in case of fatigue participants were told to continue walking rather than maintain still. Laps were counted by trained technicians. Participants received verbal time warnings at minutes 3, 4, and 5, as well as 30 s prior to the end. The last 10 s were counted down and participants were asked to remain at their position at the end of the 6 min interval in order to determine the distance covered during the final lap.

Muscular Strength and Power

Muscular strength was assessed via a medicine ball push (1 kg). The participant was asked to hold the medicine ball with two hands in front of the chest and toss the ball for maximum distance using only arms and upper body, while keeping both legs extended and feet on the ground. Distance was recorded to the nearest 10 cm using a measurement tape. Overhead throwing motions or stepping over the 0 cm line were not allowed to complete this task.

In addition, a counter movement jump was used as indicator of lower extremity power. The counter movement jump was performed on a contact measuring plate (TDS Linz, Austria) with the participant standing with hands at the waist. Upon the command "and jump" the participant jumped for maximal vertical height while keeping the hands at the waist. Legs were supposed to stay extended during the flight phase in order to avoid landing in a tucked position as this would affect the measurement.

Speed

Linear speed was assessed via a 10 m sprint. Participants started in an up-right position 1 m behind the starting line after receiving a ready-signal from the technician. In order to avoid a deceleration prior to the finish line, a finishing area was marked 3 m after the actual 10 m mark. Running time to cover the 10 m distance was measured via photocell measurement (TDS Linz, Austria).

In addition, a tapping test was performed, in which the participant was asked to perform as many alternating contacts with the left and right foot as possible within 6 s on a contact measuring plate (TDS Linz, Austria).

Agility

Agility was assessed via a standardized obstacle run that includes a forward roll, jumping over as well as moving under hurdles along with directional changes (**Figure 1**). After crossing the starting line, the participant performed a forward roll on a mat, followed by a 90° turn at the middle pole. Next, the participant jumped over the hurdle and returned by crawling underneath the same hurdle back to the middle pole, where another 90° turn was made. The same procedure was repeated for the next two hurdles. After completing all three hurdles the participant ran back to the starting line (no second forward roll). The height of the hurdles was set based on the participant's body height and completion time was measured by hand to the nearest 1/100 s. In case a participant was unable to perform a forward roll 5 s were added to the time measured.

Flexibility

Flexibility was assessed via a stand-and-reach test. The participant stood barefoot on the measurement box with the knees fully extended and legs being closed. Then, the participant was asked to reach as far as possible toward or beyond the toes along the measurement scale by bending at the hip while keeping the knees extended. At maximum extension the position needed to be held for 2 s to measure distance from the toes in mm. Positive values indicate reaching beyond the toes, while negative values indicate not reaching the toes.

Object Control

Ball handling skills were assessed by a 30-s throw-and-catch task with a European handball (size 1). The participant was instructed to throw the ball (using a one-handed overhead motion) from 1.5 m distance against a wall and catch the returning ball with two hands prior to it touching the ground. This pattern was repeated over 30 s in an attempt to complete as many throws and catches as possible. Four extra balls were prepared next to the participant in case a ball bounced away. Only successful catches following a proper one-handed overhead throw were counted. Attempts when the ball was not caught, when the ball bounced on the ground or the participant stepped over the 1.5 m line were disregarded.

Testing Procedures

All assessments were taken by trained technicians in the participating school's gymnasium within 90–120 min. Every school visit followed the procedures detailed in a written manual

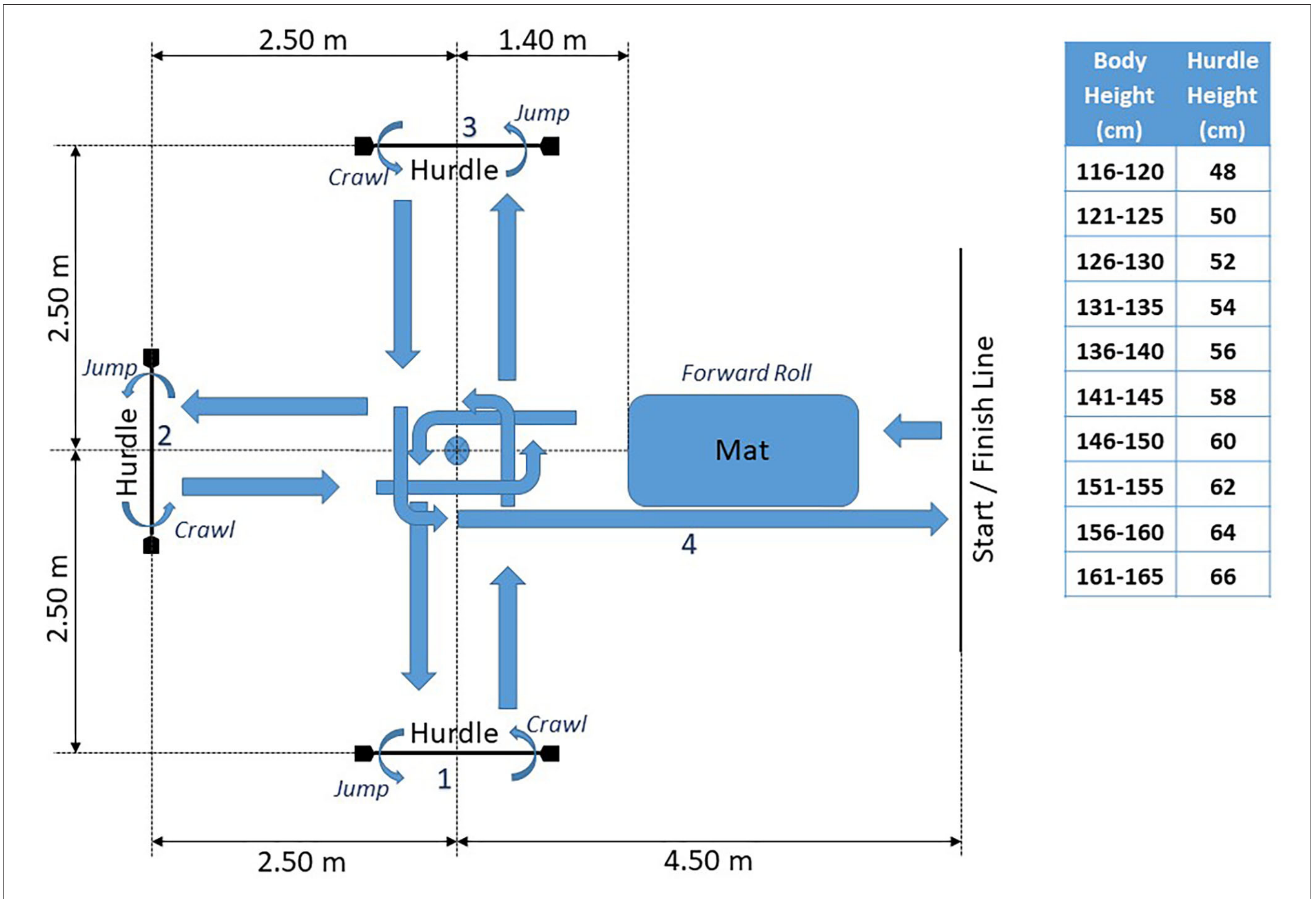

FIGURE 1 | Obstacle run course setup with height chart for hurdles.

that included information on set up of the fitness assessments, welcoming students, warm up, test administration and reporting of test results. In addition, a senior staff of the project was present to supervise procedures. All children of the respective class, who were able to participate in PE the day of the fitness tests participated in the assessments but only data of children with parental consent were entered on site in a specifically developed software. There were no make-up days for children who were sick and missed school that day or for children who were not able to participate in the fitness tests. After measuring height (kg) and weight (cm), participants completed a 5-min standardized warm up. Subsequently, the fitness tests were completed in random order, except for the 6-min run, which was completed at the end of the testing session in order to avoid undue fatigue. All tests were verbally explained and shown to the participants prior to the respective assessments. Participants performed each test twice, with sufficient recovery time between trials, except for the vertical jump (three trials back-to-back) and the 6-min run (one trial). The best attempts were used for further analyses.

Statistical Analyses

Participants were stratified by chronological age into five age groups (6.0–6.9; 7.0–7.9; 8.0–8.9; 9.0–9.9; 10.0–10.9). Descriptive statistics were calculated and data were checked for normal distribution. Chi square tests were used to examine differences in categorical variables. Multivariate analysis of variance (MANOVA) was used to examine differences across the fitness tests by sex and age group. In addition, differences in physical fitness and motor competence between overweight/obese and normal weight participants by age group were examined via 2 × 5 MANOVA. All statistical analyses were performed with SPSS 26.0 with a significance level of $p < 0.05$ and Bonferroni adjustment for multiple comparisons.

RESULTS

Since the start of the project in October 2016 a total of 28,481 assessments were completed until July 2019. During that time span 18,746 children (51% male) between the ages 6 and 11 years were tested at least once. A total of 18,168 children had valid data for all measurements and were included in the analyses. There were no significant differences in sex distribution and age between children with incomplete data and those included in the analyses. An overview of anthropometric characteristics and sex distribution by age group is provided in **Table 1**.

Across the entire sample 8.4% were considered overweight and 6.3% of the children were considered obese. More boys than girls were overweight and obese (8.7 vs. 8.1% and 6.6 vs. 5.9%, respectively). The prevalence of underweight was 8.5% with a higher prevalence in boys compared to girls (9.6 vs. 7.4%). There was also an increase in the prevalence of overweight and obesity across age groups from 7.1 and 6.3% in 6–7 year-old children to 11.2% and 7.6% in 10–11 year-old children, respectively. The prevalence of underweight remained relatively stable (9.7% in 6–7 year-old children vs. 10.1% in 10–11 year-old children).

TABLE 1 | Anthropometric characteristics by age group.

Age group (*N*, % male)	Age (years)	Height (cm)	Weight (kg)	BMI Percentile
6–7 years (352, 56.0%)	6.7 ± 0.2	122.7 ± 5.3	24.3 ± 4.6	51.3 ± 29.8
7–8 years (5,875, 49.0%)	7.7 ± 0.2	128.6 ± 5.7	27.2 ± 5.4	50.8 ± 28.7
8–9 years (8,156, 51.2%)	8.4 ± 0.3	132.5 ± 5.9	29.8 ± 6.6	51.6 ± 29.7
9–10 years (3,144, 55.2%)	9.4 ± 0.3	137.4 ± 6.5	33.6 ± 8.2	53.9 ± 31.2
10–11 years (641, 52.7%)	10.4 ± 0.3	142.1 ± 6.6	37.1 ± 9.3	53.8 ± 31.8

Values are mean ± SD.

Despite the rising prevalence of overweight/obesity with increasing age physical fitness and motor competence improved significantly across age groups (p for trend <0.01), except for flexibility, where a significant decline was observed with increasing age (p for trend <0.01). Boys performed better than girls at all test items, except for the stand and reach test, which was better in girls compared to boys ($p < 0.01$, **Table 2**).

Across the entire sample, there were significant differences in physical fitness between normal weight and overweight/obese participants ($p < 0.01$), except for the throw and catch task. Normal weight participants displayed better performance than their overweight/obese peers at the 6-min run, 10 m sprint, counter movement jump, tapping, obstacle run and stand and reach test. Ball push performance, on the other hand, was better in overweight/obese children compared to their normal weight peers.

There was a significant weight category by age group interaction on physical fitness (Wilks' Lambda = 0.99, $p < 0.01$). Interaction effects of the individual fitness tests were significant for all tests, except for the stand-and-reach test. Specifically, the difference between normal weight and overweight/obese children became more pronounced for the 6-min run, counter movement jump, 10 m sprint, tapping and obstacle run ($p < 0.01$), while the performance difference declined for the medicine ball push ($p <$

TABLE 2 | Physical fitness and motor competence by age group and sex.

		6–7 Years	7–8 Years	8–9 Years	9–10 Years	10–11 Years
6-min Run (m)	Total	921 ± 122	970 ± 126	987 ± 133	994 ± 144	1,005 ± 150
	Boys	933 ± 127	1,006 ± 127	1,021 ± 136	1,019 ± 154	1,026 ± 155
	Girls	906 ± 115	936 ± 116	951 ± 120	965 ± 123	982 ± 142
Ball push (m)	Total	2.7 ± 0.5	3.2 ± 0.7	3.5 ± 0.7	4.0 ± 0.8	4.4 ± 0.8
	Boys	2.8 ± 0.6	3.4 ± 0.6	3.8 ± 0.6	4.2 ± 0.8	4.6 ± 0.8
	Girls	2.5 ± 0.4	3.0 ± 0.5	3.3 ± 0.6	3.7 ± 0.7	4.1 ± 0.7
CMJ (cm)	Total	17.4 ± 3.2	19.2 ± 3.4	20.0 ± 3.8	20.7 ± 4.2	21.7 ± 4.6
	Boys	17.4 ± 3.3	19.7 ± 3.5	20.5 ± 3.9	21.2 ± 4.3	22.1 ± 4.6
	Girls	17.4 ± 3.2	18.8 ± 3.3	19.5 ± 3.6	20.1 ± 4.0	21.2 ± 4.6
10 m Sprint (s)	Total	2.4 ± 0.2	2.3 ± 0.2	2.3 ± 0.2	2.2 ± 0.2	2.2 ± 0.2
	Boys	2.4 ± 0.2	2.3 ± 0.2	2.2 ± 0.2	2.2 ± 0.2	2.2 ± 0.2
	Girls	2.4 ± 0.2	2.3 ± 0.2	2.3 ± 0.2	2.3 ± 0.2	2.2 ± 0.2
Tapping (# in 6 s)	Total	39.1 ± 7.2	43.1 ± 6.8	45.3 ± 7.3	47.5 ± 7.8	49.5 ± 8.6
	Boys	40.4 ± 7.0	45.1 ± 6.5	47.0 ± 6.9	49.2 ± 7.4	50.8 ± 8.7
	Girls	37.5 ± 7.1	41.1 ± 6.6	43.4 ± 7.2	45.5 ± 7.9	48.0 ± 8.4
Obstacle run (s)	Total	22.7 ± 3.8	20.5 ± 3.3	19.9 ± 3.9	19.3 ± 3.9	18.8 ± 4.2
	Boys	22.7 ± 4.1	19.9 ± 3.3	19.4 ± 3.6	18.9 ± 4.0	18.3 ± 3.8
	Girls	22.8 ± 3.5	21.0 ± 3.2	20.3 ± 3.5	19.8 ± 3.7	19.4 ± 4.6
Stand and reach (cm)	Total	2.4 ± 6.0	2.3 ± 6.2	1.7 ± 6.6	0.6 ± 7.2	0.3 ± 7.2
	Boys	1.4 ± 5.4	0.8 ± 5.9	0.1 ± 6.4	−1.0 ± 7.0	−1.5 ± 7.3
	Girls	3.6 ± 6.4	3.7 ± 6.2	3.4 ± 6.5	2.5 ± 7.0	2.4 ± 6.5
Throw and catch (# in 30 s)	Total	5.6 ± 5.6	11.7 ± 6.9	15.7 ± 6.9	19.9 ± 6.8	22.9 ± 6.9
	Boys	7.0 ± 6.0	14.2 ± 6.7	17.8 ± 6.7	21.3 ± 6.6	24.1 ± 7.1
	Girls	3.9 ± 4.6	9.3 ± 6.2	13.6 ± 6.5	18.1 ± 6.6	21.7 ± 6.3

Values are mean ± SD.
CMJ, counter movement jump.

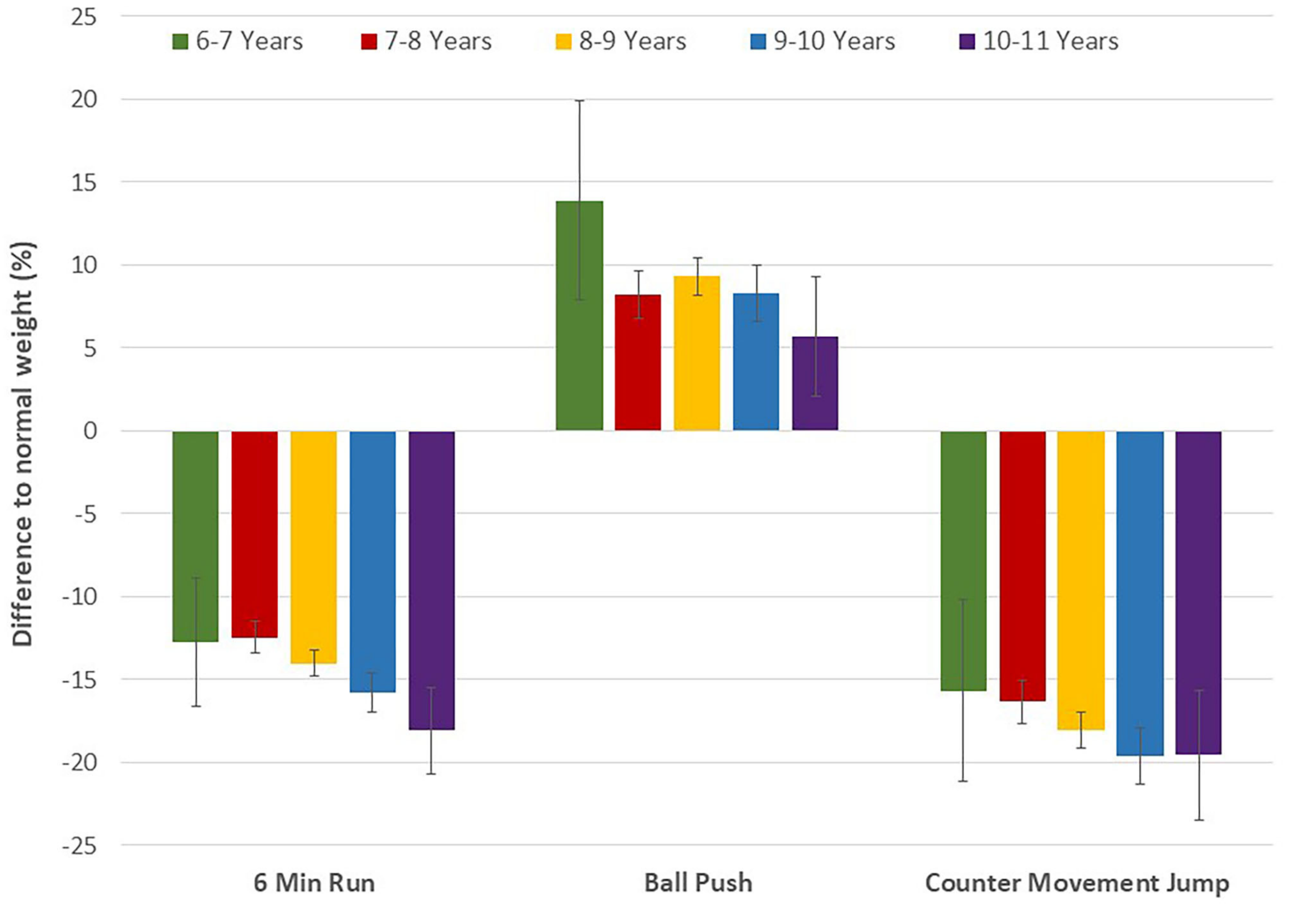

FIGURE 2 | Differences in endurance, strength, and power between normal weight and overweight/obese children by age group (from ages 6–7 to 10–11 left to right). Values are means with 95% CI.

0.01) (**Figures 2**, **3**). At the throw and catch test overweight/obese children performed better than their peers at the younger ages, while normal weight children displayed better results in the older age group. Except for the stand-and-reach test overweight/obese participants showed smaller performance differences across age groups compared to their normal weight peers (**Table 3**), which indicates a smaller improvement in physical fitness and motor competence in children with excess body weight. In fact, 6-min run performance did not change across age groups in overweight/obese, while there was a significant improvement with increasing age in normal weight children. These results remained essentially the same after adjusting for sex.

DISCUSSION

The intention of the project "wie fit bist du?" was to provide objective information on the fitness level and motor competence of elementary school children in Upper Austria. Such information can provide viable information for the implementation of various movement experiences that improve physical fitness and motor competence, particularly during PE. As expected there was an improvement in physical fitness and motor competence with increasing age, except for flexibility. Further, higher fitness and motor competence levels were observed in boys compared to girls, except for flexibility. There were also considerable differences in performance between normal weight and overweight/obese children. Normal weight children performed better in tasks that required moving their own body weight, while overweight/obese children displayed higher absolute upper body strength (i.e., medicine ball push). These results are consistent with those reported in previous studies (Ortega et al., 2013; Cattuzzo et al., 2016; Fiori et al., 2020). It should also be pointed out that improvements in fitness and motor competence with increasing age were less pronounced in children with excess body weight. Of particular concern is the lack of improvement in cardiorespiratory fitness in overweight/obese children throughout the elementary school years, as cardiorespiratory fitness is an important indicator for future health (Ortega et al., 2008; Raghuveer et al., 2020). Accordingly, these children may require additional support in order to ensure optimal motor development.

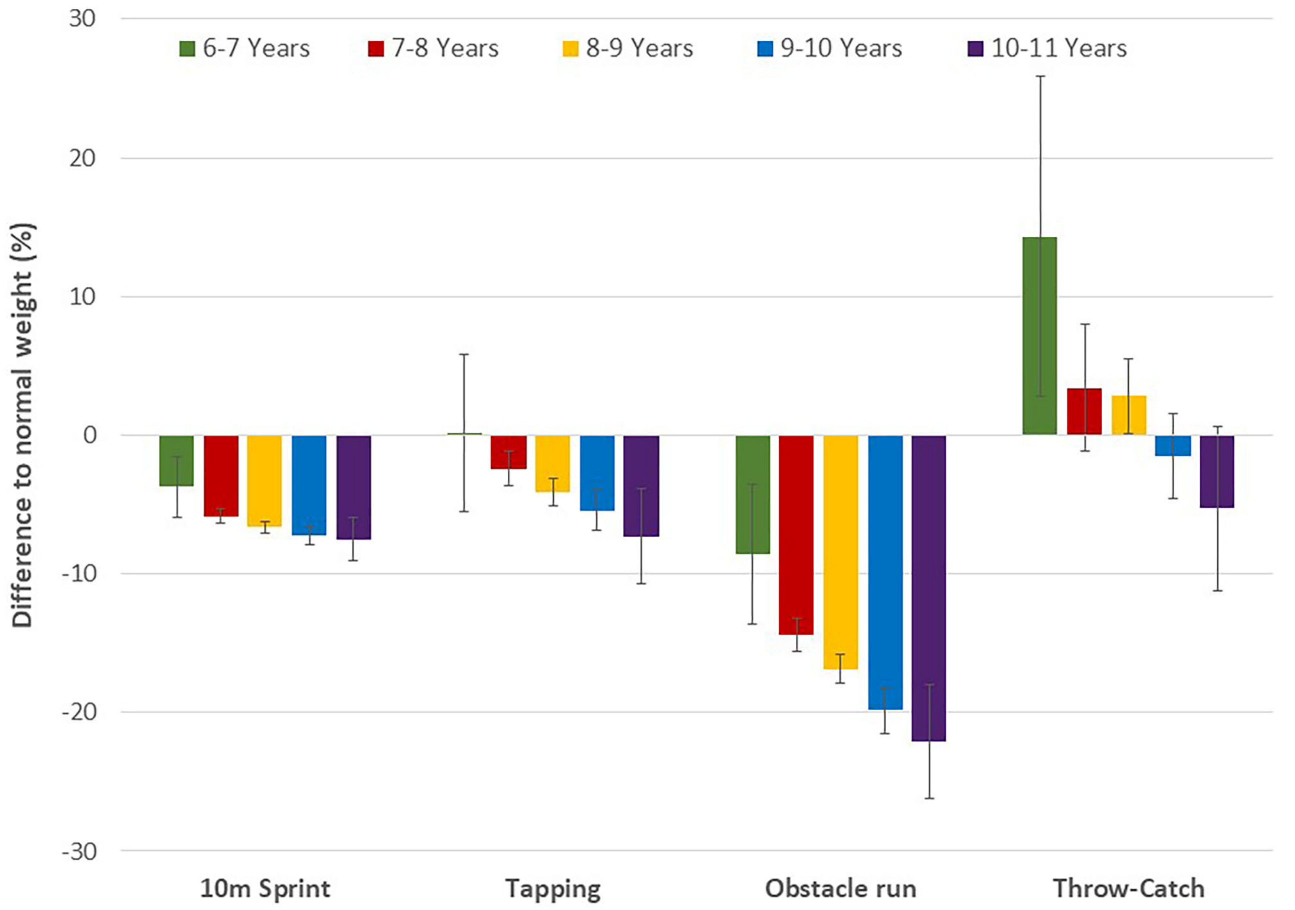

FIGURE 3 | Differences in speed, agility, and object control between normal weight and overweight/obese children by age group (from ages 6–7 to 10–11 left to right). Values are means with 95% CI.

The results of this study also support previous reports that many children do not achieve their expected motor competence (Mitchell et al., 2013; Belton et al., 2014), even though it is generally assumed that children achieve mastery of basic movement skills during the elementary school years (Gallahue et al., 2012). Given the importance of physical fitness and motor competence in the promotion of an active and healthy lifestyle (Ortega et al., 2008; Mintjens et al., 2018; Britton et al., 2020), schools and particularly PE should be considered a viable setting for the development of motor competence and physical fitness as most children can be reached independent of their socio-economic background. Even though the benefits of PA on various health-related outcomes have been well-documented (U.S. Department of Health Human Services, 2018), simply ensuring high movement time is not sufficient to promote motor competence and physical fitness; rather deliberate practice with quality movement experiences and feedback is required (Robinson and Goodway, 2009; Barnett et al., 2016; Payne and Isaacs, 2017; Schmutz et al., 2020). Adequate information on current abilities, therefore, is necessary in order to provide movement experiences that enhance motor competence and physical fitness. Accordingly, available research has shown that a targeted approach during PE, which ensures sufficient intensity, improves cardiorespiratory fitness in children even in the absence of additional time dedicated toward PE (García-Hermoso et al., 2020; Peralta et al., 2020). Further, PE lessons with fitness infusion have been shown to increase active learning time in students and, therefore, potentially increase total PA (Lonsdale et al., 2013). Given the higher capacity for PA in individuals with higher cardiorespiratory fitness, children may also be more likely to engage in active behaviors during their leisure time (Raghuveer et al., 2020). Accordingly, health-related fitness has been shown to be the strongest predictor of future PA during the transition from primary to secondary school level and higher PA levels due to increased physical fitness can also have a positive effect on motor development (Britton et al., 2020).

Children with excess body weight are particularly at risk for poor motor competence and low physical fitness. This may also be attributed to the fact that most fitness tests rely on weight-bearing activities, which puts overweight/obese children at a disadvantage and results of the present study indicate similar abilities in non-weight bearing activities. In

TABLE 3 | Physical fitness and motor competence in normal weight and overweight/obese children by age group.

		6–7 Years	7–8 Years	8–9 Years	9–10 Years	10–11 Years
6-min Run (m)	NW	937 ± 107	985 ± 120	1,007 ± 123	1,024 ± 132	1,039 ± 129
	OW/OB	820 ± 163	864 ± 122	869 ± 126	868 ± 122	858 ± 145
Ball push (m)	NW	2.6 ± 0.5	3.2 ± 0.6	3.5 ± 0.6	3.9 ± 0.8	4.3 ± 0.8
	OW/OB	3.0 ± 0.6	3.4 ± 0.6	3.8 ± 0.7	4.2 ± 0.8	4.6 ± 0.8
CMJ (cm)	NW	17.7 ± 3.1	19.6 ± 3.3	20.5 ± 3.6	21.5 ± 4.0	22.5 ± 4.5
	OW/OB	15.0 ± 2.8	16.5 ± 3.2	16.9 ± 3.2	17.4 ± 3.4	18.2 ± 3.5
10 m Sprint (s)	NW	2.42 ± 0.17	2.30 ± 0.15	2.25 ± 0.15	2.20 ± 0.15	2.16 ± 0.17
	OW/OB	2.51 ± 0.19	2.43 ± 0.18	2.40 ± 0.19	2.36 ± 0.18	2.33 ± 0.19
Tapping (# in 6 s)	NW	39.1 ± 6.9	43.2 ± 6.8	45.6 ± 7.2	48.0 ± 7.8	50.1 ± 8.7
	OW/OB	39.2 ± 9.1	42.2 ± 6.7	43.7 ± 7.3	45.4 ± 7.4	46.5 ± 8.0
Obstacle run (s)	NW	22.4 ± 3.7	20.1 ± 3.0	19.4 ± 3.1	18.6 ± 3.3	18.0 ± 3.4
	OW/OB	24.4 ± 4.0	23.1 ± 4.3	22.7 ± 4.7	22.4 ± 4.6	22.2 ± 5.6
Stand and reach (cm)	NW	2.4 ± 5.9	2.4 ± 6.1	1.8 ± 6.6	0.8 ± 7.1	0.5 ± 7.3
	OW/OB	2.0 ± 6.6	2.0 ± 6.6	1.2 ± 6.8	−0.5 ± 7.5	−0.2 ± 7.0
Throw and catch (# in 30 s)	NW	5.3 ± 5.4	11.6 ± 6.9	15.7 ± 6.9	19.9 ± 6.8	23.2 ± 6.7
	OW/OB	7.5 ± 6.8	12.0 ± 6.6	16.1 ± 6.9	19.6 ± 6.7	22.0 ± 7.4

Values are mean ± SD.
NW, normal weight; OW/OB, overweight/obese; CMJ, counter movement jump.

fact, absolute strength was higher in children with excess body weight compared to their peers. Given the fact that actual and perceived motor competence influence the enjoyment of and motivation toward PA (Loprinzi et al., 2015) strength-related activities may provide a viable option for the promotion of an active lifestyle. Muscular fitness has also been associated with various health benefits (Smith et al., 2014), and is an important correlate of future participation in sports and PA (Behringer et al., 2011; Faigenbaum et al., 2015). In addition to the beneficial association between motor competence, physical fitness and PA, these entities are also associated with academic achievement and perceived cognitive competence (Donnelly et al., 2016). Higher motor competence in children has been associated with improved executive functioning as well as higher-order cognitive skills (van der Fels et al., 2015; Bremer and Cairney, 2016) while low motor competence has been associated with greater attentional difficulties in school tasks and lower self-esteem in general, which negatively affects overall quality of life (Rebondo-Tebar et al., 2021).

Some limitations of this study, however, should be considered when interpreting the results. Given the nature of the project, the main emphasis was on the assessment of fitness and motor competence and no additional data on the school environment as well as socio-economic and cultural background of the participants was obtained. There was also no information on health status and health-related behaviors, such as PA or sports participation, which affect physical fitness and motor competence. In addition, schools volunteered to participate in the project rather than being randomly selected. The utilization of multiple tests that assess various components contributing to physical fitness and motor competence along with a stringent test protocol that was implemented consistently across all assessments and the large sample size, on the other hand, should be considered a strength of the study.

The limited published data on physical fitness in Upper Austrian elementary school children emphasizes the need for a large-scale assessment of physical fitness and motor competence. Even though a state-wide testing program does not enhance physical fitness and motor competence by itself, it does provide objective information on children's current ability level. Such information should subsequently be used for the development of adequate movement experiences that stimulate physical fitness and motor development. The identification of children at risk also facilitates early intervention efforts in order to avoid a vicious cycle of low physical fitness, impaired motor development and various health risks later in life. Repeated assessments may further increase the motivation of children for a more active engagement in PE and potentially increase the likelihood to pursue more active leisure choices in order to improve their results in a subsequent test (Wiersma and Sherman, 2008; Jaakkola et al., 2013). The elementary school years appear to be a particularly critical period for the promotion of an active and healthy lifestyle as various lifestyle habits are established during childhood and early life PA habits have been shown to be associated with PA behavior later in life (Nelson et al., 2006; Telama et al., 2014; Rauner et al., 2015; Rovio et al., 2018; Hayes et al., 2019). Accordingly, fitness monitoring should be incorporated in the elementary school curriculum in order to facilitate the promotion of an active and healthy lifestyle.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Upper Austrian School Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

FH conceptualized the study and managed data collection. CD performed the statistical analysis, prepared the tables and figures, and prepared the manuscript with critical input from KG and FH. All authors have read and approved the submitted version of the manuscript.

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A Multicomponent Intervention Program With Overweight and Obese Adolescents Improves Body Composition and Cardiorespiratory Fitness, but Not Insulin Biomarkers

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Objective: To verify the effect of a multicomponent intervention with overweight/obese adolescents on physical fitness, body composition, and insulin biomarkers.

Methods: A quasi-experimental study with 37 adolescents, aged 10 to 17 years, of both sexes, overweight and obese, allocated in two groups (Intervention—IG Group, $n = 17$; Control—GC Group, $n = 20$). The IGs were submitted to a multicomponent intervention for 6 months (three weekly sessions) consisting of physical exercises (sports, functional circuit, recreational, and water activities) and nutritional and psychological guidance. Participants were assessed before and after intervention on body composition [body mass index (BMI), body fat, waist circumference, and waist-to-hip ratio (WHR)], physical fitness [cardiorespiratory fitness (CRF) and abdominal strength], and biomarkers of insulin (glucose, insulin, evaluation of the homeostasis model of insulin, and resistin resistance). The prevalence of responders in both groups was obtained according to the theoretical model applied in previous studies similar to this one to determine the cutoff points for response to intervention. Poisson regression was used to verify the difference in the prevalence ratio (PR) of the interviewees between the groups.

Results: The responders' prevalence between groups CG and IG showed significant differences for body fat (CG = 30.0%; IG = 70.6%; PR = 1.396; $p < 0.001$), WHR (CG = 30.0%; IG = 76.5%; PR = 1.730; $p < 0.001$), and CRF (CG = 15.0%; IG = 52.5%; PR = 1.580; $p < 0.001$).

Conclusions: A 6-month multicomponent intervention program improved certain body composition parameters and the CRF of overweight and obese adolescents but did not improve insulin biomarkers.

Clinical Trial Registration: Clinical Trials under Protocol ID: 54985316.0.0000.5343.

Keywords: adolescents, obesity, cardiorespiratory fitness, exercise, biomarkers

INTRODUCTION

Nowadays, excess weight contributes to the increase in factors that lead to morbidity and mortality, such as sleep disorders, eating disorders, physical inactivity, and sedentary behaviors (Jääskeläinen et al., 2014). It is during adolescence when behaviors that will last into adult life are developed, contributing inadequately to the development of future metabolic and cardiovascular diseases such as type 2 diabetes mellitus, dyslipidemia, and hypertension. Finding alternatives to prevent this condition is extremely important, for young people with obesity as for those with overweight (Lakshman et al., 2015).

The increase in body fat accelerates the process of chronic inflammation of adipose tissue, causing hormonal dysfunction and leading to a high release of inflammatory cytokines (Galic et al., 2010). Several cytokines expressed in obesity can manipulate the action of the insulin hormone (Wensveen et al., 2015), such as resistin, which inhibits the signaling of its receptors (Yamasaki et al., 2018) and increases lipolysis in cells of fat, causing a greater release of fatty acids (Nakamura et al., 2014). As a consequence, high levels of free fatty acids can cause insulin resistance in tissues, such as liver and muscles (Zhang et al., 2011), a worrying fact considering that insulin resistance is known as the first phase for the development of cardiometabolic diseases (Patel et al., 2013).

There is evidence that physical exercise can reduce the abovementioned inflammation (Brunelli et al., 2015; Lopes et al., 2016), as it is characterized as a viable alternative to reduce body fat and improve cardiorespiratory fitness (CRF), being able to induce physiological, endocrine, and cardiovascular adaptations (Cordero et al., 2014; Medrano et al., 2017). Thus, physical exercise exerts positive changes and has become a protagonist in the processes of preventing excess weight and treating obesity, modifying the metabolic hormones related to chronic inflammation (Ping et al., 2018). Results of physical exercise in health parameters are mainly evidenced on mean values and considering groups, but there is an individual variability in their response that has not yet been explored sufficiently in children and adolescents (Bouchard et al., 2012; Alvarez et al., 2017; Álvarez et al., 2017). This means that although the same stimulus is being applied, some individuals may respond in different ways, obtaining positive or negative responses after an intervention with physical exercise, characterizing them as responders and non-responders (Montero and Lundby, 2017). In view of the need to develop strategies that can match the complexity presented in the diagnosis of excess weight, interventions that include multicomponent actions, encompassing social, environmental, curricular, and educational aspects, deserve to be highlighted and are strongly recommended (Rajmil et al., 2017).

In this sense, multicomponent intervention programs are considered one of the best options for the treatment and reduction of excess weight, as they work with actions from different professional areas, with the purpose of promoting behavioral adaptations related to the levels of physical activity and healthy eating habits (Hampl et al., 2016). Bearing in mind that a multicomponent intervention program with sessions of aerobic and anaerobic exercise and nutritional and psychological guidance can promote improvements in the health parameters of individuals with overweight and obesity, the present study aims to verify the effect of a multicomponent intervention with overweight/obese adolescents in physical fitness, body composition, and insulin biomarkers.

MATERIALS AND METHODS

Study Design

This is a quasi-experimental study, part of the project "Obesity in elementary school students: a multicomponent intervention study—Phase III" developed with overweight/obesity adolescents from public and private schools, of both sexes, aged between 10 and 17 years old. The multicomponent intervention program consisted of physical exercise sessions and psychological and nutritional guidance. The project was developed in 2016, over 6 months. All procedures were approved by the Scientific Council of the Research Unit that leads the project under number CAAE: 54985316.0.0000.5343 and opinion number: 1.498.338, and are registered at Clinical Trials under Protocol ID: 54985316.0.0000.5343. All participants presented the free and informed consent form signed by the parents and guardians, along with the consent form signed by the adolescents' themselves.

Participants and Procedures

Participants for the intervention group (IG) were invited among the overweight/obese adolescents included in the cross-sectional survey "Schoolchildren's health—phase IV" with overweight and obesity. To increase the sample size in the IG, we invited individuals from the community with the same characteristics, through disclosures and communication strategies (radio, newspapers, and social networks); interested ones should contact the project coordinators. Visits and meetings were held in schools in the municipality, with a pedagogical team, parents, and guardians, to present the intervention program. After that, schools indicated which students would take part in the study.

To join the control group (CG), schoolchildren with similar characteristics were invited, such as being overweight or obese and belonging to schools in the municipality. Participants were selected by convenience criteria, according to the available data from the research. There was no intervention in the lifestyle of this group.

The sample size calculation was performed in G * Power program (Faul et al., 2007). Based on the estimates by Hulley (2013), it was considered a test power of 0.8, an effect of 0.30, and a significance level of 95%, requiring at least 11 subjects for the CG and 11 subjects for the IG. **Figure 1** shows the selection of control and intervention groups at baseline, considering the inclusion and exclusion criteria.

Multicomponent Intervention Program

The IG took part in a multicomponent program with activities distributed in 2-h sessions, three times a week (Mondays, Wednesdays, and Fridays) in the afternoon, after the school schedule. The intervention was carried out over 6 months and included the participation of a multicomponent team with

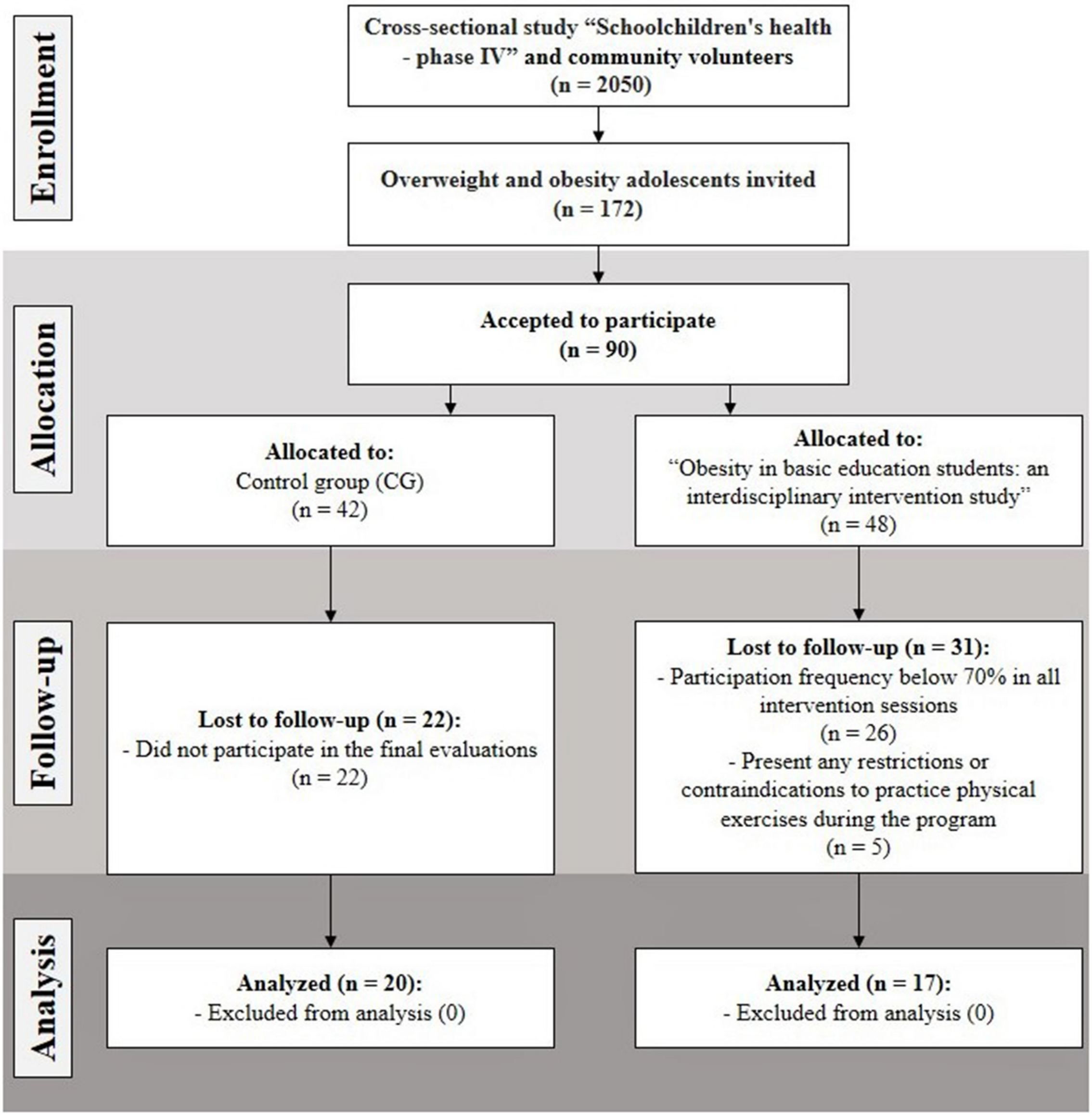

FIGURE 1 | Sample flowchart.

professionals of Physical Education, Pharmacy, Physiotherapy, Nutrition, Psychology, Nursing, and Medicine, among others. Physical exercise sessions and psychological and nutritional guidelines were applied.

Physical Exercise Intervention

The following physical exercise plans were developed and applied: Monday sessions consisted of a warm-up, stretching, walking, and sports activities (futsal, handball, basketball, and jiu-jitsu). On Wednesdays, sessions consisted of water activities such as water aerobics, recreational activities, and swimming for beginners. On Fridays, aerobic workouts, a circuit of functional and resistance workouts, as well as breathing exercises were proposed. During the exercise, heart rate (HR) was controlled using HR monitors (Polar Cardiac Monitor—FT1), and training intensity was defined to induce HR between 50 and 70% of maximum HR, considering the Karvonen equation (maximum HR = 220 – age). More details and information on physical activity and sports sessions can be accessed in the **Supplementary Document**.

Nutritional Education Intervention

The nutritional sessions were held once a week, more precisely on Wednesdays, consisting of food re-education with activities that aimed to know foods; reduce fats, sugar, and sodium consumption; choose the healthiest foods; and identify the daily portions; among others. Conversations, games, videos, teaching materials, and practical classes were held with healthy recipes for adolescents.

Psychological Intervention

Psychological intervention sessions were held once a week, on Mondays, with collective guidance and cognitive training, using techniques focused on the thoughts and feelings aroused by obesity. Relaxation methods were also developed to restructure these thoughts (Lüdtke et al., 2018).

MEASUREMENTS

Maturational Stages

As an indicator of sexual maturation, Tanner's adapted staging method (Tanner, 1962) was applied and a self-assessment test was performed individually, using images that represent the stage of development of pubic hair. Pubic hair is evaluated for its characteristics, quantity, and distribution, in both sexes. The stages of development are classified from 1 to 5, with stage 1 being the infantile phase (pre-pubertal) and stage 5 being the adult phase (post-pubertal). Thus, stages 2, 3, and 4 characterize the pubertal period.

Anthropometric Measures and Body Composition

To verify weight and height, a calibrated anthropometric scale was used, composed of a coupled stadiometer. Body mass index (BMI) was calculated through the equation BMI = weight/height² (kg/m²), to later classify the results through the percentile curves of WHO (1988), which considers overweight individuals with $p \geq 85$ and $p < 97$ and with obesity $p \geq 97$. A measuring tape with a resolution of 1 mm not extensible was used to measure waist circumference (WC) and hip circumference (HC). Then, waist-to-hip ratio (WHR) was calculated following the equation: waist (cm)/hip (cm). A skinfold caliper (Lange, Beta Technology Inc., Houston, USA) was used to assess triceps and subscapular skinfolds and calculate the body fatness following the equation proposed by Slaughter et al. (2016).

Aerobic and Muscular Fitness

The assessments of aerobic and muscular fitness were performed according to the protocols and cutoff points defined in the Project Sport Brazil manual (Gaya and Gaya, 2016), including the CRF test and abdominal strength (sit up). The CRF test consists of a 6-min running/walking test, in which participants must complete the largest number of laps, running or walking, on an official athletics track, marked with signage indicated in meters. The CRF was evaluated by the number of laps performed and the distance covered until the final test time for those who did not complete a lap. A complete lap on the track consists of 400 m covered, so it was calculated for the test classification: the number of laps covered × 400 m + the remaining distance covered in meters if the subject did not complete the lap in the last minute of the race. The abdominal strength test was performed with the subjects lying on a mat, in supine position, with knees flexed, arms crossed over the chest, and ankles fixed on the floor by the evaluator. The movement consisted of flexing the trunk until it touched thighs with elbows, returning to the initial position, accounting for the largest number of repetitions of the complete movement in 1 min. From this, the cutoff points stratified by sex and age were used, established in two categories for both tests: (1) health risk zone when below expectations and (2) healthy zone when equal or above expectations.

Biochemical Assays

A trained professional extracted the blood for biochemical analyses at the Laboratory of Exercise Biochemistry, at the University of Santa Cruz. Ten milliliters of blood was collected in the brachial vein, of which 5 ml was used in the vacutainer tube without anticoagulant (for analysis of biochemical, inflammatory, and metabolic indicators) and 5 ml of whole blood for EDTA vacutainer tube (for blood count measurement). Participants were instructed to remain fasting for 12 h. Insulin was measured through the serum (Architect i2000SR, Abbott Laboratories, Chicago, USA). The homeostasis model assessment of insulin resistance (HOMA-IR) was calculated using the formula HOMA = fasting glucose (mmol/L) × insulin (μU/L)/22.5 (Huang et al., 2002); the results were classified according to the cutoff established by Rocco et al. (2011) considering >1.65 for girls and >1.95 for boys. The measurement of serum resistin levels was performed using a serum sample (Luminex® Platform, Life Technologies, Inc., São Paulo, BRA) and an outsourced Laboratory performed it.

Statistical Analysis

Shapiro–Wilk tests were conducted to test the normality and Levene's test was used for homogeneity of variance. Statistical analyses (Student's *t*-test and chi-square) were performed to rule out possible differences from the total sample. For this, the two groups were matched for sex, age, and anthropometric variables (WC, BMI, and body fat). The *t*-test for independent samples and the chi-square test was used to compare groups' characteristics. The effect size between pre- and post-intervention was also calculated using the means and standard deviation of the groups through Cohen's *d*, with results classified as >0.2, small effect; >0.5, moderate effect; >0.8, large effect; and >1.2, very large effect (Cohen, 1992).

The prevalence of responders in the outcome variables in both groups was obtained according to the theoretical model applied in previous studies with results of anthropometric, physical, and biochemical variables, considering the Δ% effect. The Δ% values obtained in previous interventions were considered acceptable, apparently with the same procedures and variables to determine the parameters and cutoff points for intervention responders (*R*). For this study, it was considered the follow cutoff point to determine responders and non-responders in each one outcome: BMI (change in cutoff points $R > -3.29\%$) and WC (change in cutoff points $R > -3.97\%$) were based on Ranucci et al. (2017), WHR (change in cutoff points $R > -3.57\%$) was based on Nourse et al. (2015), and body fatness (change in cutoff points $R > -10.42\%$) was based on Nardo Junior et al. (2016). For abdominal strength (change in cutoff points $R > 12.2\%$), it was based on Silva et al. (2013) while Oliveira et al. (2017) considered a reference for CRF (change in cutoff points $R > 10\%$). For glucose (change in cutoff points $R > -5.88\%$), insulin (change in cutoff points $R > -34.88\%$) and HOMA-IR (change in cutoff points $R > -9.95\%$) were based on Garanty-Bogacka et al. (2011), and resistin (change in cutoff points $R > -16\%$) was based on McFarlin et al. (2013). Poisson regression was used to verify the difference in the prevalence of responders between IG and CG. All analyses were performed on IBM SPSS 23.0 (SPSS, Inc., Chicago, Illinois, USA). The level of statistical significance was considered as $p < 0.05$.

RESULTS

Participants' characteristics are shown in **Table 1**. The sample consisted of 43.2% boys and 56.8% girls. There was a significant difference in WHR ($p = 0.02$) and in the sexual maturation stage ($p = 0.05$) for adolescents at baseline.

Table 2 shows the effect of time, group, and interaction on the studied variables. Significant interaction (time × group) was found in body fat ($p = 0.004$), WHR ($p = 0.003$), CRF ($p = 0.029$), and resistin ($p = 0.008$). When analyzing the effect sizes of the intervention using Cohen's d, it is observed that the changes in the IG had a very large effect size on WHR ($d = 1.33$), a large effect size on body fat ($d = 1.01$) and WC ($d = -0.86$), and a moderate effect size on CRF ($d = 0.65$). On the other hand, resistin showed a large effect size ($d = 1.09$) and HC presented a moderate effect size ($d = -0.50$) for the changes observed in the CG.

Figures 2–4 show the prevalence of individuals who responded positively to the multicomponent intervention process according to the pre-established cutoff points for each variable, presented in the method of the present study. The CG graphs are shown on the left and the IG graphs are shown on the right; both groups present those evaluated in equal positions for all graphs. Regarding the prevalence of respondents between the control and intervention groups, significant differences were found in body fat (CG = 30%; IG = 70.6%; PR = 1.396; $p < 0.001$), WHR (CG = 30%; IG = 76.5%; PR = 1.730 $p < 0.001$), and CRF (CG = 15%; IG = 52.5%; PR = 1.580; $p \leq 0.001$); the other variables did not show differences in the prevalence of responders (**Table 3**).

TABLE 1 | Participants' descriptive characteristics by group.

	Baseline			Post-intervention		
	CG (*n* = 20)	**IG (*n* = 17)**	***p***	**CG (*n* = 20)**	**IG (*n* = 17)**	***P***
Age (years)	13.15 (1.66)	12.94 (1.14)	0.67	13.55 (1.73)	13.29 (1.21)	0.61
Weight (kg)	67.72 (15.25)	72.49 (14.47)	0.34	68.05 (15.99)	71.19 (14.45)	0.54
Height (m)	1.56 (0.09)	1.60 (0.10)	0.29	1.59 (0.09)	1.63 (0.09)	0.26
BMI (kg/m^2)	27.44 (4.16)	28.26 (4.28)	0.56	26.63 (4.90)	26.75 (4.26)	0.94
Body fat (%)	29.22 (6.00)	32.26 (6.23)	0.14	29.32 (7.62)	27.25 (7.92)	0.43
WC (cm)	81.12 (8.52)	87.30 (10.58)	0.06	79.77 (10.29)	79.74 (8.30)	0.99
HC (cm)	100.67 (10.16)	100.93 (7.04)	0.93	97.76 (11.50)	101.87 (10.18)	0.26
WHR (cm)	0.80 (0.07)	0.86 (0.07)	0.02	0.82 (0.09)	0.78 (0.04)	0.11
CRF (m)	809.25 (147.06)	810.00 (140.85)	0.99	797.35 (172.26)	889.29 (197.59)	0.14
Abdominal strength (rep)	21.10 (6.75)	19.29 (12.88)	0.53	22.10 (7.75)	22.47 (8.39)	0.89
Glucose (mmol/L)	4.98 (0.33)	4.90 (0.32)	0.44	4.93 (0.35)	4.83 (0.41)	0.42
Insulin (μU/L)	6.63 (3.19)	7.56 (3.60)	0.41	5.83 (3.84)	8.05 (6.43)	0.20
HOMA-IR	1.47 (0.71)	1.4 (0.76)	0.48	1.29 (0.87)	1.71 (1.31)	0.25
Resistin (ng/ml)	32.79 (14.05)	28.03 (9.89)	0.25	22.08 (8.58)	27.15 (14.97)	0.21
	***n* (%)**					
Maturational stages*						
Not matured	7 (35.0)	1 (5.9)	0.05	3 (15.0)	1 (5.9)	0.30
Continuing maturation	9 (45.0)	14 (82.4)		14 (70.0)	10 (58.8)	
Matured	4 (20.0)	2 (11.7)		3 (15.0)	6 (35.3)	
HOMA-IR*						
Normal	13 (65.0)	10 (58.8)	0.48	15 (75.0)	10 (58.8)	0.24
Not normal	7 (35.0)	7 (41.2)		5 (25.0)	7 (41.2)	

*Data expressed as mean and standard deviation; t-test for independent samples; significant differences for p < 0.05; CG: control group; IG, intervention group; BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; CRF, cardiorespiratory fitness; HOMA-IR, homeostasis model assessment of insulin resistance. *Data expressed as frequencies and percentages; chi-square test; significant differences for p < 0.05.*

DISCUSSION

The present study evaluated the effects of a 6-month multicomponent intervention program based on aerobic and resistance physical exercises (sports, functional circuit, recreational, and water activities), with nutritional recommendations and psychological support on body composition, aerobic, and muscular physical fitness and insulin biomarkers in overweight and obese adolescents. There was a significant effect on the prevalence of responders for body fat (70.6%), WHR (76.5%), and CRF (52.5%) of the adolescents participating in the intervention concerning CG.

The search for evidence on the effects of physical exercise on overweight and obesity in children and adolescents is broad, given that the reduction in body measures is related to the cardiometabolic risks (Rajjo et al., 2016). An intervention study of 28 weeks of high-intensity interval training (HIIT) during physical education classes with overweight and obese adolescents conducted by Delgado-Floody et al. (2018) showed reduction in BMI, WC, WHR, and body fat after the intervention. In the present study, there was a significant prevalence of responders for body fat (70.6%) and WHR (76.5%) in the IG who performed

TABLE 2 | Effect of intervention on time, group, and interaction on indicators of body composition, aerobic and muscular physical fitness, insulin resistance, and serum resistin levels.

				Mixed ANOVA*								
				Time			Group			Time × Group		
		Δ%	*d*	*F*	*p*	Eta	*F*	*p*	Eta	*F*	*p*	Eta
BMI (kg/m^2)	CG	−3.10	−0.60	4.543	0.041	0.124	0.038	0.847	0.001	0.029	0.865	0.001
	IG	−4.86	−0.48									
Body fat (%)	CG	−0.16	0.02	6.825	0.014	0.176	0.089	0.767	0.003	9.823	0.004	0.235
	IG	−16.09	−1.01**									
WC (cm)	CG	−1.53	−0.18	2.531	0.121	0.073	0.613	0.439	0.019	3.497	0.071	0.099
	IG	−8.08	−0.86**									
HC (cm)	CG	−2.88	−0.50*	0.830	0.369	0.025	0.199	0.659	0.006	3.000	0.093	0.086
	IG	1.03	0.11									
WHR (cm)	CG	1.98	0.11	1.175	0.286	0.035	0.382	0.541	0.012	10.362	0.003	0.245
	IG	−8.90	1.33***									
CRF (m)	CG	−0.95	−0.09	1.939	0.173	0.057	1.754	0.195	0.052	5.230	0.029	0.140
	IG	9.74	0.65*									
Abdominal strength (rep)	CG	5.19	0.13	0.341	0.563	0.011	0.032	0.859	0.001	0.078	0.781	0.002
	IG	50.36	0.33									
Glucose (mmol/L)	CG	−0.84	−0.16	5.522	0.025	0.147	1.356	0.253	0.041	0.196	0.661	0.006
	IG	−1.14	−0.16									
Insulin (µU/L)	CG	−7.68	−0.24	0.655	0.424	0.020	0.633	0.549	0.011	0.134	0.716	0.004
	IG	3.99	0.10									
HOMA-IR	CG	−8.04	−0.23	0.227	0.637	0.007	0.194	0.662	0.006	0.001	0.972	0.000
	IG	3.80	0.11									
Resistin (ng/ml)	CG	−29.40	1.15**	0.244	0.625	0.008	0.145	0.706	0.005	7.982	0.008	0.198
	IG	−5.15	−0.10									

*BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-height ratio; CRF, cardiorespiratory fitness; HOMA-IR, homoeostasis model assessment of insulin resistance. Δ%: percentage delta; Cohen's d; * moderate d effect size (d > 0.5); **large d effect size (d > 0.8); ***very large d effect size (d > 1.2); F: Mixed ANOVA; p: significance level <0.05; Eta, eta squared effect; CG, control group; IG, intervention group; adjusted for sex, age and sexual maturation.*

exercises considered to be of moderate intensity. Thus, it is expected that after an intervention program with moderate to high physical exercises and with different modalities, it is possible to decrease the parameters of body composition. It should be noted that these are indicators of metabolic risk and that inadequate values directly affect the health of adolescents, which can have long-term consequences (Bridger, 2009; Jankowski et al., 2015).

In our study, the IG also showed a significant prevalence of responders for CRF, in which 52.9% of participants presented an improvement after the intervention. An intervention study carried out with obese adolescents showed significant improvements in aerobic indexes and cardiovascular efficiency within only 12 weeks of exercise interspersed with sports, circuits, and swimming three times a week (Klijn et al., 2007). In the study by Brand et al. (2019), overweight and obese children had no effect on CRF after a multicomponent intervention program with intense exercise sessions twice a week for 12 weeks. Indeed, CRF is considered a predictor of mortality and a physiological, psychosocial, and cognitive indicator in children and adolescents (Lang et al., 2018). Therefore, Sigal et al. (2014) consider that at least three sessions of aerobic or combined physical exercise of moderate to high intensity per week are sufficient to obtain an improvement in CRF of overweight or obese adolescents. Improving aerobic and anaerobic fitness in children and adolescents is indeed encouraging, given the low levels of physical fitness in this population today. The effects of interventions that aim to improve this parameter may be related to the content and structure of the applied exercise sessions. Developing sessions focused on motor skills, strength training, and physical conditioning appropriate to the profile of the participants can be a positive strategy, since pleasurable activities promote feelings of motivation that contribute to a better commitment (Bonney et al., 2019).

The present study had no significant effects on the variables glucose, insulin, and HOMA-IR. The same was observed in the study by Sigal et al. (2014), which demonstrated that there were no effects on changes in lipid and glucose levels after a combined 4-week exercise program. The lack of effect on these markers could be due to values at baseline that were in the normal range and reduces the capacity of improvement; this occurred in our study with the variable HOMA-IR, and most of the participants were classified as normal for that parameter in the baseline. In a recent study that included sports, psychotherapy, and nutritional

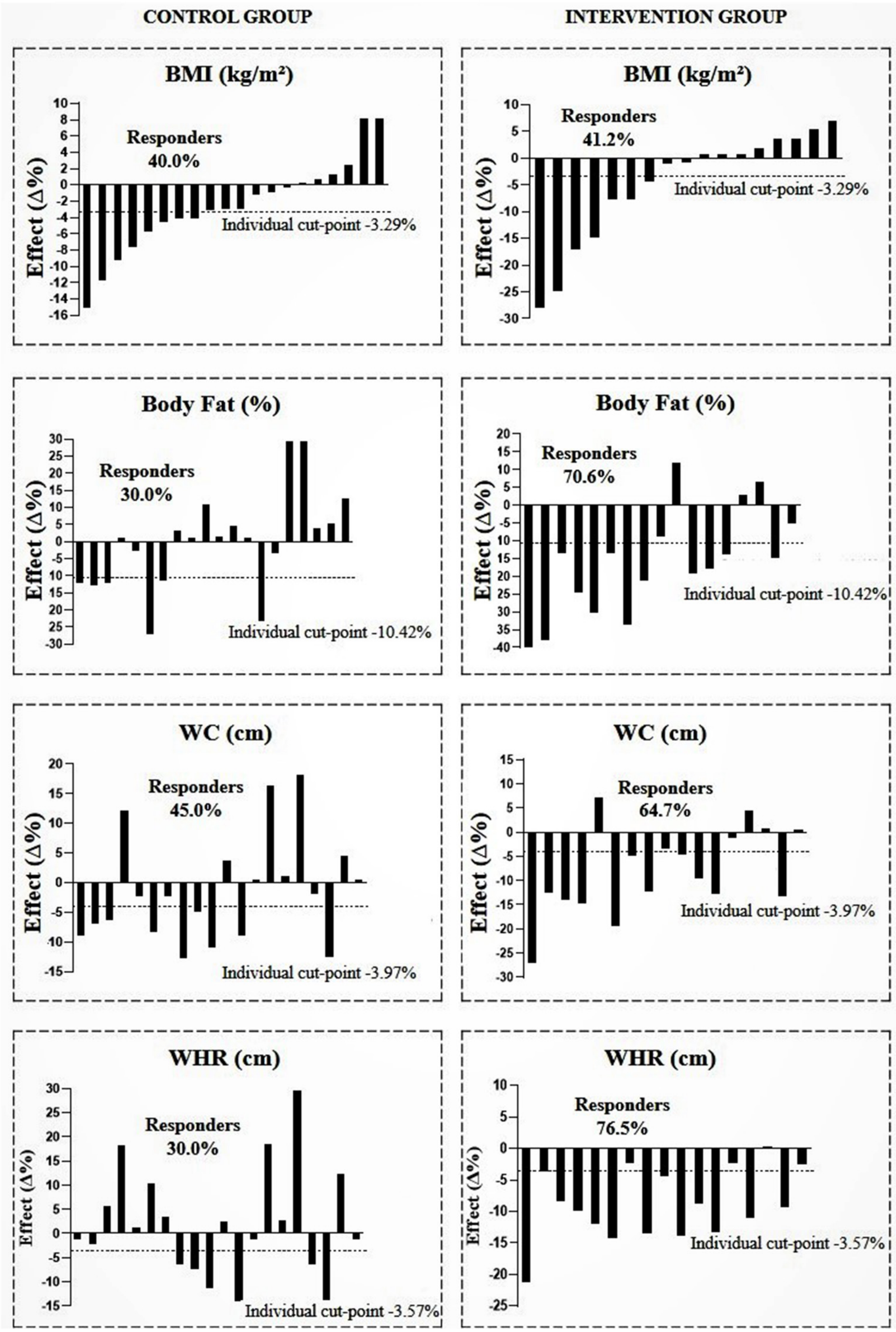

FIGURE 2 | Prevalence of responders in the control and intervention group after multicomponent intervention for body mass index (BMI), body fat, waist circumference (WC), and waist/hip ratio (WHR). CG, $n = 20$; IG, $n = 17$. The analyses were adjusted for sex, age, and sexual maturation.

counseling, HOMA-IR levels in obese children and adolescents decreased, demonstrating that this was a sensitive parameter for a short-term intervention (5 months) (Mayerhofer et al., 2020). According to Zhai et al. (2015) and Wagner et al. (2013), insulin resistance may be influenced by the stage of maturation, and excess weight is already known as a modulator of sexual maturation, causing the onset of puberty at an early stage. HOMA-IR levels vary physiologically according to age and are

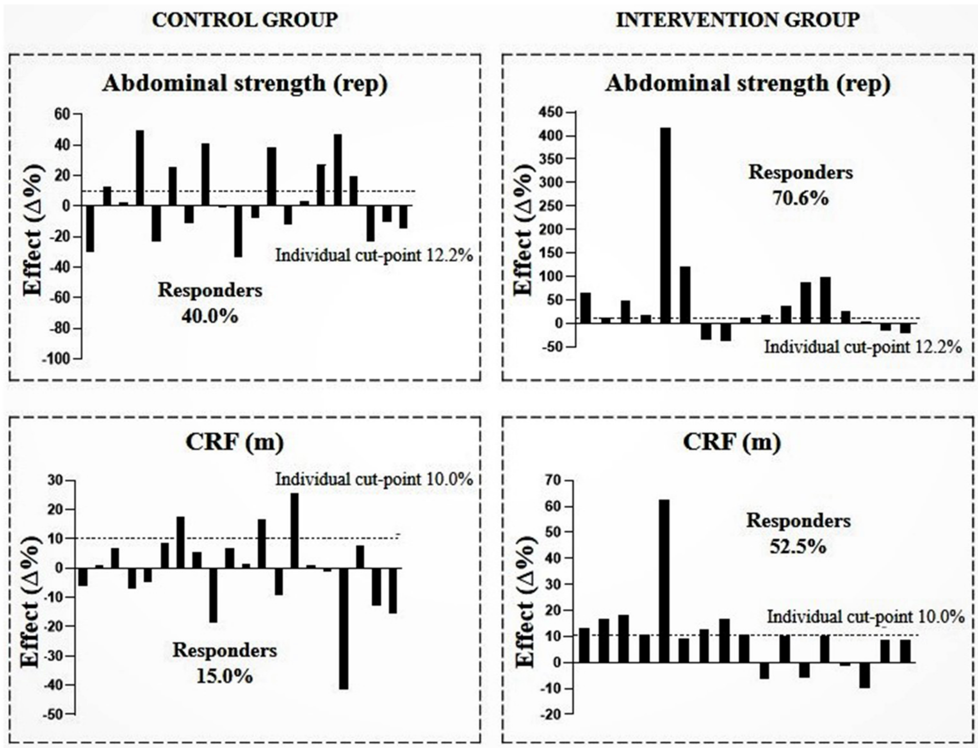

FIGURE 3 | Prevalence of responders in the intervention and control group after multicomponent intervention for abdominal strength and cardiorespiratory fitness (CRF). CG, $n = 20$; IG, $n = 17$. The analyses were adjusted for sex, age, and sexual maturation.

higher when there is a diagnosis of obesity; the peak can be reached between 13 and 15 years of age and after, and return to normal levels at the end of the maturation process (Shashaj et al., 2016). Therefore, the cutoff values for HOMA-IR may be higher in individuals during the puberty process than in individuals who have not yet entered the maturation process (Kurtoglu et al., 2010).

In addition to having no effect, when observing the prevalence of responders in the variables insulin and HOMA-IR, response in the CG was greater compared to the GI in the present study. Mayerhofer et al. (2020) studied the correlation of BMI and body fat with changes in HOMA-IR and did not find any association of these parameters, suggesting that the decrease in HOMA-IR levels during the physical exercise program and nutritional guidance is independent of changes in corporal composition. Therefore, there is a possibility that the short-term effects of exercise may increase the uptake of glucose in muscle tissue, causing a decrease in insulin secretion and lower HOMA-IR levels. However, some studies have found associations between changes in BMI with HOMA-IR after long-term (over 6 months) intervention programs (Kalavainen et al., 2012; Santos et al., 2015). On the other hand, there is evidence that liver fat may be an independent determinant for HOMA-IR in adolescents, and not visceral or total fat (Linder et al., 2014). Therefore, it could be assumed that there is a mechanism different from HOMA-IR levels for overweight and obese adolescents.

Resistin was a marker that, despite not showing significant differences between groups, unexpectedly showed higher prevalence of responders for CG adolescents (75.0%). Gerber et al. (2005) concluded that resistin level in children and adolescents shows a correlation with pubertal stage and age. In thin boys, this correlation is positive, while in girls, this correlation is significant and positive only when obese girls are included in the analysis. These results are confirmed by the correlation of resistin with testosterone in thin and obese boys and with estradiol in obese girls. An increase in resistin levels during pubertal maturation is also supported by a progressive multiple regression model, including age, Tanner stage, estradiol, testosterone, WC, WHR, BMI, weight, and height. Tanner's stage was the only significant independent predictor for resistin, explaining 11% ($p < 0.001$) of its variance. Considering that the correlations between resistin and BMI were of low significance for the obese group and absent in the lean study group, it is suggested that the parameters of pubertal maturation are the strongest variation of the resistin and that only states of morbid obesity are associated with high levels of resistin (Savage et al., 2001). These findings may justify what happened in our study, in which adolescents are at different stages of maturation and within a wide age range, explaining the lack of effect and the unexpected response in insulin biomarkers.

In this sense, Nascimento et al. (2016) did not find changes in resistin after an intervention program in school physical

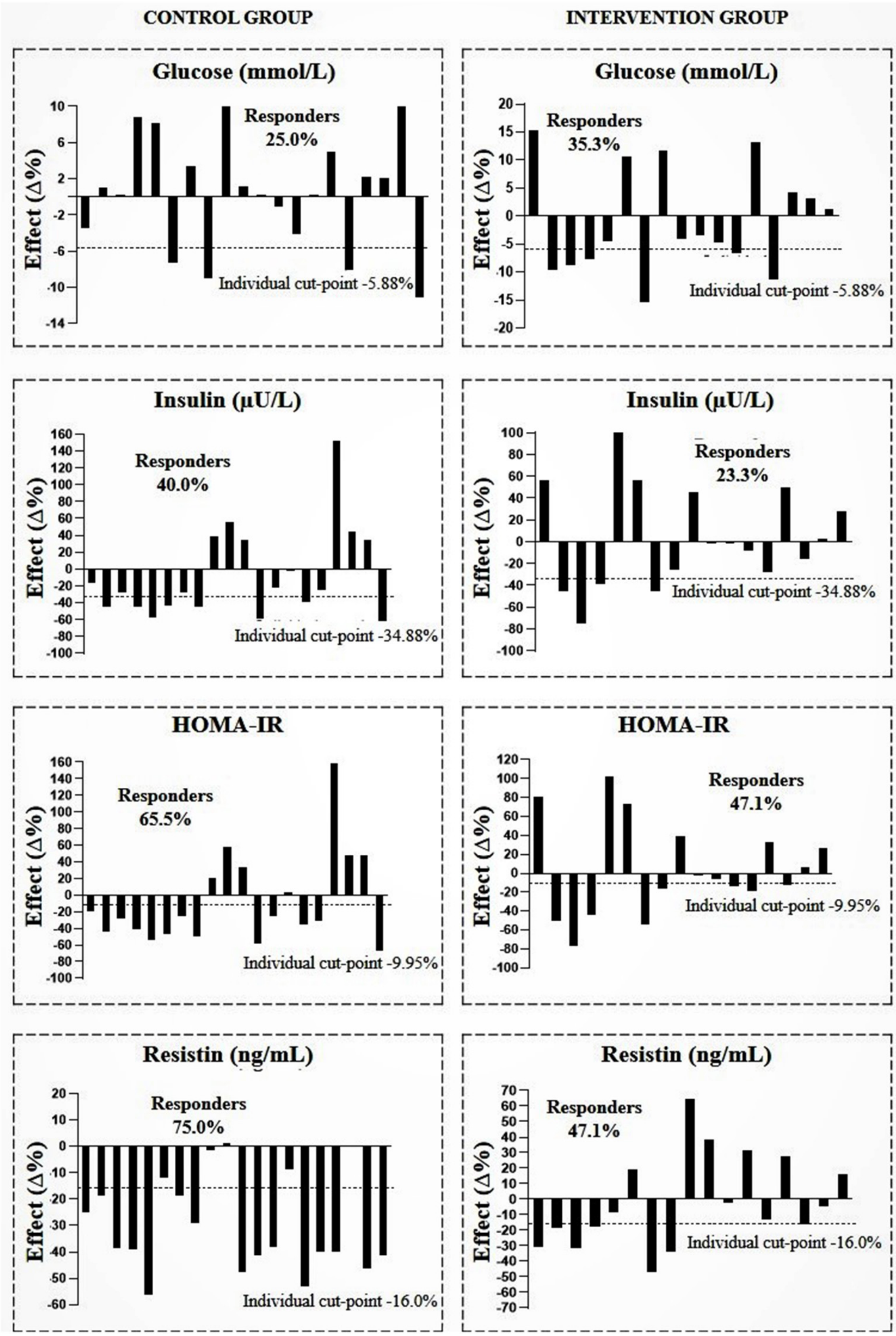

FIGURE 4 | Prevalence of responders in the intervention and control group after multicomponent intervention for glucose, insulin, homeostasis model assessment of insulin resistance (HOMA-IR), and resistin. CG, $n = 20$; IG, $n = 17$. The analyses were adjusted for sex, age, and sexual maturation.

education, but found a positive correlation between resistin, triglycerides, and TNF-alpha at baseline, and that higher concentration was associated with increased other inflammatory markers, including IL-6. Therefore, according to Bokarewa et al. (2005) and Lehrke et al. (2004), it is suggested that resistin is produced in response to other inflammatory stimuli and induces

TABLE 3 | Differences in the prevalence of responders between IG and CG.

	Responders		
	PR	**95% CI**	***P***
CG × IG			
BMI (kg/m^2)	0.911	0.668–1.241	0.554
Body fat (%)	1.396	1.158–1.684	<0.001
WC (cm)	1.173	0.869–1.584	0.296
WHR (cm)	1.730	1.321–2.265	<0.001
CRF (m)	1.580	1.213–2.058	<0.001
Abdominal strength (rep)	1.209	0.892–1.638	0.221
Glucose (mmol/L)	1.189	0.902–1.566	0.219
Insulin (μU/L)	0.773	0.567–1.054	0.103
HOMA-IR	0.787	0.566–1.094	0.154
Resistin (ng/ml)	0.806	0.590–1.103	0.175

BMI, body mass index; WC, waist circumference; WHR, waist-to-height ratio; CRF, cardiorespiratory fitness; HOMA-IR, homeostasis model assessment of insulin resistance. CG, control group; IG, intervention group; Poisson regression; PR, prevalence ratio; p: significance level <0.05; adjusted for sex, age, and sexual maturation.

the synthesis of other pro-inflammatory cytokines. With respect to the relationship between insulin resistance and cytokines, Rubin et al. (2008) sought to find associations between vigorous physical activity and HOMA-IR with some inflammatory markers. Regarding resistin, vigorous physical activity interacted opposite to HOMA-IR, indicating that the increase in resistin induces an increase in HOMA-IR in individuals with high levels of vigorous physical activity. No weight status and general adiposity, as indicated by BMI, puberty, or ethnicity, explained this association. Therefore, it is clear that the evidence on resistin is still inconsistent. Further clinical studies aimed at investigating the expression and manifestation of this protein are needed to determine its mechanism within the inflammatory process of obesity.

The effects of excess weight, more specifically obesity, indicate a higher prevalence of cardiometabolic risk factors. However, studies showed a good prognosis for overweight or slightly obese individuals, calling this the obesity paradox. This paradox may be related to unmeasured confounding factors, such as unintentional weight loss in individuals who do not participate in exercise programs or obesity treatment (Lavie et al., 2013, 2014, 2015). Also, genetic characteristics may be involved in this paradox, meaning that individuals closer to having an adequate body composition may present a less favorable clinical profile concerning blood pressure, lipid, glycemic, and inflammatory parameters. That is, the etiology and genetic disposition may be associated with the unfavorable clinical condition (Lavie et al., 2016).

Our multicomponent intervention program with varied exercises (sports, functional circuit, recreational, and water activities) and nutritional and psychological guidance was effective for the body composition parameters (body fat and WHR) and for the CRF, therefore emphasizing the importance of programs with multicomponent approaches (physical exercise and nutritional and psychological orientation) with efforts aimed at the profile of individuals and with the collaboration of a community body that aims at an integrated service of a multidisciplinary nature.

LIMITATIONS

The present study has some limitations, such as the limited sample size to obtain a medium effect, making it impossible to detect small effects, and not having assessed the levels of physical activity of participants in the control and intervention groups to determine whether the effects presented were directly caused by the exercise program. It was also not possible to control eating behavior, as the program only offered guidance on eating habits. We did not perform correlation analysis to find out how the variables are related. However, the study has several strengths, since most studies to date assess the relationship between adiposity and biochemical and physical fitness markers in an observational way. In addition, the study not only assessed the effect of the intervention program but also considered the response to adolescents' inter-individual variability. It is also relevant because it is one of the few studies that evaluated resistin as a biomarker of insulin in the pediatric population.

CONCLUSION

The 6-month multicomponent intervention program with varied exercises (sports, functional circuit, recreational, and water activities) and nutritional and psychological guidance improved certain parameters of body composition and the CRF of overweight and obese adolescents but did not improve insulin biomarkers. The present results suggest that other indicators, such as age and maturation stage, may play a more important role regarding the effects of the intervention on insulin biomarkers in overweight and obese adolescents, highlighting mainly that resistin is still an inflammatory marker with an inconsistent mechanism in this relationship. Therefore, this intervention model can be considered and adapted for schools and community establishments as a way to improve the indicators of body composition and CRF in overweight and obese adolescents.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by all procedures were approved by the Scientific Council of the Research Unit that leads the project under number CAAE: 54985316.0.0000.5343 and opinion number: 1.498.338 and are registered at Clinical Trials under Protocol ID: 54985316.0.0000.5343. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

LBorb, CP, AG, JB-S, and CB were responsible for the conception and design, data acquisition, data analysis and interpretation, writing of the initial article, and critical review of important intellectual content. LBorf and JD were responsible for the conception and design, data acquisition, and review of all the minutes of the article. All authors read and approved the final article.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2021.621055/full#supplementary-material

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Childhood Sports Participation Is Associated With Health-Related Quality of Life in Young Men: A Retrospective Cross-Sectional Study

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The aim of the study was to examine whether sports participation (SP), engagement in competitive sports (CS), and the type of sport undertaken at the age of 12 are associated with the physical and mental components of health-related quality of life (HRQoL) in young adulthood. The data were collected using questionnaires prior to a compulsory military refresher training course in Finland. The sample consisted of 784 men (mean age 26 years). HRQoL was measured with RAND 36 and childhood SP with a series of questions. Data were analyzed with logistic regression. Higher frequency of SP, participation in district-level CS; performing team, endurance, or extreme sports; and playing yard games in childhood were after adjustments all associated with better HRQoL in early adulthood. The association was mainly found with the mental component, and to a lesser extent with the physical component, of HRQoL. Team (OR 1.43, CI 1.00–2.06) and extreme sports (OR 1.77, CI 1.19–2.63) were associated with better mental HRQoL, while playing yard games (OR 0.62, CI 0.44–0.89) reduced the likelihood for having low physical HRQoL. SP in childhood—in the forms of team or individual sports, but also as informal physical activity, such as playing yard games—is associated with HRQoL in young adulthood.

Keywords: sports participation, health-related quality of life, mental health, physical activity, leisure time, childhood, men, quality of life

INTRODUCTION

The positive impact of physical activity (PA) on physical and mental health as well as on health-related quality of life (HRQoL) has been well-established (Biddle, 2016; Warburton and Bredin, 2017; Wu et al., 2017; Bize et al., 2018; Marker et al., 2018). HRQoL is a multidimensional concept that includes physical, mental, emotional, and social functioning (Ferrans, 2005). On the individual level, HRQoL includes perceptions of physical and mental health status. It encompasses the perceived health attributes such as the sense of comfort or well-being, and the ability to maintain good physical, emotional, and cognitive functions including the ability to take part in social activities (Bize et al., 2018). The concept of HRQoL has gained attention in the past few decades, as it has been found to be a stronger predictor of mortality and morbidity than many other objective measures of health (Dominick et al., 2002; DeSalvo et al., 2006). Finding determinants and predictors of HRQoL may help to prevent diseases and disabilities and to promote general well-being in different populations. HRQoL is known to associate with various socioeconomic factors and variables related to health behavior, such as body mass index (BMI), use of alcohol, smoking, and PA (Wu et al., 2017; Bize et al., 2018; Marker et al., 2018; Ellina et al., 2019).

Participation in sports during leisure time leads to various psychological, social, and health benefits both in adults (Eime et al., 2013b) and in children (Eime et al., 2013a). Furthermore, previous research has provided evidence of a positive association between sports participation and HRQoL in children (Moeijes et al., 2019a,b), adolescents (Snyder et al., 2010), university students (Shaikh et al., 2016), and women (Eime et al., 2010). However, there is a lack of evidence on the association of childhood sports participation and HRQoL in adulthood. Few studies with a longitudinal study design have investigated this relationship, but commonly in children and with a relatively short follow-up periods of between 1 and 2 years (Vella et al., 2014; Moeijes et al., 2019a). Stracciolini et al. (2018) investigated the association between sports participation in college and HRQoL in middle age and older adulthood. They found that participation in collegiate sports was associated with positive health outcomes in later life. However, association was also found with increased anxiety in older age.

Associations between different levels and types of sports participation and HRQoL have not been widely studied. The study by Moeijes et al. (2019b) found that particularly outdoor sports, rather than indoor sports, were significantly associated with better HRQoL in children. The association seemed to be present especially in the physical domain of HRQoL and to a lesser degree in the psychological domain of HRQoL. Similarly, the systematic reviews by Eime et al. (2013a,b) found that sports participation has many different psychological, social, and health benefits both in adult populations as well as in children and adolescents. Particularly, club-based or team-based sports, rather than individual activities, are associated with improved health outcomes (Eime et al., 2013a,b). However, there is insufficient evidence regarding the relationship between sports participation and HRQoL and lack of knowledge on the impact of participating in different sport types in childhood on HRQoL in adulthood.

Evidence on HRQoL outcomes of competitive sports across the life span is scarce. Previous research indicates that HRQoL is commonly higher in athletes than in non-athletes (Houston et al., 2016). In other respects, this topic has been most commonly investigated from the perspective of physical, mental, or psychosocial health rather than directly from the perspective of HRQoL (Backmand et al., 2009; Sorensen et al., 2014; Appelqvist-Schmidlechner et al., 2018). From a longitudinal perspective, some evidence is provided by a study among former Finnish elite athletes (Backmand et al., 2009) and the study of Sorensen et al. (2014), indicating some physical health concerns but better psychosocial health among elite intercollegiate student-athletes compared with non-athletes in a life-span perspective. In our previous study (Appelqvist-Schmidlechner et al., 2018) with the same sample of young men, competitive sports in childhood were associated with better mental health in adulthood. However, to the best of our knowledge, there is no previous research about the impact of participation in competitive sports in childhood on HRQoL in young adulthood.

The aim of the present study was to investigate retrospectively the association between sports participation in childhood and HRQoL in young adulthood among young Finnish men from the perspective of physical and mental aspects of HRQoL. The study aimed to explore this association in terms of (1) frequency of organized sports participation, (2) the role and level of participation in competitive sports, and (3) the type of sport at the age of 12 years. Despite partly contradictory findings of previous studies, we hypothesized that higher frequency and level of sports participation in childhood would be associated with higher HRQoL in adulthood. Furthermore, especially group-based sports were expected to be associated with higher HRQoL.

MATERIALS AND METHODS

The study participants were young adult men (mean ± SD age 26 ± 7 years) who were called up to the military refresher training organized by the Finnish Defence Forces. In Finland, the Defence Forces are based on a universal male conscription; and each year, 70–75% of all young Finnish men (about 20,000 men) perform their military service. After the military service, they can be called up to a military refresher training lasting 4–10 days as reservists.

The study participants were informed about the study in the military refresher training call-up letter. The data were gathered with a self-administered questionnaire at the beginning of seven military refresher training courses that were carried out in 2015 in different counties around Finland. Participation in the study was voluntary, and of 823 course participants, 792 participated in the study. All participants signed a written consent form. The sample of this study consisted of all male participants ($n = 784$). Due to some missing values in the outcome variables, the total study sample was 777.

The study was part of the Finnish Reservist 2015 study that aimed to investigate the physical performance and health of Finnish reservists. The study was approved by the ethical committees of the Central Finland Health Care District and the Headquarters of the Finnish Defence Forces (AM5527). The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Measurements

HRQoL was measured using the Finnish RAND 36-item health survey (Aalto et al., 1995). It contains eight dimensions that can be aggregated into two summary scores: the physical (including physical functioning, physical role functioning, bodily pain, and general health) and mental (including emotional role functioning, vitality, mental health, and social role functioning) component summary scores. The reliability and validity of the scale have been reported to be good (Cronbach's alpha coefficient between 0.80 and 0.94) (Aalto et al., 1995). The responses were given in a six-point scale. First, numeric values were recoded per the scoring key and transformed into a 0–100 scale, with higher scores indicating higher HRQoL. Then, items in the same dimensions were averaged together to create scores for the eight dimensions and main component of the scale. For further analysis, in order to see if relations are different in different parts of the response distribution, the scores were divided into three tertiles (low, moderate, and high levels of HRQoL) for the physical and mental components of RAND 36. The scores within physical component were ≤86.88 for low, 86.89–93.02 for moderate, and ≥93.03 for high and within mental component ≤78.88 for low level, 78.89–89.75 for moderate level, and ≥89.76 for a high level of HRQoL.

Participation in sports in childhood was measured with one single question "How often did you participate in training or other structured sports activity at the age of 12 years?" The responses were 1 = not at all, 2 = once a month, 3 = 2–3 times a month, 4 = 1–2 times a week, 5 = 3–4 times a week, and 6 = 5 times a week or more. For the analysis, responses 2 and 3 were combined, as both responses indicate a similarly low level of participation. Study participants were asked to choose from the list of all the types of sports, which they performed regularly (weekly) at the age of 12 years. The list included the following types of sports (with examples of types of sports in parentheses): team sport (football, ice hockey, basketball, etc.), endurance sport (running, orienteering, swimming, cycling, etc.), strength sport (gym, cross fit, weightlifting, etc.), sports that require technical performance (golf, gymnastics, table tennis, etc.), extreme sport (climbing, diving, surfing, and alpine skiing), combat sport (wrestling, boxing, judo, karate, etc.), and playing yard games.

Participation in competitive sports in childhood was measured with the question "If you participated in competitive sports in childhood, at which level did you compete?" The responses were 1 = I did not participate in competitive sports, 2 = school, 3 = sports club, 4 = district, 5 = national, and 6 = international. For the analysis, responses 5 and 6 were combined.

Self-reported leisure-time PA (LTPA) in adulthood was determined from responses to a single question "Which of the following definitions best describe your leisure-time physical activity habits? (Think of the last 3 months and consider all leisure-time physical activities that lasted at least 20 min per session)" with six response categories: 1 = less than once a week; 2 = no vigorous activities, but light or moderate PA at least once a week; 3 = brisk PA once a week; 4 = vigorous activity twice a week; 5 = vigorous activity three times a week; and 6 = vigorous activity at least four times a week. The question has been validated against fitness (Fogelholm et al., 2006) but not against other instruments measuring PA. For further analysis, groups for inactive (less than once a week), low (light or moderate PA at least once a week), medium (vigorous PA once to three times a week), and high (vigorous activity at least four times a week) activity groups were computed to distinguish four clearly different groups in terms of PA.

The questionnaire also included sociodemographic background (including age, educational level, employment, and marital status) and health behavior (smoking and use of alcohol). Body height and weight were measured, and BMI was calculated and classified into four categories: underweight < 18.50, normal 18.50–24.99, overweight 25.00–29.99, and obesity/severe obesity ≥ 30.

Statistics

The descriptive data of the study sample are presented in **Table 1**. The normality of distribution of RAND 36 was tested by Shapiro–Wilk test, and the data proved non-normally distributed. The mean scores for combined physical and mental component scores of RAND 36 were grouped together by variables describing the sports participation of the study participants at the age 12 (**Table 2**). The statistical significance of the RAND 36 score

TABLE 1 | Characteristics of the study population.

Variable	Mean/frequency (%)
Age (*n* = 777)	26 (SD 7) years
Marital status (*n* = 777)	(%)
Married/cohabiting	55
Single	45
Education (*n* = 776)	
Comprehensive school	6
Vocational school	42
High school degree	30
Upper secondary school or academic degree	23
Employment status (*n* = 755)	
Employment/studying	71
Not in employment or education	29
Leisure-time physical activity (*n* = 777)	
Inactive (less than once a week)	12
Low (light or moderate physical activity at least once a week)	18
Medium (vigorous physical activity 1–3 times a week)	49
High (vigorous activity at least four times a week)	21
BMI (*n* = 754)	
<18.5	2
18.50–24.99	52
25–29.99	34
≥30	12
Smoking (*n* = 760)	
Yes	32
No	68
Use of alcohol (*n* = 777)	
Not using	7
Once a month or less often	17
About twice a month	22
Once or twice a week	35
3–4 times a week	13
5–6 times a week or daily	6

BMI, body mass index.

TABLE 2 | Mean scores of the physical and mental components of HRQoL according to sports participation at the age of 12 years.

Variable	%	Mean score physical component	*p**	Mean score mental component	*p**
Participating in organized sports (*n* = 777)					
No participating	25	87.53		77.61	
1–3 times a month	11	86.82		78.14	
1–2 times a week	29	87.85		80.78	
3–4 times a week	26	88.83		82.81	
At least 5 times a week	10	88.37	ns	84.27	<0.001
Participating in competitive sports (*n* = 776)					
No competitive sports	34	87.73		78.39	
At school level	9	87.86		80.78	
At sports club level	22	87.48		81.19	
At district level	27	88.82		82.31	
At national or international level	9	87.53	ns	81.89	0.013
Participating in team sports (*n* = 777)					
Yes	66	88.58		82.02	
No	34	86.91	0.003	77.63	0.001
Participating in endurance sports (*n* = 777)					
Yes	35	89.08		81.92	
No	65	87.43	0.008	79.73	ns
Participating in strength sports (*n* = 777)					
Yes	5	88.50		83.49	
No	95	87.98	ns	80.37	ns
Participating in sports that requires technical performance (*n* = 777)					
Yes	11	88.05		81.70	
No	89	87.99	ns	80.41	ns
Participating in extreme sports (*n* = 777)					
Yes	20	88.83		84.81	
No	80	87.81	ns	79.48	<0.001
Participating in combat sports (*n* = 777)					
Yes	16	86.63		79.82	
No	84	88.27	ns	80.63	ns
Playing yard games (*n* = 777)					
Yes	69	88.61		81.88	
No	31	86.65	0.006	77.42	0.004

ns, non-significant differences between the groups; HRQoL, health-related quality of life.
**Kruskal–Wallis or Mann–Whitney U-tests.*

differences between the groups was calculated using the non-parametric Kruskal–Wallis and Mann–Whitney tests, as the data were not normally distributed. The association between sports participation and HRQoL, in terms of physical and mental component scores of RAND 36, was then explored with the help of logistic regression analyses. Before regression analysis, Spearman's rank correlation coefficient was used to give an indication of the magnitude of association (collinearity) between explanatory variables. Odds ratios and 95% confidence intervals (CIs) were calculated in the physical and mental components of HRQoL for each group. Unadjusted and fully adjusted models are presented for low compared with moderate and high HRQoL (**Table 3**) and for high compared with moderate and low HRQoL (**Table 4**), as the focus of interest was to detect if the relations are different in the different parts of the response distribution. Age, educational level (primary, secondary, and high school), employment status (employment or education/not in employment or education), marital status (married or cohabitation/single), the present LTPA (inactive/low/medium/high), use of alcohol (not using/once a month or less often/about twice a month/1–2 a week/3–4 a week/5–6 a week or daily), smoking, and BMI (categories 1–4 presented above) were used as covariates in the fully adjusted model. The level of statistical significance was set to $p < 0.05$. Analysis was performed with IBM SPSS Statistic 26 program.

RESULTS

The characteristics of the study population are presented in **Table 1**. The study participants were on average 26 (SD 7) years

TABLE 3 | Odds ratios (OR) and 95% confidence intervals (CIs) separately for low compared with moderate and high scores in the physical and mental component summary of RAND 36 by variables describing sports participation at age 12 years.

	Low compared with moderate and high HRQoL Physical component				Low compared with moderate and high HRQoL Mental component			
	Unadjusted		Fully adjusted[a]		Unadjusted		Fully adjusted[a]	
	OR	CI (95%)	OR	CI (95%)	OR	CI (95%)	OR	CI (95%)
Participation in organized sports								
No participating	Ref.		Ref.		Ref		Ref.	
1–3 times a month	1.27	0.75–2.16	1.69	0.95–2.99	0.82	0.48–1.40	0.92	0.52–1.62
1–2 times a week	0.77	0.51–1.16	0.83	0.53–1.31	0.56	0.37–0.85**	0.60	0.38–0.94*
3–4 times a week	0.75	0.49–1.14	0.95	0.59–1.53	0.50	0.32–0.77**	0.54	0.34–0.89*
At least 5 times a week	0.70	0.39–1.24	0.95	0.50–1.78	0.56	0.31–0.99*	0.65	0.35–1.20
Participation in competitive sports								
No competitive sports	Ref.		Ref.		Ref.		Ref.	
At school level	0.89	0.50–1.57	1.09	0.59–2.00	0.73	0.41–1.30	0.70	0.39–1.28
At sports club level	0.97	0.66–1.45	0.96	0.62–1.51	0.66	0.43–1.01	0.62	0.39–0.98*
At district level	0.72	0.48–1.06	0.85	0.54–1.32	0.63	0.42–0.94*	0.70	0.45–1.09
At national or international level	0.93	0.53–1.63	1.21	0.65–2.26	0.68	0.38–1.22	0.76	0.41–1.43
Participating in team sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	0.66	0.48–0.90**	0.77	0.54–1.09	0.66	0.48–0.91*	0.76	0.54–1.08
Participating in endurance sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	0.71	0.52–0.99*	0.84	0.59–1.20	0.72	0.52–1.00*	0.81	0.57–1.15
Participating in strength sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	0.70	0.33–1.48	0.63	0.28–1.43	0.50	0.21–1.16	0.45	0.18–1.11
Participating in sports that requires technical performance								
No	Ref.		Ref.		Ref.		Ref.	
Yes	0.89	0.55–1.45	0.90	0.52–1.54	0.76	0.46–1.27	0.70	0.40–1.22
Participating in extreme sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	0.80	0.54–1.18	0.84	0.55–1.28	0.59	0.39–0.90*	0.61	0.40–0.96*
Participating in combat sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	1.24	0.83–1.86	1.12	0.72–1.74	1.15	0.76–1.74	119	0.76–1.86
Playing yard games								
No	Ref.		Ref.		Ref.		Ref.	
Yes	0.60	0.43–0.83**	0.62	0.44–0.89**	0.66	0.48–0.92*	0.75	0.53–1.07

[a]*Adjusted for age, educational level, marital status, employment status, leisure-time physical activity, smoking, use of alcohol, and body mass index (BMI).*
**p < 0.05, **p < 0.01.*

old. About half of them (55%) were married or cohabiting and 71% employed or in the school. One third reported that they were inactive or engaged in low levels of LTPA. Approximately half of the participants (49%) reported medium levels, and 21% reported high levels of LTPA. Of note, 33% of the participants were overweight, 12% were obese, 19% used alcohol at least three times a week, and 32% were smokers (**Table 1**).

A majority of the participants reported that they were engaged in organized sports (75%) and competitive sports (64%) at the age of 12 years (**Table 2**). Team sports were the most common type of sport in childhood. Participants were more likely to engage in team sport (66%). Two of three participants (66%) reported that they engaged in team sports at the age of 12 years, 35% engaged in endurance sport, and 27% engaged in extreme sport. A majority of respondents (69%) played yard games at this age.

Unadjusted mean scores of RAND 36 by different levels of sport participation at age of 12 years are presented in **Table 2**. Men who had participated in team ($p = 0.003$) or endurance sports ($p = 0.008$) or played yard games ($p = 0.006$) at the age of 12 years had higher scores in the physical component of HRQoL. Higher frequency of sports participation ($p < 0.001$) and level of competitive sports ($p = 0.013$) as well as participation in team (p

TABLE 4 | Odds ratios (OR) and 95% confidence intervals (CIs) separately for high compared with low and moderate scores in the physical and mental component summary of RAND 36 by variables describing sports participation at age 12 years.

	High compared with low and moderate HRQoL Physical component				High compared with low and moderate HRQoL Mental component			
	Unadjusted		Fully adjusted[a]		Unadjusted		Fully adjusted[a]	
	OR	CI (95%)	OR	CI (95%)	OR	CI (95%)	OR	CI (95%)
Participation in organized sports								
No participating	Ref.		Ref.		Ref		Ref.	
1–3 times a month	0.71	0.39–1.29	0.58	0.31–1.10	0.81	0.42–1.55	0.72	0.36–1.44
1–2 times a week	1.09	0.71–1.65	0.92	0.58–1.45	1.62	1.04–2.55*	1.62	1.00–2.60*
3–4 times a week	1.35	0.88–2.07	1.05	0.66–1.67	2.29	1.46–3.61***	2.27	1.39–3.69**
At least 5 times a week	1.28	0.72–2.26	0.86	0.51–1.75	2.51	1.41–4.47**	2.35	1.27–4.36**
Participation in competitive sports								
No competitive sports	Ref.		Ref.		Ref.		Ref.	
At school level	1.10	0.62–1.97	0.84	0.45–1.57	1.28	0.71–2.34	1.28	0.69–2.38
At sports club level	0.96	0.63–1.46	0.94	0.60–1.50	1.49	0.96–2.29	1.52	0.96–2.40
At district level	1.25	0.84–1.85	1.04	0.67–1.59	1.92	1.28–2.87**	1.83	1.18–2.83**
At national or international level	0.93	0.52–1.68	0.70	0.37–1.33	1.28	0.71–2.40	1.25	0.66–2.36
Participating in team sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	1.35	0.97–1.87	1.14	0.80–1.62	1.53	1.09–2.14*	1.43	1.00–2.06*
Participating in endurance sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	1.37	0.99–1.89	1.20	0.85–1.69	1.15	0.84–1.60	1.07	0.76–1.50
Participating in strength sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	1.54	0.78–3.07	1.76	0.85–3.65	1.96	0.98–3.92	1.87	0.92–3.81
Participating in sports that requires technical performance								
No	Ref.		Ref.		Ref.		Ref–	
Yes	1.31	0.81–2.12	1.33	0.80–2.19	1.14	0.70–1.86	1.21	0.73–2.01
Participating in extreme sports								
No	Ref.	0.94–2.01	Ref.		Ref.		Ref.	
Yes	1.37		1.30	0.87–1.93	1.71	1.17–2.50**	1.77	1.19–2.63**
Participating in combat sports								
No	Ref.		Ref.		Ref.		Ref.	
Yes	0.85	0.56–1.30	0.95	0.61–1.48	100	0.65–1.53	0.96	0.62–1.50
Playing yard games								
No	Ref.		Ref.		Ref.		Ref.	
Yes	1.33	0.95–1.88	1.29	0.90–1.86	1.44	1.02–2.05*	1.34	0.93–1.93

[a]*Adjusted for age, educational level, marital status, employment status, leisure-time physical activity, smoking, use of alcohol, and body mass index (BMI).*
$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

= 0.001) or extreme sports ($p < 0.001$) or playing yard games ($p = 0.004$) at the age of 12 years were associated with higher scores in the mental component of HRQoL.

Logistic regression analysis was conducted to find associating factors for both low (**Table 3**) and high levels (**Table 4**) of HRQoL. In terms of the physical component of HRQoL, no significant association was found between frequency or level of competitive sports in childhood and HRQoL in adulthood. However, the unadjusted logistic regression analysis showed a significant association between participation in team (OR 0.66, CI 0.48–0.90) and endurance sports (OR 0.71, CI 0.52–0.99), as well as in yard games (OR 0.60, CI 0.43–0.83) with a low level of HRQoL. Nonetheless, after confounding factors were adjusted, only association with playing yard games at the age of 12 years remained statistically significant (OR 0.62, CI 0.44–0.89). In terms of a high level of HRQoL in the physical component, no significant associations were found.

Several significant associations were found between childhood sports participation and the mental component of HRQoL in young adulthood. In unadjusted models, a low level of HRQoL was significantly associated with less participation in organized sports (OR 0.56, CI 0.37–0.85); lower levels of competitive sports

(OR 0.62, CI 0.42–0.94) and nonparticipation with team (OR 0.66, CI 0.48–0.91), endurance (OR 0.72, CI 0.52–1.00), or extreme sports (OR 0.59, CI 0.39–0.90); or playing yard games (OR 0.66, CI 0.48–0.92). Respectively, a high level of HRQoL in the mental component was significantly associated with higher frequency of participation in organized sports, competitive sports at the district level (OR 0.63, CI 0.42–0.94) and participation in team (OR 1.53, CI 1.09–2.14) or extreme sports (OR 1.71, CI 1.17–2.50) or in yard games (OR 1.44, CI 1.02–2.05). After confounding factors were adjusted, participation in team or endurance sports and playing yard games attenuated to non-significant as predictor for a low level of HRQoL and playing yard games as a predictor for a high level of HRQoL. All other associations remained statistically significant. Higher frequency of sports participation was associated only from the perspective of a high level of HRQoL. Thus, the higher the weekly participation, the higher the odds for having a high level of HRQoL in the mental component in young adulthood. The odds for having a low level of HRQoL were the lowest in the group of men who participated in organized sports once to four times a week, but not more. In terms of competitive sports, the likelihood for having a high level of HRQoL in the mental component of HRQoL in young adulthood was the highest in the group of men who had engaged in district-level competitive sports at age of 12 years (OR 1.83, CI 1.18–2.83).

DISCUSSION

The findings of the present study showed that participation in organized sports at the age of 12 years was positively associated with the mental component of HRQoL, but no clear association was found with the physical component of HRQoL. A higher frequency of childhood participation was associated with a stronger likelihood for having a high level of HRQoL in young adulthood.

Support for these findings can be found particularly in studies with focus on the association between childhood sports participation and mental health in adulthood (Jewett et al., 2014; Sabiston et al., 2015; Ashdown-Franks et al., 2017; Appelqvist-Schmidlechner et al., 2018). Even though the focus of the present study was HRQoL, previous findings with focus on mental health are relevant, as mental health contributes to the mental component of HRQoL. The mental component of the scale includes—besides mental health itself—emotional and social role functioning as well as vitality, with all fields being determinants or strong associating factors of mental health. In the present study, high frequency of sport participation in childhood seemed to be relevant especially from the perspective of having high HRQoL in the mental component of HRQoL in adulthood. In terms of physical component of HRQoL, childhood sports participation seemed to be less associated with the HRQoL in adulthood or associate only with having a low level of HRQoL in adulthood. Thus, PA in childhood may contribute more for mental component of HRQoL, while the physical component of HRQoL is more dependent on the current status of PA. However, drawing direct links from childhood to adulthood is not possible. The findings allow evidence only for associations, not for causality. No direct link between childhood sports participation and HRQoL in young adulthood can be established.

However, there are several potential mechanisms explaining the association between childhood sports participation and HRQoL in young adulthood, especially in terms of mental component of HRQoL and how childhood sports participation may have potential to contribute to the HRQoL in young adulthood. The mechanism behind this relationship may be related to physical self-perception, self-esteem, life skills, social interaction and connectedness, and opportunity to improve social skills through participation in organized sports (Findlay and Coplan, 2008; Lubans et al., 2016). Organized sport groups can be seen as social catalysts that lead to enhanced involvement and participation (Rutten et al., 2008) contributing to increased HRQoL also in the longer term. Lubans et al. (2016) investigated mechanisms between PA for cognitive and mental health in youth in their systematic review. They identified improvements in physical self-perceptions and enhanced self-esteem as the strongest mechanisms responsible for the positive effects of participation in PA on mental well-being. Similarly, the study by Findley and Coplan (Findlay and Coplan, 2008) found that sports participation is positively related to social skills and self-esteem in children. These aspects may in some degree explain the mechanism between childhood sports participation and mental component of HRQoL in adulthood.

The findings of the present study indicate that competitive involvement in sports in childhood may be beneficial for mental component of HRQoL in young adulthood. No association was found between the physical component of HRQoL and participation in competitive sports at the age of 12 years. To the best of our knowledge, there are no previous studies investigating this relationship. However, this finding is supported by several studies that suggest competitive sports to be beneficial for HRQoL (Houston et al., 2016) and mental health (Appelqvist-Schmidlechner et al., 2018; Dore et al., 2018a; Sneddden et al., 2018). There are several potential underlying mechanisms that may explain this relationship. First, competitive sports may teach children valuable life skills, such as goal setting, commitment, and coping strategies to handle stressful situations, which prepare them for to handle challenges and pressures of daily life also in later life (Merkel, 2013) and in this way contribute especially to the mental component of HRQoL in adulthood. Second, perceived sport competence that results in increased self-esteem may play a mediating role in the relationship between competitive sports and mental component of HRQoL (Wagnsson et al., 2014).

Based on comparisons of unadjusted mean scores of HRQoL, team sports and yard games seemed to be associated with both better physical and mental components of HRQoL. Respectively, endurance sports in childhood associated only with the physical component and extreme sports with the mental component of HRQoL in young adulthood. After confounding variables were adjusted, only team and extreme sports as well as yard games in childhood seemed to be associated with HRQoL in later life, with team and extreme sports affecting the mental component and playing yard games the physical component of HRQoL. Some support from previous research can be found to explain these findings (Downward and Rasciute, 2011; Vella et al., 2014; Sabiston et al., 2015; Dore et al., 2018a,b). Dore et al. (2018b) found that particularly team sports and PA in informal groups—like engagement in yard games—were positively associated with mental well-being in young adulthood. The important role of team sports and opportunity for social interaction through sports will be supported also by several other the studies, especially from the perspective of mental health (Downward and Rasciute, 2011; Eime et al., 2013b; Vella et al., 2014; Sabiston et al., 2015). Eime et al. (2013a) found in their systematic review that, particularly, team sports associate with improved health outcomes compared with individual activities. Social nature of team sport and positive involvement of peers and adults may serve as mechanism in this association. However, also individual sports may benefit psychosocial well-being by enhancing the development of true self-awareness and personal growth (Eime et al., 2013b).

An interesting finding was the positive association between HRQoL and participation in extreme sports—most commonly understood as sport that involves speed, height, a high level of physical exertion, and/or highly specialized gear including sports such as skateboarding, snowboarding, parkour, mountain biking, motocross, and alpine skiing. There is existing evidence supporting the meaningfulness of extreme sports and providing links to positive physical and mental health outcomes (Immonen et al., 2017; Roberts et al., 2018). Immonen et al. (2017) summarized the benefits of action and adventure sports—commonly used as synonym for extreme sports—as "(1) opportunities to fulfill basic psychological needs of autonomy, competence and relatedness, (2) opportunities to overcome challenge, (3) opportunities to experience intense emotions, (4) increased positive psychological outcomes such as resilience, self-efficacy, and positive affect, (5) increased physical activity levels and (6) feelings of connection to nature." They all have potential to promote mental health in childhood in a way that may bear fruit also in young adulthood in terms of mental component of HRQoL. Action and adventure sports present an interesting method for sport-based interventions that can be used also for promoting HRQoL.

Strengths and Limitations of the Study

There are some limitations of the study that should be taken into consideration when interpreting the findings. First, HRQoL was measured with a validated and widely recognized instrument, but retrospective self-reports about sports participation in the childhood were measured with unvalidated questions without information about the frequency of participation. Furthermore, recall bias may have occurred due to the retrospective nature of the questions. However, competitive sport, particularly, represents the most intensive and regular type of sports participation, and it can be assumed that study participants have reported it accurately. Second, although the present self-reported LTPA in adulthood has been validated against fitness (Fogelholm et al., 2006), it has not been validated against, e.g., device-based PA. The main limitation, however, regarding this question is that the variation in the amount of light and moderate PA cannot be assessed. Third, in terms of HRQoL, the differences in scores across the different types and levels of sports performance were quite small and not all necessarily clinically important or meaningful differences. Fourth, in a cross-sectional study with even a retrospective perspective, a causal link between participation in organized sports in childhood and HRQoL in young adulthood cannot be established. There are many other factors, such as different lifestyle or childhood living condition, that may contribute to the HRQoL in adulthood and affect the observed association. For instance, data on family background (e.g., socioeconomic background) in the childhood, which may have a major impact on the possibilities to participate in organized sports at the age of 12 years, were not available. No explanation can be provided if children who participate in organized sports have stronger basis for creating better HRQoL in later life, per se. Fifth, as the sample used in this study—reservists participating in the refresher course—represents a group of healthy young men being physically and mental capable of participating in the course, young men with various health concerns are underrepresented. Future studies with longitudinal study designs are needed to enhance the understanding about the role of sports participation in the childhood for the HRQoL in the life span.

CONCLUSION

The present study showed that higher frequency of participation in organized sports, engagement in district-level competitive sports, and performing team, endurance, or extreme sports or sports in informal groups in childhood were all independently associated with better HRQoL in young adulthood. The association was, particularly, found in the mental component of HRQoL and to a lesser extent in the physical component of HRQoL.

In terms of sport types, team and extreme sports seemed to be associated with the mental component of HRQoL and playing yard games with the physical component of HRQoL. Thus, engagement in organized sports—both team-based and individual sports—but also PA in informal groups, such as playing yard games, in childhood may contribute to HRQoL in later life. However, as suggested by Moeijes et al. (2019a), the frequency of sports participation and learning an active lifestyle is more relevant than the form of sports participation. As particular individuals with active childhood sports participation are known to continue their PA also in later life (Telama et al., 1996), children and adolescents should be encouraged to perform any kind of sports activity on a regular basis and support to maintain their active lifestyle as long as possible. Strategies and activities that enhance organized sport participation for children and young people should therefore be promoted. Furthermore, specific strategies should be developed to encourage children and young people with different levels of ability and commitment to participate in organized sport.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical committees of the Central Finland Health Care District and the Headquarters of the Finnish Defence Forces (AM5527). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The study is part of the Finnish Reservist 2015 Study led by HK. KA-S, HK, AH, TV, MM, and JV contributed to the study design and methodology. JV led the data collection with the assistance of research assistants. KA-S conducted the statistical analysis and led the writing process. All authors provided critical revisions to the manuscript, and accept responsibility for the contents of the article. KA-S had final responsibility for the decision to submit for publication. All authors read and approved the final version submitted.

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Validation of a Modified Submaximal Balke Protocol to Assess Cardiorespiratory Fitness in Individuals at High Risk of or With Chronic Health Conditions—A Pilot Study

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Objectives: This study aims to validate a submaximal treadmill walking test for estimation of maximal oxygen consumption (VO_{2max}) in individuals at high risk of or with chronic health conditions.

Method: Eighteen participants (age 62 ± 16 years; VO_{2max} 31.2 ± 5.9 ml kg^{-1} min^{-1}) at high risk of getting or with established chronic diseases performed two valid modified Balke treadmill walking protocols, one submaximal protocol, and one maximal protocol. Test duration, heart rate (HR), and rate of perceived exertion (RPE) were measured during both tests. VO_{2max} was measured during the maximal test. VO_{2max} was estimated from the submaximal test by multiple regression using time to RPE ≥ 17, gender, age, and body mass as independent variables. Model fit was reported as explained variance (R^2) and standard error of the estimate (SEE).

Results: The model fit for estimation of VO_{2max} from time to RPE ≥ 17 at the submaximal test, body mass, age, and gender was $R^2 = 0.78$ (SEE = 3.1 ml kg^{-1} min^{-1}, $p \leq 0.001$). Including heart rate measurement did not improve the model fit.

Conclusions: The submaximal walking test is feasible and valid for assessing cardiorespiratory fitness in individuals with high risk of or chronic health conditions.

Keywords: submaximal test, estimation, maximal oxygen consumption, aerobic fitness, healthy life centers

INTRODUCTION

Cardiorespiratory fitness is a strong predictor of all-cause mortality and longer life expectancy (Kodama et al., 2009; Barry et al., 2014). The gold standard for assessing an individual's cardiorespiratory fitness is to directly measure their maximal oxygen consumption (VO_{2max}) by the measurement of expiratory gases during maximal exercise (ATS/ACCP, 2003). VO_{2max} was first defined by Hill et al. (1924) as the oxygen consumption at a training intensity where oxygen intake reaches a plateau, despite an increase in workload. Thus, measurement of VO_{2max} is often performed during maximal graded exercise tests (Vehrs et al., 2007), where workload is increased until exhaustion. However, the direct measurement of VO_{2max} requires highly skilled personnel and sophisticated instrumentation and relies on participants' motivation and capability to push themselves to their physical limit.

When treadmill and cycle ergometer testing were first introduced into clinical practice, practitioners often used protocols such as the Balke protocol (Balke and Ware, 1959), from which VO_{2max} can be estimated from time to exhaustion (Pollock et al., 1982). A modified version of the Balke protocol has been used to assess cardiorespiratory fitness in a large sample of adults and elderly in Norway, where it was shown that VO_{2max} could be estimated reasonably well from time to exhaustion [$R^2 =$ 0.78, standard error of the estimate (SEE) = 4.6 ml kg^{-1} min^{-1}] (Aadland et al., 2016). However, such maximal protocols may be less suitable for individuals with a variety of chronic health conditions (Lennon et al., 2012; Sartor et al., 2013), which has stimulated the development of submaximal tests for estimation of VO_{2max} (Jørgensen et al., 2009; Sartor et al., 2013).

In Norway, about half of the municipalities have established healthy life centers (HLCs) as a primary health care service to promote physical activity, smoking cessation, and a healthy diet among individuals at high risk of getting or with established chronic diseases (Ekornrud and Thonstad, 2018; Helsedirektoratet, 2019). The HLCs primarily recruit obese adults and older adults with multiple chronic conditions including musculoskeletal disorders and cardiovascular risk factors and diseases (Blom et al., 2019). The HLCs have applied a modified submaximal Balke walking treadmill protocol to asses cardiorespiratory fitness (Blom et al., 2020a), using Borg scale measured rate of perceived exertion (RPE) $\geq$ 17 (Borg, 1982) as the criterion for completing the test. The protocol was modified to suit the target group with multiple chronic conditions (i.e., with lower start speed than the original protocol) and for application with various types of treadmills with limited inclination and speed adjustment intervals. However, the validity of the submaximal protocol used in Norwegian HLCs has not been evaluated. Therefore, our aim was to validate this protocol in individuals at high risk of or with chronic health conditions against VO_{2max}.

MATERIALS AND METHODS

Design

In the present study, we performed two modified Balke protocols (Aadland et al., 2016; Blom et al., 2020a) on a motor-driven treadmill (Woodway PPS 55; WOODWAY GmbH, Weil am Rhein, Germany). The participants first performed a submaximal test that was terminated at RPE $\geq$ 17 and then a maximal test to exhaustion. The two tests were separated by a minimum of 4 days (12 $\pm$ 11) to allow the participants to recover between the tests.

Patient and Public Involvement

During data collection in a previously published study (Blom et al., 2020b), employees at HLCs expressed the need for a valid tool to interpret and communicate HLC participants' cardiorespiratory fitness. Through communication with the HLC employees participating in the study (Blom et al., 2020a), the research question for the present study was developed. The local HLC recruited participants for the present study. The HLCs will be provided with the equation to estimate VO_{2max} for each participant undertaking the submaximal test and hence be able to interpret and communicate the participant's cardiorespiratory fitness by comparison with normal values.

Participants

We recruited 23 adult participants (14 women and 9 men) aged 18–85 years taking part in exercise programs for individuals at high risk of or with established chronic disease(s) (i.e., HLC, union for heart and lung disease, cancer rehabilitation, and rheumatism habitation). The participants self-reported their risk factors for cardiometabolic diseases and known cardiometabolic diseases in a questionnaire previously used in other Norwegian studies testing cardiorespiratory fitness in HLCs (Blom et al., 2020a) and the general population (Aadland et al., 2016). Three participants (13%) had known heart disease, two (9%) occasionally felt chest pain at rest or when performing physical activity, five (22%) had hypertension, six (26%) used medication for hypertension or heart disease, and four (17%) had close relatives with heart infraction of sudden death before the age of 55 and 65 years for men and women, respectively. Three participants (13%) smoked regularly, six (26%) had hypercholesterolemia, and four had diabetes. Eight participants (35%) had none of the conditions mentioned above. Participants were not eligible if they had been advised by their physician to avoid heavy physical work. No potential participants volunteered for the study and were found not eligible. The test laboratory had access to a defibrillator, and an emergency room with a physician on call situated <1 km away provided medical backup. The study was approved by the Norwegian Centre for Research Data (reference number: 663351) and conducted according to the Helsinki declaration. All participants provided written informed consent and completed a health declaration prior to performing any tests. Information about the tests was given to each participant in a standardized manner.

Tests

Submaximal Test Used in Norwegian HLC (Blom et al., 2020a)

Participants performed a self-paced treadmill familiarization prior to testing (speed 2.0–3.5 km h^{-1} for 2–7 min). The test started with a walking speed of 4.0 km h^{-1} on a flat treadmill. After 4 min, the treadmill inclination increased by 2% every minute until an inclination of 12%. We then increased the speed by 0.5 km h^{-1} every minute. The participants were asked to report RPE on the Borg 6–20 scale (Borg, 1982) 10 s before each increase in workload, and the test was terminated the first time an RPE $\geq$ 17 was reported. A progressive test protocol up to RPE 17 at the Borg scale has previously been shown to predict maximal oxygen uptake with reasonable accuracy compared to lower RPE (Coquart et al., 2014). Performance is reported as the time to RPE $\geq$ 17.

Maximal Test Previously Used in a Large Norwegian Study in Individuals ≥55 Years Old (Aadland et al., 2016)

A self-paced familiarization was performed prior to testing (speed 2.0–4.0 km h^{-1} for 2–7 min). The test started with a walking speed of 3.8 km h^{-1} at 2% inclination. After 4 min, inclination was increased by 2% each minute until it reached 20%. We then increased the speed by 0.5 km h^{-1} every minute until exhaustion. The test was terminated when participants were unable to keep up with the increasing workload despite verbal encouragement. Oxygen consumption was measured using the Moxus Modular VO_2 system with mixing chamber and averaged over 30 s (AEI Technologies, Pittsburgh, Pennsylvania, USA), through a mask connected to a two-way valve (Hans Rudolph Inc., Kansas City, USA). The mask was thoroughly checked for any leaks prior to testing. VO_2 was measured every 30th second and VO_{2max} was defined as the mean of the two highest, subsequent measured values. The VO_{2max} was considered valid if two of the three following criteria was achieved: (1) RPE ≥ 19, (2) respiratory exchange ratio (RER) ≥ 1.0, and (3) ≥97% of estimated heart rate maximal values (HR_{max}). VO_{2max} is reported as milliliters per kilogram per minute. The end criteria was set to secure maximal intensity at test termination and to end up with a reasonable sample size. Besides VO_{2max}, performance was measured using time to exhaustion and time to RPE ≥ 17 (for comparison with the submaximal test).

RPE and heart rate (HR) were measured continuously during both tests. HR was measured using a chest strap (Polar, Kempele, Finland). During the submaximal test, HR was displayed on the treadmill and measured every minute simultaneously with RPE, 10 s before increase in workload. During the maximal test, HR was measured through the Moxus software with a 30-s interval. RPE was assessed using the Borg 6–20 scale (Borg, 1982). HR is presented as the maximal values (HR_{max}) and as a percent of estimated HR_{max} (HR_{max}%) according to a previously published equation (211 – 0.64·age) (Nes et al., 2013). We measured height (without shoes) and body mass (with light clothing and no shoes) prior to the maximal test.

Statistical Analysis

Data are presented as means and standard deviations (SD) unless stated otherwise. Associations between various measures of performance obtained from the two protocols are reported as the explained variance (R^2). Differences between the included and excluded participants were tested with unpaired *t*-tests. We estimated VO_{2max} on the maximal protocol using multiple linear regression with time to RPE ≥ 17 at the submaximal protocol, age, body mass, gender, and HR_{max}% as independent variables. The model fit is reported as the explained variance (R^2) and standard error of the estimate (SEE). Assumption for linear regression was assessed with Kolmogorov–Smirnov and Shapiro–Wilk tests to test for normality in the dependent variable and collinearity between the independent variables; correlation between the independent variable was tested with Pearson's coefficient of correlation; normality of the residuals of the dependent variable was tested with plots (P-P and scatter); and residual statistics were assessed with standard residuals and Cook's distance. All analyses were performed using SPSS v. 25 (IBM Corporation, Software Group, Somers, NY).

RESULTS

Of the 23 participants, one participant only performed the submaximal test and four were excluded for not meeting the present study's criteria for a valid VO_{2max} test (three had too low HR and RER and two had too low HR, RER, and RPE). Thus, the main analysis comprise18 participants aged 35–85 years (11 women and 7 men). **Table 1** presents descriptive data and results from the exercise tests for both the included and the excluded participants. In addition to lower HR and RER, the excluded participants had lower performance at the maximal test and lower heart rate at the submaximal test. The association between time to RPE ≥ 17 at the submaximal test and time to exhaustion at the maximal test was $R^2 = 0.71$, the association between time to RPE ≥ 17 at the submaximal test and time to RPE ≥ 17 at the maximal test was $R^2 = 0.81$, and the association between time to exhaustion at the maximal test and time to RPE ≥ 17 at the maximal test was $R^2 = 0.89$ (all $p \leq 0.001$) (**Figure 1**).

The best model for estimation of VO_{2max} from the submaximal test was as follows: $VO_{2max} = 45.873 + (1.159$ submaximal test time$) + (-0.301$ body mass$) + (-0.264$ age$) +$ $(7.627$ gender$)$. This model showed strong association between estimated VO_{2max} and measured VO_{2max} ($R^2 = 0.78$, SEE = 3.1 ml kg^{-1} min^{-1}, $p \leq 0.001$). Adding HR_{max}% from the submaximal test to this model did not improve its performance ($R^2 = 0.79$, SEE = 3.2, $p \leq 0.001$).

As sensitivity analysis, we performed the analysis including both the 18 included participants and the four participants excluded for not meeting the present study's criteria for a valid VO_{2max} test, and the association between estimated VO_{2max} and measured VO_{2max} was identical ($R^2 = 0.79$, SEE = 2.9, $p \leq 0.001$).

VO_{2max} was normally distributed ($p = 0.12/0.07$), and there was no collinearity between the independent variables ($r < 0.7$); age ($r = -0.5$) and RPE ≥ 17 at the submaximal test ($r = 0.6$) were correlated with VO_{2max}. Weight was not correlated to VO_{2max} ($r = 0.1$). Standard residuals ranged from −1.5 to 1.3 and Cook's distance ranged from 0.0 to 0.5.

DISCUSSION

This study shows that performance at the submaximal exercise test used to assess cardiorespiratory fitness among individuals at high risk of or with chronic health conditions at HLCs in Norway associated strongly with performance at the maximal test performed according to the gold standard for cardiorespiratory fitness testing. Thus, time to reach RPE 17 is a valid measure of cardiorespiratory fitness in this at-risk population and can be used to estimate VO_{2max} by the equation suggested herein.

The present study showed a strong association between estimated VO_{2max} from performance at the submaximal test and directly measured VO_{2max} in individuals at high risk of getting or with established chronic diseases. Pollock et al. (1982) and Vehrs

TABLE 1 | Descriptive data, results from cardiorespiratory fitness tests, and estimated VO_{2max} in individuals at high risk of getting or with established chronic diseases.

	Women (*n* = 11)	Men (*n* = 7)	Total (*n* = 18)	Excluded 2♀and 2♂
Age (years)	65 ± 12	57 ± 20	62 ± 16	72 ± 10
Weight (kg)	69.5 ± 13.7	92.6 ± 12.0	78.5 ± 17.2	86.4 ± 16.5
Submaximal test (SMT)				
Time to ≥17 RPE (min)	12.38 ± 2.73	13.20 ± 2.50	12.70 ± 2.60	10.06 ± 1.65
HR_{max} (bpm)	158 ± 16	157 ± 15	158 ± 16	132 ± 23.28*
HR_{max}%	93 ± 10	90 ± 7	92 ± 9	81 ± 14
Maximal test (MT)				
Time to exhaustion (min)	12.60 ± 2.02	13.49 ± 2.49	12.95 ± 2.19	9.50 ± 1.85*
Time to RPE 17 (min)	10.36 ± 2.46	11.86 ± 3.08	10.94 ± 2.73	7.58 ± 1.65*
HR_{max} (bpm)	166 ± 17	169 ± 12	167 ± 15	142 ± 25*
HR_{max}%	99 ± 5	99 ± 3	99 ± 4	87 ± 14.74*
RER	1.07 ± 0.09	1.05 ± 0.05	1.07 ± 0.08	0.93 ± 0.09*
VO_{2max} (ml kg^{-1} min^{-1})	29.84 ± 3.78	33.44 ± 8.09	31.24 ± 5.90	22.46 ± 3.07*
Estimated VO_{2max} (ml kg^{-1} min^{-1})				
Using SMT time, age, weight, and gender	29.80 ± 3.59	33.40 ± 6.81	31.21 ± 5.22	na
Using SMT time, age, weight, gender, and HR_{max}%	29.85 ± 3.65	33.45 ± 6.84	31.25 ± 5.25	na

*HR_{max}, maximal heart rate; bpm, beats per minute; HR_{max}%, percent of estimated maximal heart rate; RPE, rate of perceived exertion; RER, respiratory exchange ratio; VO_{2max}, maximal oxygen consumption; na, not applicable; *p < 0.05 for the difference between the included and the excluded participants.*

et al. (2007) reported an even stronger association with lower SEE when estimating VO_{2max} from a graded maximal treadmill walk test in healthy women and for a submaximal treadmill jogging test at a self-selected pace in fit adults, respectively. However, the association found in the present study was similar to the ability of the maximal modified Balke treadmill protocol used to estimate VO_{2max} in a large Norwegian adult population (Aadland et al., 2016) and more accurate than a previously published model estimating VO_{2max} from a submaximal treadmill walking test in overweight children (Nemeth et al., 2009). Thus, we regard the submaximal walking protocol evaluated in the present study well-suited for the assessment of cardiorespiratory fitness in an adult clinical and subclinical population.

The submaximal test used at Norwegian HLCs does not require measurements of HR. However, we investigated if including HR_{max}% during the submaximal test improved the model fit when estimating VO_{2max}, based on the linear relationship between HR and oxygen consumption (Sartor et al., 2013). Yet, adding HR_{max}% to the model did not improve the model. Given that the performance of both models was similar, adding measurements of HR for estimation of cardiorespiratory fitness is not necessary.

Potential Bias

The mean number of days between the tests was 12 ± 11 days. This illustrates that some participants had several weeks from the submaximal test to the maximal. We have no information about the lifestyle or change in lifestyle within this period, and fitness may have changed between the two tests. For instance, if participants lost weight, stopped smoking, or became more physically active in the period between the tests, this change may have had an impact on their performance. Indeed, the time to RPE ≥ 17 at the maximal test was more strongly associated with measured VO_{2max} than time to RPE ≥ 17 at the submaximal test, which might indicate some day-to-day variation in fitness and/or change in fitness between the tests.

RPE is a simple, valid, and reliable means to quantify the subjective feeling of exercise tolerance and exertion (Kang et al., 1998; Doherty et al., 2001). Borg's scale relies on verbal anchors connected to the different scores of RPE, and it is possible that individuals at high risk of disease interpret the meanings of the verbal anchors differently than those used to construct the scale (Dawes et al., 2005). The participants in this study had little or no previous experience with exercise, use of Borg scale, and treadmills and lacked experience with strenuous exercise, which may have introduced a bias to the measurements. However, the population in the present study is comparable to participants in HLCs performing the tests as a part of their lifestyle change program. At the maximal test, the participants had already performed a walking test on a treadmill, and the difference in experience with strenuous treadmill walking may have introduced a systematic bias between the two tests. We could have randomized the order of the two tests or performed a familiarization test to reduce this systematic bias. However, we wanted to perform the submaximal tests as close as possible to the HLCs' test setting, as we believe that the bias introduced by familiarization to strenuous treadmill walking ahead of the submaximal test would be larger than the bias introduced by the fixed order of tests.

The duration of the maximal test was 13 ± 2.2 min; thus, it exceeded the traditionally accepted optimal VO_{2max} test duration of 10 ± 2 min (Ross, 2003). However, in their review, Midgley et al. (2008) found that treadmill protocols lasting between 5 and 26 min produced valid VO_{2max} measurements. Given that time to exhaustion from this study slightly exceeded the traditional 8–12-min duration and that Midgley et al. (2008) found that

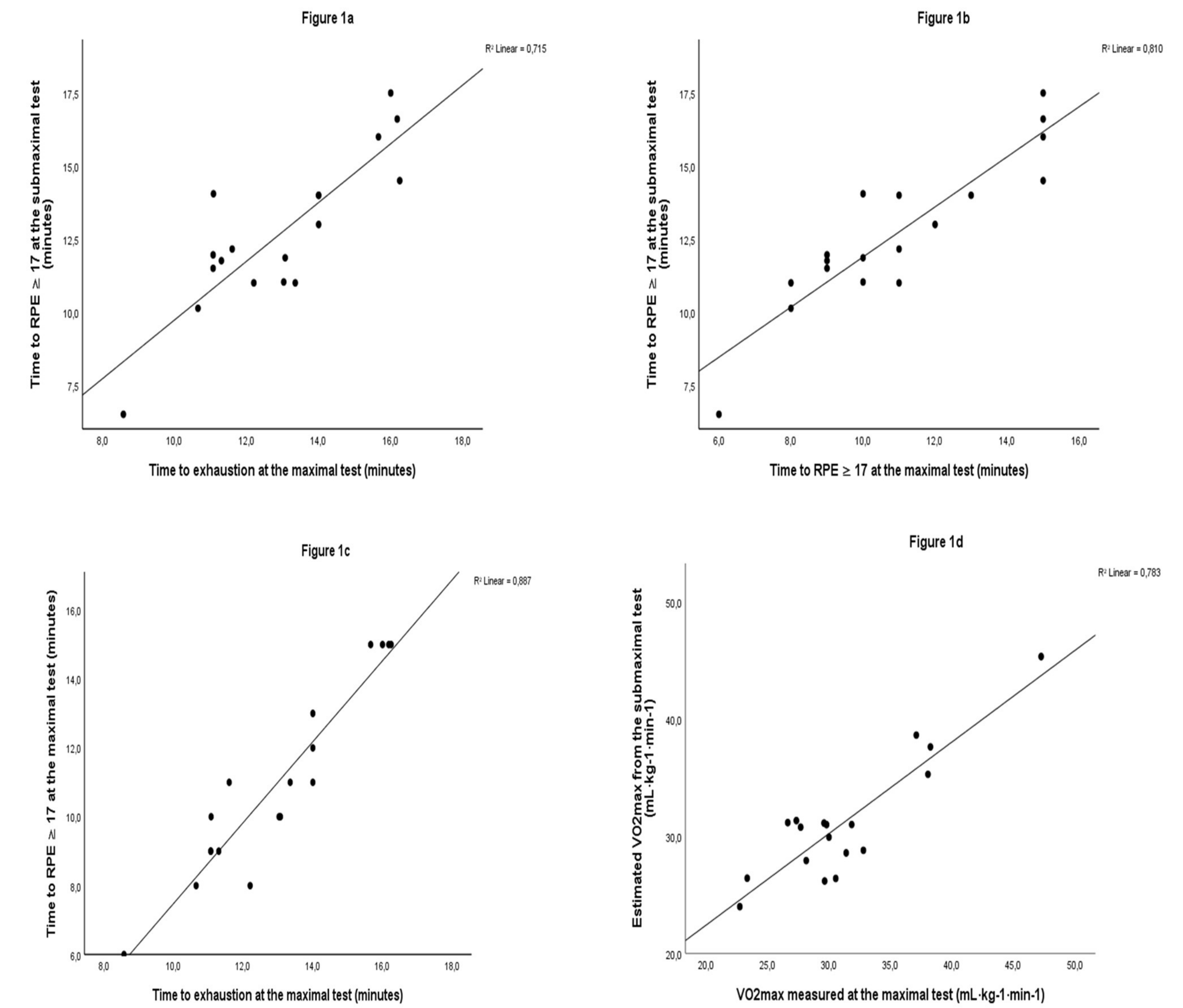

FIGURE 1 | The correlation between time to RPE ≥17 at the submaximal test and time to exhaustion at the maximal test **(a)**, time to RPE ≥17 at the submaximal test and time to RPE ≥17 at the maximal test **(b)**, time to RPE ≥17 at the maximal test and time to exhaustion at the maximal test **(c)**, and estimated VO_{2max} and measured VO_{2max} **(d)** in individuals at high risk of getting or with established chronic diseases.

much shorter and longer treadmill protocols also produced valid VO_{2max} measurments indicate that the duration of our maximal test did not compromise the validity of the VO_{2max} measurement.

Participants were allowed to slightly support themselves if feeling pain or to maintain balance. However, supporting oneself during a submaximal test may increase time to "exhaustion" and thus lead to an overestimation of VO_{2max} (Manfre et al., 1994). In our study, participants supporting themselves during the submaximal test also supported themselves during the maximal test to standardize the test condition. Supporting oneself during direct measurement of VO_{2max} will probably not increase VO_{2max}, as support during treadmill walking/running decreases the exercise load, and one must increase exercise load to increase VO_2. Thus, support may create a bias in estimation of VO_{2max}, as it might be overestimated in subjects supporting themselves and underestimated in subjects not supporting themselves. However, in a real-life test setting, some subjects with chronic health conditions will need to support themselves, and we chose to include both participants supporting themselves and those not supporting themselves to increase the external validity of our results.

Unfortunately, the questionnaire assessing risk factors for cardiometabolic diseases and known cardiometabolic diseases was used as eligibility screening, and the answers were not linked to the result from the tests; thus, we cannot link the results from the questionnaire to individuals. Six participants used medication for hypertension or heart disease. We do not know the type of medication. If someone took beta-blockers, it would probably blunt the heart rate response to the exercise tests (Wonisch et al., 2003). However, all included participants reached ≥97% of estimated HR_{max}, and the performance of the model remained the same also when we included the participants not fulfilling our criteria for a valid VO_{2max} test. Thus, the use of beta blockers probably did not affect the results in the present study.

Submaximal tests for estimating VO_{2max} have shown to produce valid and reliable measures in different populations (Oja et al., 1991; Vehrs et al., 2007; Nemeth et al., 2009). Estimation using the UKK walk test (Oja et al., 1991) is a simple self-paced field test and can be applied in large groups of healthy adults, but it requires a large area of flat ground. Our findings suggest the submaximal protocol evaluated herein is a valid and feasible test. Since treadmills are accessible in most fitness facilities and laboratories, the test setting is easily standardized and not limited by climate or weather. Using the best-fit model from this study will allow HLCs to compare their participants with national reference values and ultimately define the health risk of this specific population.

Strengths and Limitations

A strength of this study is the inclusion of a clinical or subclinical population with various health conditions, leaving direct evidence of test performance in this group for which the test is intended for use. Another strength is the strict criteria for verification of a maximal performance, ensuring that all included VO_{2max} measurements were valid. The appropriate criteria for VO_{2max} is highly debated (Edvardsen et al., 2014), and we opted for stricter criteria for VO_{2max} than the criteria used for testing the general population in Norway (Aadland et al., 2016). Our criteria for valid VO_{2max} may have been stricter than necessary as when we included the four subjects not meeting our criteria, the performance of the model remained unchanged. Our sample includes 18 subjects, which is lower than the minimum sample size for regression of 25 recommended by Jenkins and Quintana-Ascencio (Jenkins and Quintana-Ascencio, 2020). Thus, the low sample size reduces the power and generalizability of our findings. The data met all the tested assumptions for linear regression except for a correlation between VO_{2max} and age; however, age was a significant contributor in the model. Due to the small sample size, we could not perform a cross validation of our equation for estimation of VO_{2max}. Thus, despite a relatively large variation in age, cardiorespiratory fitness, and health conditions among our participants, which strengthens the generalizability of our findings, the findings should be interpreted with caution, and future studies should seek to include a larger sample and perform a cross validation in a similar population.

CONCLUSION

The present study found a strong association between performance on a submaximal treadmill walking protocol and measured VO_{2max} in a clinical or subclinical population. The study demonstrates that the submaximal walking test is valid and feasible as a means for assessing cardiorespiratory fitness in a population and in a setting where direct measurement of VO_{2max} is challenging. However, our findings need verification in a larger study sample.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the subjects signed an informed consent stating that the data should be handled by the researchers conducting the study and deleted after the study was published according to the approval given by Norwegian Centre for Research Data. Requests to access the datasets should be directed to Amund Riiser, amund.riiser@hvl.no.

ETHICS STATEMENT

The study was reviewed and approved by Norwegian Centre for Research Data (Reference No: 663351). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

GE designed the study, collected the data, drafted the manuscript, and approved the final version. EA designed the study, planned the analysis, contributed to the manuscript, and approved the final version. EB designed the study, contributed to the manuscript, and approved the final version. AR planned the study, performed the analysis, and finalized the manuscript.

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Sitting for Too Long, Moving Too Little: Regular Muscle Contractions Can Reduce Muscle Stiffness During Prolonged Periods of Chair-Sitting

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In modern Western societies, sedentary behavior has become a growing health concern. There is increasing evidence that prolonged sitting periods can be associated with musculoskeletal disorders. While it is generally recognized that back muscle activity is low during chair-sitting, little is known about the consequences of minor to no muscle activity on muscle stiffness. Muscle stiffness may play an important role in musculoskeletal health. This study investigated the effects of regular muscle contractions on muscle stiffness in a controlled experiment in which participants sat for 4.5 h. Neuromuscular electrical stimulation in the lumbar region of the back was applied to trigger regular muscle contractions. Using stiffness measurements and continuous motion capturing, we found that prolonged sitting periods without regular muscle contractions significantly increased back muscle stiffness. Moreover, we were able to show that regular muscle contractions can prevent those effects. Our results highlight the importance of consistent muscle activity throughout the day and may help explain why prolonged periods of chair-sitting increase the susceptibility to common pathological conditions such as low back pain.

Keywords: prolonged sitting, muscle stiffness, muscle contraction, sedentary behavior, back muscles, electrical stimulation, biomechanics

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INTRODUCTION

Common sedentary behaviors include office work, driving automobiles, using public transportation, and screen time. In modern Western societies, those behaviors can sum up to a sitting time of 8.4–9.3 h per day (Healy et al., 2011; Clemes et al., 2014; van der Velde et al., 2017). Recent research related to the coronavirus disease 2019 (COVID-19) indicate that sedentary behavior time has further increased since the beginning of the pandemic, particularly in people who are now working from home (Fukushima et al., 2021; Wilke et al., 2021). Those prolonged periods of sitting are considered as an independent risk factor for health, including an increased risk of developing metabolic and chronic cardiovascular diseases (Hamilton et al., 2007; Healy et al., 2011) and increased mortality (Chau et al., 2013; Stamatakis et al., 2019). Further research associates long sitting periods with musculoskeletal disorders, such as increased muscle stiffness (Kett and Sichting, 2020), fatigue (Callaghan and McGill, 2001; van Dieën et al., 2001), discomfort (Sammonds et al., 2017; Cardoso et al., 2018; Waongenngarm et al., 2020), and, at worst, low back pain (Porter and Gyi, 2002; Gupta et al., 2015; Lunde et al., 2017). Notably, low back pain is a growing public health concern in modern Western societies and a tremendous socioeconomic burden (Lis et al., 2007; Manchikanti et al., 2009; Hartvigsen et al., 2018).

A recent study by Raichlen et al. (2020) on sitting behavior among the Hadza, a hunter-gatherer population, sheds new light on the association between sedentary behavior and musculoskeletal disorders (Raichlen et al., 2020). Interestingly, the hunter-gatherers show similar periods of inactivity (9.9 h per day) compared to industrialized populations (Raichlen et al., 2020). However, associated musculoskeletal disorders are scarce among non-industrialized populations (Volinn, 1997; Lopez et al., 2006). The lower level of musculoskeletal disorders among non-industrialized populations might be related to a greater level of physical activity. Another possible explanation for the discrepancy in musculoskeletal disorders might be the style of rest during periods of inactivity. While industrialized populations often sit on chairs, sedentary postures among hunter-gatherers include kneeling, squatting, and ground-sitting (Pontzer et al., 2010; Raichlen et al., 2020). Raichlen et al. (2020) showed that those postures, particularly squatting, require higher muscle activity levels than chair-sitting (Raichlen et al., 2020). Based on these findings, it seems reasonable to question the general association between sedentary behavior and musculoskeletal disorders. One can hypothesize that our bodies are not well-built for spending much of our day sitting in chairs with minor to no muscle activity (O'Keefe et al., 2010; Hamilton, 2018; Raichlen et al., 2020).

Previous research has shown that prolonged periods of chair-sitting result in increased passive back muscle stiffness (Kett and Sichting, 2020). It has been suggested that the low level of muscle activity during chair-sitting, and the static nature of the sitting postures causes a restriction of the muscle metabolism, with adverse effects on blood flow, muscle tissue oxygenation, and regulation of inflammation (McGill et al., 2000; Valachi and Valachi, 2003; Visser and van Dieën, 2006; Kell and Bhambhani, 2008). Further, the reduced muscle metabolism appears to trigger a reactive imbalance in the muscle cell (McGill et al., 2000; Kell and Bhambhani, 2008), promoting spontaneous formations of weak but long-lasting cross-bridges between myosin heads and actin filaments (Hill, 1968; Campbell and Lakie, 1998). Subsequently, passive muscle stiffness increases (Simons and Mense, 1998; Proske and Morgan, 1999). If this theoretical framework proves to be true, intervention strategies that elicit dynamic muscle contractions during chair-sitting should counter an increase in passive muscle stiffness (Hsueh et al., 1997; Campbell and Lakie, 1998) by improving muscle metabolism (Saltin et al., 1998; Crenshaw et al., 2006).

This study aims to provide experimental evidence for the above-mentioned theoretical framework. Using surface electrical stimulation of lower back muscles during prolonged periods of chair-sitting allows us to stimulate back muscles at a sensory and motor threshold level (Hultman et al., 1983; Maffiuletti et al., 2011). When using low-amplitude currents, electrical stimulation is perceived through somatic sensory receptors mainly located in cutaneous and subcutaneous tissues (termed sensory threshold). Thus, electrical stimulation at the sensory threshold does not trigger muscle contractions directly (Purves et al., 2004; Maffiuletti et al., 2008). In contrast, when applying current amplitudes above the sensory threshold (termed motor threshold), an increasing number of efferent terminal axon branches are excited and result in contractile protein interaction (Hultman et al., 1983; Maffiuletti et al., 2008). Previous studies have shown that surface electrical stimulation above the sensory threshold is an effective tool for stimulating lumbar muscles (Kim et al., 2016; Sions et al., 2019). Comparing the effects of surface electrical stimulation at the sensory and motor threshold on the lower back's passive muscle stiffness during a 4.5-h sitting period will help us to test the general hypothesis that intervention strategies that elicit muscle activity during chair-sitting counter an increase in passive muscle stiffness. We predict that stimulation at the motor threshold will diminish increases in passive muscle stiffness. In contrast, we predict that electrical stimulation of the back muscles at the sensory threshold will not affect passive muscle stiffness. Spinal kinematics will be recorded during all measurements to monitor the possible effects of sitting posture and postural variation on passive muscle stiffness during the multiple sitting periods.

MATERIALS AND METHODS

Participants

Fifteen volunteers (seven women and eight men) participated in this study. The volunteers were employees or students at the university. All participants (age: 28.9 ± 5.0 years, weight: 74.5 ± 10.3 kg, height: 176.9 ± 10.0 cm) were required to be healthy, with no current injuries or conditions that would cause sitting abnormalities or prohibit the application of surface electrical stimulation. Further, all participants had to pause moderate and high physical activities 24 h before the experiment to avoid possible muscle fatigue and altered muscle stiffness. Each participant gave written informed consent to participate in the study. The study was approved by the institutional ethics committee of the Faculty of Behavioral and Social Sciences at Chemnitz University of Technology (approval number: V-370-17-FS-E.-Stimulation-07022020) and conducted in accordance with the Declaration of Helsinki.

Intervention Strategies and Settings

We used neuromuscular electrical stimulation (NMES) applied by a portable stimulator (PHYSIOMED-Expert; PHYSIOMED Elektromedizin AG, Schnaittach, Germany) at the lumbar region of the back to test the effect of regularly induced muscle contractions on passive muscle stiffness. In total, we tested three conditions for each participant: CONTROL (sitting without NMES), $NMES_{SENSOR}$ (stimulation with low-amplitude currents, where electrical stimulation is perceived through somatic sensory receptors mainly located in cutaneous and subcutaneous tissues), and $NMES_{MOTOR}$ (electrical stimulation with greater current amplitudes, where an increasing number of efferent terminal axon branches are excited). We used $NMES_{MOTOR}$ to test the effect of regular muscle contractions on muscle stiffness, and $NMES_{SENSOR}$ to test for placebo effects of the electrode application. The skin was disinfected before electrode placement. Following the motor point map

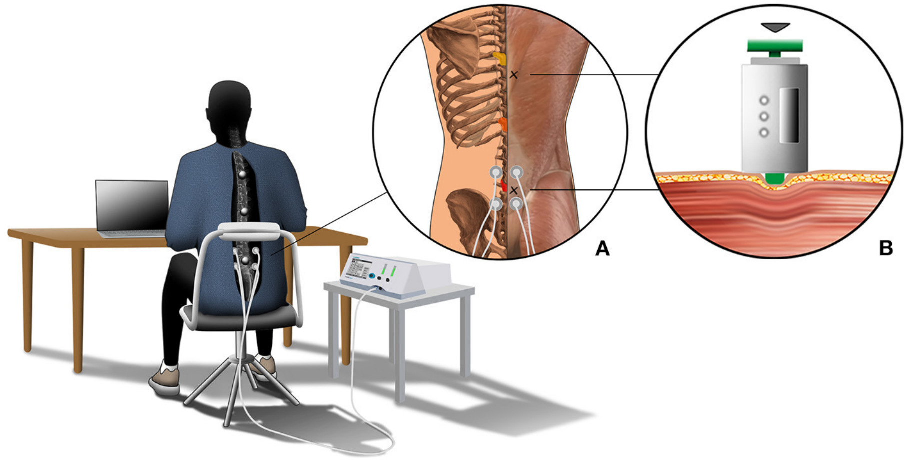

FIGURE 1 | The graphical depiction illustrates the experimental setup. All participants sat for 4.5 h at a desk on a height-adjustable chair to complete their regular office activities. The chair's back cushion was removed, leaving only the metal frame cushioned with foam to guarantee marker visibility. Further, all participants had to wear a long-sleeve T-shirt with a cut-out at the back exposing the spinal area. Motion data of the back were captured using three retro-reflective skin markers, which were placed on the spinous processes of vertebrae T5, T10, and L2. The three vertebrae are colored in yellow (T5), orange (T10), and red (L2) in close-up **(A)**. Further, close-up **(A)** shows the locations of the stiffness measurement (marked with an x) and details about the NMES condition. Here, two electrodes were placed on the left and right sides of the lumbar spine. Close-up **(B)** shows details about the passive muscle stiffness measurement. Muscle stiffness was defined by the slope of the relationship between indentation depth and resistance force.

by Behringer et al. (2014), we placed two electrodes (electrode diameter: 3.2 cm, inter electrode distance: 5 cm) on the left and right side of the lumbar spine (**Figure 1**) (Behringer et al., 2014). We chose a frequency-modulated current for the $NMES_{SENSOR}$ and $NMES_{MOTOR}$ conditions (pulse shape: triangular biphase, stimulation frequency: 7–14 Hz, contraction time = 1 ms, rest time: 70–142 ms, duration: 5 min) (Tucker et al., 2010). To determine the individual current amplitude for the $NMES_{SENSOR}$ condition, we followed the protocol proposed by Maffiuletti et al. (2011). The participants had to lay relaxed in a prone position. Following electrode positioning and instructions, current amplitude was progressively increased by the investigator from zero to the point of current perception, when the participant indicated initial (lowest) perception of stimulus sensation (tingling, itching, heat). The respective current amplitude was defined as the sensory threshold. After reaching the sensory threshold, the current was reduced to zero again. Threshold determination was repeated twice at each side of the lumbar spine, and the average current was used as the individual sensory threshold. Among all participants, the average sensory threshold current was 3.6 ± 1.3 mA. For the $NMES_{MOTOR}$ condition, the motor threshold was defined as three times the individual sensory threshold, following Kantor et al. (1994). When the calculated current amplitude exceeded 16.1 mA (current density, which the manufacturer declares not to exceed), we used 16.1 mA as the motor threshold. Among all participants, the average motor threshold current was 9.7 ± 2.5 mA.

Experimental Protocol

Each participant completed three sitting periods of 4.5 h each within 10 days to test the three conditions (CONTROL, $NMES_{SENSOR}$ and $NMES_{MOTOR}$). The order of the conditions was randomized for each subject. Each sitting period started between 7:00 and 8:00 a.m. Participants sat at a desk on a height-adjustable chair to conduct their regular office activities (e.g., reading and writing documents, laptop computer work) (**Figure 1**). Kinematic data were collected for periods of 15 min throughout the 4.5 h sitting period. Between the intervals, short breaks (<5 min) were allowed, e.g., to use the restroom. Stiffness data of the back muscles were collected before and after the sitting period. One examiner collected all kinematic and stiffness data and supervised the NMES. For the $NMES_{SENSOR}$ and $NMES_{MOTOR}$ conditions, NMES was applied at the sensory or motor threshold for 5 min, followed by a 10-min recovery phase. The first electrical stimulation started after 15 min and was applied 17 times during the 4.5-h sitting period.

Stiffness Measurement

We measured the muscle's resistance against deformation as a surrogate measure for muscle stiffness (Simons and Mense, 1998; Wilke et al., 2018) using a custom-built indentometer device. The handheld device was used in a previous study to non-invasively investigate back muscle stiffness (Kett and Sichting, 2020). A prior study by Wilke et al. (2018) on the gastrocnemius muscle indicates an excellent test-retest reliability (intraclass correlation coefficient: 0.84) for the indentometer device (Wilke et al., 2018). As described by Kett and Sichting (2020), the device contains a load cell (Compression Load Cell FX1901, TE Connectivity, Schaffhausen, Switzerland) and a membrane potentiometer (ThinPot 10 kOhm, Spectra Symbol, Salt Lake City, USA) to measure the resistance force and displacement of a circular indentation probe (Ø 11.3 mm) (Kett and Sichting, 2020). As depicted in **Figure 1B**, the probe was placed two centimeters to the right lateral side of the lumbar and thoracic spine to measure the muscles alongside the spine. For the stiffness measurements, the participants lay down in a relaxed prone position. Each measurement consisted of three consecutive indentations, where the investigator compressed the tissue up to a defined indentation depth. The indentation depth was 12 mm for the muscles alongside the lumbar spine. The indentation depth at the muscles alongside the thoracic spine was 8 mm. The corresponding force of resistance was recorded to calculate the passive muscle stiffness.

Acquisition and Analysis of Kinematic Data

Motion data were captured at 30 Hz using an eight-camera motion analysis system (Vicon Motion Systems Ltd., Oxford, United Kingdom). Three retro-reflective skin markers (diameter: 16.0 mm) were placed on the spinous processes of the vertebrae T5 (thoracic spine), T10 (thoracic spine), and L3 (lumbar spine) (**Figure 1**) (Claus et al., 2009; Korakakis et al., 2014) to quantify three-dimensional motions of the back. We modified the chair's backrest and participant's garment to guarantee the markers' continuous visibility (**Figure 1**). Data processing was performed using Vicon Nexus 2.8.1 (Vicon Motion Systems Ltd, UK) and R Studio (R Foundation for Statistical Computing, Vienna, Austria). Motion capture data were downsampled to 1 Hz, and a recursive fourth-order Butterworth low-pass filter (5 Hz cutoff frequency) was used to process the kinematic data.

The thoracolumbar angle (θ_{TH}), calculated as the angle between T5, T10, and L3, was used to evaluate sitting posture. Further, sample entropy (SampEn), a time series regularity measure, was used to evaluate postural variation. According to (Delgado-Bonal and Marshak, 2019), SampEn measures with a tolerance r the regularity of patterns similar to a given template of a given length (further defined as m) (Delgado-Bonal and Marshak, 2019). The continuously recorded θ_{TH} was used for the time series analysis. A lower value of SampEn during a given sitting period indicates more self-similarity in the time series and, thereby, a lower postural variation. Based on protocols from previous postural control studies, $m = 2$ was utilized and a tolerance of $r = 0.1^{*}$SD was chosen (Søndergaard et al., 2010; Lubetzky et al., 2018). The Package "TSEntropies" in R Studio was used to compute SampEn.

Data Analysis and Statistics

All statistical analyses were carried out using IBM SPSS Statistics, version 25 (IBM, Armonk, New York, USA). Means and standard deviations (mean ± SDs) were calculated for the stiffness/kinematic data, and a Shapiro–Wilk test of normality was performed. Day-to-day variability (interday coefficient of variation, CV%) has been analyzed for the stiffness measurements before the sitting period on the three days of data recording. A two-way repeated ANOVA was used for normally distributed data to analyze the impact of sitting time and conditions on back muscle stiffness of the lumbar and thoracic spine. When a significant main effect between conditions (CONTROL, $NMES_{SENSOR}$ and $NMES_{MOTOR}$) and/or time (measurement before and after the sitting period) was observed, a Bonferroni-adjusted *post-hoc* analysis was performed.

Further, we performed one-way repeated ANOVAs for normally distributed data to test whether sitting posture (mean spinal curvature) and postural variation (SampEn) were different between the three conditions (CONTROL, $NMES_{SENSOR}$ and $NMES_{MOTOR}$). If a significant main effect was observed between conditions, a Bonferroni-adjusted *post-hoc* analysis was performed. The level of significance was set at $\alpha = 0.05$ for all statistical tests.

RESULTS

The day-to-day variability was 9.8 and 16.6% for the lumbar and thoracic muscle stiffness measurements. Further, the two-way repeated ANOVA indicated no significant differences between the initial stiffness measurements (before sitting) on the 3 days of data recording. Changes in lumbar and thoracic muscle stiffness after the 4.5-h sitting period are presented in **Figure 2** for each condition (CONTROL, $NMES_{SENSOR}$, and $NMES_{MOTOR}$). Lumbar and thoracic muscle stiffness increased significantly for CONTROL (lumbar: +16.5%, pre: 2.5 ± 0 .5 vs. post: 2.9 ± 0.5 N/mm, $p < 0.01$; thoracic: +9.4%, pre: 2.9 ± 0.6 vs. post: 3.2 ± 0.6 N/mm, $p = 0.02$), and $NMES_{SENSOR}$ (lumbar: +17.6%, pre: 2.3 ± 0.5 vs. post: 2.7 ± 0.5 N/mm, $p = 0.02$; thoracic: +12.8%, pre: 3.2 ± 0.8 vs. post: 3.6 ± 0.9 N/mm $p = 0.045$). For $NMES_{MOTOR}$, lumbar muscle stiffness decreased significantly by −10.8% (pre: 2.5 ± 0.6 vs. post: 2.2 ± 0.5 N/mm, $p = 0.06$), but thoracic muscle stiffness did not change significantly (+4.1%, pre: 3.1 ± 0.6 vs. post: 3.2 ± 0.8 N/mm, $p = 0.36$).

Among the conditions, changes in lumbar muscle stiffness differed significantly (**Figure 2**). $NMES_{MOTOR}$ was significantly different from CONTROL and $NMES_{SENSOR}$ ($p < 0.01$, respectively). In contrast, no significant difference was found between CONTROL and $NMES_{SENSOR}$ ($p = 0.73$). No significant differences were found between the NMES conditions for the changes in thoracic muscle stiffness (**Figure 2**).

Besides muscle stiffness, we analyzed sitting posture and postural variation to test for differences between the conditions. During the 4.5-h sitting period, the average θ_{TH} was 164.1 ± 3.7° for CONTROL, 165.0 ± 4.6° for $NMES_{SENSOR}$, and 165.6 ± 4.2° for $NMES_{MOTOR}$. A one-way repeated ANOVA revealed no significant differences between the conditions. Similarly, no statistically significant differences were found for postural variation. On average, SampEn was 0.3 ± 0.1 for CONTROL, 0.3 ± 0.1 for $NMES_{SENSOR}$, and 0.3 ± 0.1 for $NMES_{MOTOR}$.

DISCUSSION

This study aimed to assess the importance of regular muscle activity during prolonged chair-sitting. We hypothesized that regular muscle contractions could counter an increase in passive back muscle stiffness. To test the hypothesis, we applied bouts of electrical stimulation to the lumbar back area—both at a sensory and a motor threshold level. The most important finding was that the stimulation at the

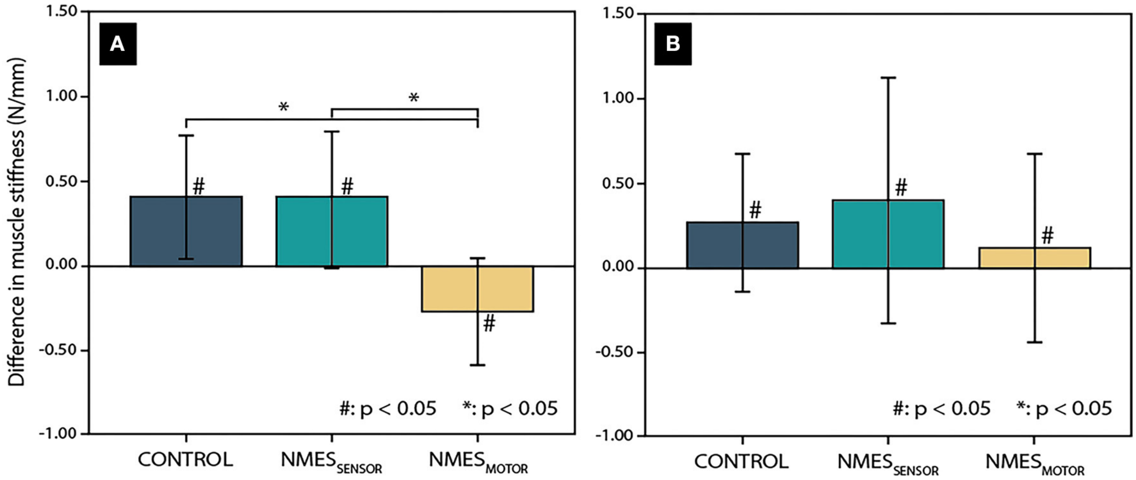

FIGURE 2 | Change in muscle tissue stiffness after a 4.5-h sitting period in the lumbar spine **(A)** and thoracic spine **(B)** for the three conditions (CONTROL: without neuromuscular electrical stimulation, $NMES_{SENSOR}$: neuromuscular electrical stimulation at the sensory threshold, and $NMES_{MOTOR}$: neuromuscular electrical stimulation at the motor threshold.) Significant differences related to the sitting period are indicated by a hash sign (#), while an asterisk (*) indicates significant differences between the tested conditions.

motor threshold level during a 4.5-h sitting period led to a significant decrease in back muscle stiffness. Another important result was that the stimulation at the sensory threshold level showed no effect on back muscle stiffness. Similar to the control condition (no electrical stimulation involved), we found a significant increase in back muscle stiffness. These results add to the growing body of literature recognizing the importance of regular muscle activity during daily sedentary behaviors (Hamilton, 2018; Kuster et al., 2020; Raichlen et al., 2020).

Consistent with previous findings (Kett and Sichting, 2020), the control condition showed a significant increase in back muscle stiffness of +16.5% in the lumbar spine and of +9.4% in the thoracic spine after a prolonged sitting period of 4.5 h. While the mechanisms for this sitting-related effect remain unclear, most hypotheses revolve around reduced metabolism in muscle tissue due to the low activity of postural muscles during predominantly static chair-sitting postures (Valachi and Valachi, 2003; Visser and van Dieën, 2006; Akkarakittichoke and Janwantanakul, 2017; Raichlen et al., 2020). However, this study did not measure any indicator of muscle tissue metabolisms, such as blood flow or inflammation markers directly, several lines of evidence indicate that the vicious circle of restricted microcirculation and increased muscle stiffness is most pronounced in the often-preferred slump sitting posture. Slumped sitting is characterized by an excessive posterior tilt of the pelvis and decreased lumbar spine lordosis (Claus et al., 2009; Nairn et al., 2013). It is proposed that this posture relies mainly on the passive lumbopelvic structures (e.g., spinal ligaments) to maintain a resting sitting position. Following this argument, previous research has shown that the activity level seems to be lowest during slump sitting (Claus et al., 2009; Mörl and Bradl, 2013; Nairn et al., 2013). Our motion analysis revealed that the average thoracolumbar angle (θ_{TH}) was about 165°. Under the assumption that a θ_{TH} of 180° represents a flat sitting posture, the participants in our study likely spent most of their sitting time in a slump sitting posture ($\theta_{TH} < 180°$). However, caution is required here, since a detailed analysis of sitting postures requires the calculation of angles at the thoracic, thoracolumbar, and lumbar regions. Such an approach was used, for example, by Claus et al. (2009). Despite the uncertainty about the degree of slump sitting, our motion analysis showed that the sitting postures and postural variabilities were generally similar between the three tested conditions. These results strengthen confidence in our findings on the effects of electrical stimulation on back muscle stiffness.

The most prominent finding to emerge from the electrical stimulation interventions is that stimulation at the motor threshold level led to a significant decrease in stiffness of the lumbar back muscles of −10.8% after the 4.5-h sitting period. This finding is likely related to regular muscle contractions. When applying current amplitudes at a motor threshold level, an increasing number of efferent terminal axon branches are excited and result in contractile protein interaction (Hultman et al., 1983; Maffiuletti et al., 2008; Sions et al., 2019). It may be that the rhythmic muscle contractions evoked by the electrical stimulation mimicked the naturally acting blood and lymph pump and thereby enhanced the microcirculation in the muscle tissue (Levine et al., 1990; Pittman, 2000; Tucker et al., 2010). Here we speculate that these processes led to maintenance or restoration of the physiological muscle tissue metabolism, preventing an imbalance in the muscle cell and consequent formations of long-lasting cross-bridges between myosin heads and actin filaments. A similar argument was provided by Hsueh et al. (1997), who showed that electrical stimulation at a motor threshold level reduced the muscle stiffness in muscles with myofascial trigger points (Hsueh et al., 1997). One somewhat unexpected finding of our study was that stiffness of the lumbar back muscles dropped below the baseline measurement after the prolonged sitting period of 4.5 h. The result suggests that the electrical stimulation at the motor threshold level not only compensates for increased muscle stiffness but further promotes muscle relaxation, similar to massage interventions (Kett and Sichting, 2020). Another interesting result was that we found significant effects of the electrical stimulation for the lumbar region but not for the thoracic region. This result may be explained by the fact that NMES recruits muscle zones close to the electrode. The recruitment diminishes proportionally with increasing distance from the electrode (Vanderthommen et al., 2000). Although the results of the thoracic measurements indicate a trend toward a reduced increase in muscle stiffness, considerably more research is required to develop a complete picture of muscle tissue response caudal and cranial to the stimulated area.

In contrast to stimulation at the motor threshold level, our stimulation at the sensory threshold level did not affect lumbar back muscle stiffness. Despite regular stimulation, muscle stiffness increased by 17.6% in the lumbar spine and 12.8% in the thoracic spine over the 4.5-h sitting period. This finding is consistent with a previous study by Hsueh et al. (1997), who also found no effect of electrical stimulation at the sensory level on muscle stiffness. A possible explanation for this result may be that electrical stimulation at the sensory threshold level is perceived through somatic sensory receptors mainly located in cutaneous and subcutaneous tissues (Purves et al., 2004). Thus, the low-amplitude currents likely do not trigger muscle contractions (Maffiuletti et al., 2008).

To gain more confidence in our findings, further research could investigate the effects of electrical stimulations in more detail and address some limitations. It would be of interest to identify the muscles of the lower back that were recruited by the electrical stimulation. Here, this study leaves some uncertainties. Further, the precise mechanism which explains the decrease in muscle stiffness in response to impulses at the motor threshold level remains to be analyzed. In this regard, accompanying blood flow measurements are strongly recommended. The effects of electrical stimulation on blood flow are currently limited to lower body muscles (Levine et al., 1990; McNeil et al., 2006; Tucker et al., 2010). Another question that remains to be answered is how to translate the muscle response elicited by the electrical stimulation into regular movements and voluntary contractions. For this study, we applied low-frequency electrical stimulation, which seems comparable to muscle activities during moderate aerobic exercises at 60–70% of the peak heart rate (Deley et al., 2005). However, considerably more work needs to be done to determine the contraction forces elicited by stimulation at the motor threshold level relative to maximum voluntary contractions. To quantify muscle contractions, a study similar to this one should be carried out using assessment techniques that are independent of electrical signals between the nerve and muscle, including laser doppler myography (Scalise et al., 2013; Casaccia et al., 2015), acoustic myography (Harrison et al., 2013; Harrison, 2018), or piezoresistive sensors (Esposito et al., 2018).

Notwithstanding these limitations, our study seems to support the Inactivity Missmatch Hypothesis proposed by Raichlen et al. (2020). They suggest that human physiology is adapted to more consistent muscle activity throughout the day associated with a combination of both moderate-to-vigorous physical activity and sedentary time spent in active rest postures. In this regard, Raichlen et al. (2020) showed that resting postures in hunter-gatherers involve increased muscle activity that is greater than chair-sitting sedentary postures used in industrialized populations (Raichlen et al., 2020). Although these findings are limited to electromyographic measurements of leg muscles, they align with a growing body of literature, which agrees on generally low muscular activity during chair-sitting (Claus et al., 2009; van Dieën et al., 2009). We add to these findings by providing the first experimental evidence that regular contractions of lumbar back muscles during prolonged chair-sitting can counter an increase in passive muscle stiffness.

Albeit this study used electrical stimulation to mimic regular bouts of increased muscular activity, the results support the evidence-based guidelines for frequent active breaks during prolonged periods of chair-sitting (Thorp et al., 2014; Waongenngarm et al., 2018). Another important practical implication of this study is that NMES revealed its potential as an intervention strategy for people forced to engage in prolonged periods of chair-sitting, such as professional drivers or people with disabilities. A future study could assess the long-term effects of electrical stimulation at the motor threshold level during prolonged sitting periods on low back pain development. Another question raised by this study is whether populations that spend most of their sedentary time in active rest postures, like the Hadza (Raichlen et al., 2020), would show a minor increase in back muscle stiffness. Following these avenues would be a fruitful area for further work. It might help gain a broader understanding of musculoskeletal disorders associated with chair-sitting sedentary postures used in industrialized populations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Ethics Committee of the Faculty of Behavioral and Social Sciences at Chemnitz University of

Technology. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AK, FS, and TM designed the study, analyzed, interpreted the data, and wrote the manuscript. AK and FS collected and processed the data and prepared all figures. All authors contributed to the article and approved the submitted version.

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A Cross-Sectional Study of the Relationship Between Exercise, Physical Activity, and Health-Related Quality of Life Among Japanese Workers

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Background: Studies have determined that exercise and physical activity positively affect physical and mental health, and that healthy workers contribute to increased work performance. The relationship between the time spent on exercise during leisure time and physical activity, including work, with health-related quality of life (HRQOL) in workers is unclear, with variations observed between occupational types. This cross-sectional study examined these associations among Japanese workers from various occupations during the COVID-19 pandemic.

Methods: An Internet-based national health survey—Collaborative Online Research on Novel-coronavirus and Work-study (CORoNaWork study)—was conducted among 33,087 Japanese workers in December 2020. After excluding invalid responses, 27,036 participants were categorized into four and five groups according to exercise and physical activity time, respectively. Each group's scores were compared on each of the four questions on the Japanese version of the Centers for Disease Control and Prevention Health-Related Quality of Life (CDC HRQOL-4) using generalized linear models. Age-sex adjusted and multivariate models were used to compare each index of the CDC HRQOL-4.

Results: Compared to the reference category (almost never), any level of exercise (ORs 0.56–0.77) and physical activity (ORs 0.93–0.88) were associated with better self-rated health in the multivariate model. Any exercise was also associated with significantly reduced odds for physically or mentally unhealthy days; however, high levels of physical activity ($\geq$120 min/day) were associated with significantly increased odds for these outcomes (ORs = 1.11 and 1.16, respectively).

Conclusions: The results suggest that exercise habits are more critical to workers' HRQOL than physical activity. Interventions that encourage daily exercise even for a short time are likely to be associated with better workers' health and work performance.

Keywords: exercise, physical activity, health-related quality of life, self-rated health, worker

INTRODUCTION

People who frequently engage in physical activity and have good exercise habits have good physical and mental health (Goodwin, 2003; Inoue et al., 2008; Schuch et al., 2016; Bull et al., 2020). Furthermore, studies regarding the occupational field show that absenteeism due to health problems decreased with increased physical activity (López-Bueno et al., 2020); additionally, regular aerobic exercise and strength training prevented work productivity loss due to presenteeism (Walker et al., 2017a), increased physical activity and reduced work restrictions (Walker et al., 2017b). Therefore, we believe that workers require appropriate exercise habits for good health and enhanced work performance.

The coronavirus disease 2019 (COVID-19) pandemic significantly and globally impacted daily life and work in 2021. In Japan, the COVID-19 infection spread rapidly in April 2020. Initially declaring a state of emergency in several prefectures on April 7, 2020, the government expanded it to the whole country on April 16, 2020. Under this declaration, people were urged to avoid the three Cs (closed space with poor ventilation, crowded places with many people nearby, and close-contact settings, such as close-range conversations) and refrain from going out to reduce contact opportunities by 80%. Additionally, to prevent the spread of infection, facilities where many people gather, such as department stores, movie theaters, and sports clubs and playgrounds were requested to be closed (Office for Novel Coronavirus Disease Control CS Government of Japan, 2021).

A study conducted in China in February 2020 reported that about 75% of the target population participated in physical activity at least twice a week before the pandemic; however, 65% of the population had low physical activity levels during the pandemic (Qi et al., 2020). Additionally, in a survey conducted among 5,000 Japanese in February 2020, 40.3% of respondents reported decreased physical activity compared to the same month the previous year (before the pandemic) (Yamada et al., 2020). Another study showed that the COVID-19 home confinement negatively affected physical activity (Ammar et al., 2020). Considering the above, it can be discerned that the state of emergency implemented in April 2020 affected people's exercise habits and reduced physical activities, such as walking, in Japan.

As recognized, exercise and physical activity are associated not only with diseases and work performance but also with the quality of life (QOL). For example, studies have shown that increased physical activity, higher energy physical activity, and exercise interventions are associated with a higher quality of life in older adults, pregnant women, young adult cancer patients, and colorectal cancer patients (Phillips et al., 2013; Krzepota et al., 2018; Zhi et al., 2019; Singh et al., 2020). As for workers, a meta-analysis of physical activity and HRQOL among office workers found that physical activity improved the latter (Nguyen et al., 2021). One study reported a positively correlation between the frequency of physical activity among construction workers and HRQOL (Malak, 2017). Conversely, a study investigating the relationship between lifestyle and QOL of manufacturing industry workers showed that the low QOL group had significantly longer physical activity time than the high QOL group (Rabanipour et al., 2019). Therefore, we believe that further research on the relationship between exercise/physical activity and QOL of workers, regardless of their occupation, is needed. In the present study, we focused on the relationship between exercise, physical activity, and health-related quality of life (HRQOL), which is defined as an individual's or group's perceived physical and mental health over time (Centers for Disease Control Prevention of USA, 2021a).

Understanding the relationship between the time spent exercising during leisure, time spent engaged in physical activity, including work, and HRQOL will provide important information for developing interventions to improve workers' health and work performance. Furthermore, we thought that it would be useful to investigate these relationships during the COVID-19 pandemic, mainly because physical activity tends to be restricted. As such, this study investigated the relationship between exercise, physical activity, and HRQOL using a large-scale Internet survey of workers conducted during the COVID-19 pandemic.

METHODS

Study Design and Setting

The present cross-sectional study used a part of the baseline data of a prospective cohort study conducted by a research group at the University of Occupational and Environmental Health in Japan. The study is called the Collaborative Online Research on Novel-coronavirus and Work-study (CORoNaWork study). A Japanese Internet survey company—Cross Marketing Inc. Tokyo—implemented the study, which involved a self-administered questionnaire survey. Baseline survey data were collected from December 22–25, 2020. Incidentally, the baseline survey occurred during the third wave of the pandemic when the number of COVID-19 infections and deaths was overwhelmingly higher than in the first and second waves; therefore, Japan was on high alert. The details of the study protocol are provided by Fujino et al. (2021).

Abbreviations: HRQOL, health-related quality of life; WHO, World Health Organization; COVID-19, coronavirus disease 2019; CDC, centers for disease control and prevention; GLMs, generalized linear models.

Participants

The participants were between 20 and 65 years and working at the time of the baseline survey. A total of 33,087 adults participated in the CORoNaWork study, which employed stratified cluster sampling by gender, age, region, and occupation. A database of 27,036 individuals was created by excluding 6,051 who were determined to have provided invalid responses. Invalid responses include abnormally short response time (<6 min), abnormally short height (<140 cm), abnormally low weight (<30 kg), different answers to similar questions in the survey (e.g., inconsistent answers to questions about living with family members), and incorrect answers to questions used to identify inappropriate responses (e.g., choosing the third-highest number from the following five numbers).

Questionnaire

The questionnaire items are described in detail by Fujino et al. (2021). We used questionnaire data on sex, age, presence of illness under medical treatment, average exercise time during leisure time per day, average physical activity time including work per day, educational background, area of participants' residence, job type, working hours per day, telecommuting frequency, and HRQOL. Exercise time during leisure time per day, and average physical activity time, including work per day, were ascertained based on the following question: "On average, how much time do you spend on the following activities?—Exercise time/Physical activity (including work)." The response options included more than 2 h/more than 1 h/more than 30 min/<30 min/almost never. These questions were asked in a matrix format to make it easier for the participants to answer. We randomly assigned half of the subjects to each group to check the reliability of the responses between subjects and found no significant difference in the means [SD] between the two groups for either the exercise or physical activity questions (3.11 [1.1] vs. 3.11 [1.1], $p = 0.984$ and 3.15 [1.6] vs. 3.16 [1.6], $p = 0.724$, respectively). Moreover, a validity study using the results of a 24-h physical record and questions about activity during work and leisure times showed a moderate to strong correlation between the two values (Fujii et al., 2011). From this result, we believe that the questions in this study have a certain degree of validity.

The CDC HRQOL-4, developed by the Centers for Disease Control and Prevention (CDC) as a tool for public health surveillance (Centers for Disease Control, 2001), was used to assess overall HRQOL. The CDC HRQOL-4 includes the following four items: (a) self-rated health, (b) the number of physically unhealthy days in the past 30 days, (c) the number of mentally unhealthy days in the past 30 days, and (d) the number of days with activity limitation in the past 30 days. Self-rated health was recorded as excellent, very good, good, fair, or poor and ranged from a minimum score of 1 to a maximum of 5, with lower scores indicating better self-rated health (Centers for Disease Control Prevention of USA, 2021b).

International studies have provided support for the reliability and validity of the CDC HRQOL-4. In 2020, the Japanese version of the CDC HRQOL-4 was developed and evaluated for its reliability and validity for use with workers (Chimed-Ochir et al., 2020a). Furthermore, because the CDC HRQOL-4 was found to be associated with indicators of work functioning impairment (Chimed-Ochir et al., 2020b), the measurement of HRQOL is helpful for both health and labor-management assessment of workers.

Outcomes and Measures

As for outcome variables, we used CDC HRQOL-4 scores for self-rated health (5-point Likert scale: 1 = excellent, 2 = very good, 3 = good, 4 = fair, and 5 = poor) and the number of days in the past 30 days reported for physically unhealthy days, mentally unhealthy days, and activity limitation days. The number of physically unhealthy days, mentally unhealthy days, and activity limitation days were categorized as more than 5 days and <5 days based on the 75th percentile value of physically unhealthy days and mentally unhealthy days.

As for the exposure variables, we used exercise time during leisure and physical activity time, including work. Based on the responses to the questionnaire, the participants were divided into groups. For exercise time during leisure, there were only a few responses of more than 2 h; accordingly, we classified them into four groups: ≥60 min/day, 30–59 min/day, 1–29 min/day, and almost never. Participants were also classified into five groups according to their physical activity time, including work: ≥120 min/day, 60–119 min/day, 30–59 min/day, 1–29 min/day, and almost never. The following items were used as confounding factors. Sex, age (20–29, 30–39, 40–49, 50–59, and ≥60 years of age), educational background (junior or senior high school, junior college, or vocational school, university, or graduate school), and presence of illness under medical treatment were used as personal characteristics. Job type (desk work, hospitality work, manual work), telecommuting frequency (4 days/week or more, 2–3 days/week, 1 day/week or less, almost never), working hours per day (<8 h/day, 8–9 h/day, 9–11 h/day, 11 h/day or more) were used as work-related factors.

Statistical Method

To analyze the four domains of CDC HRQOL-4 among the four groups of exercise time or the five groups of physical activity time, we used generalized linear models (GLMs). They included logistic regression and ordinal logistic regression, with two models of the sex-age-adjusted model and the multivariate model. For the multivariate model, we added variables related to educational background, presence of illness under medical treatment, job type, telecommuting frequency, and working hours per day as explanatory variables to GLMs. In all the tests, the threshold for significance was set at $P < 0.05$. We used SPSS 25.0 J analytical software (IBM, NY, USA) for statistical analyses.

RESULTS

Participants and Descriptive Data

A total of 13,814 (51.1%) respondents were men, and the mean age was 47.0 years (SD: 10.5). Of the total population, 13,171 (48.7%) workers had a university or graduate school education, 13,468 (49.8%) were engaged in desk work, and 21,276 (78.7%) did not telecommute. As for exercise during leisure, 3,202 (11.8%) participants spent 60 min/day or more, 4,210 (15.6%) spent 30–59 min/day, 6,123 (22.6%) spent 1–29 min/day, and 13,501 (49.9%) reported they almost never exercised. As for physical activity time including work, 6,843 (25.3%) participants spent more than 120 min/day, 3,062 (11.3%) spent 60–119 min/day, 4,257 (15.7%) spent 30–59 min/day, 4,770 (17.6%) spent 1–29 min/day, and 8,104 (30.0%) reported they almost never spent time engaged in physical activity (**Table 1**). The relationship between exercise time and physical activity time is presented in **Table 2**. Participants with almost never physical activity tended to have never exercised. The group spent more than 120 min/day in physical activity time. Notably, the percentage with almost never exercise time was the largest.

Comparison of the Scores on the CDC HRQOL-4 Among the Exercise Time Groups

In the age–sex-adjusted and multivariate models, we used GLMs to compare the CDC HRQOL-4 scores for each of the four groups according to exercise time (**Tables 3, 4**). In the multivariate model for self-rated health (lower scores indicating better self-rated health), compared to the almost never group, all groups showed significantly lower odds ratios (OR [95%CI]); ≥60 min/day (0.56 [052–0.60]), 30–59 min/day (0.67 [0.63–0.71]), and 1–29 min/day (0.77 [0.72–0.81]). For ≥5 days of physically and mentally unhealthy days, all groups showed significantly lower odds ratios than the almost never group. For ≥5 days with activity limitation, the 30–59 and 1–29 min/day groups showed significantly lower odds ratios compared to the almost never group (0.87 [0.78–0.97], 0.84 [0.76–0.93]).

Comparison of the Scores on the CDC HRQOL-4 Among the Physical Activity Time Groups

The age–sex-adjusted and multivariate models were also used to compare the CDC HRQOL-4 scores for each of the five groups according to physical activity time (**Tables 3**, **4**). In the multivariate model for self-rated health, compared to the almost never group, all groups showed significantly lower odds ratios (OR [95%CI]); ≥120 min/day (0.93 [0.88–1.00]), 60–119 min/day (0.80 [0.74–0.87]), 30–59 min/day group (0.84 [0.78–0.90]), and 1–29 min/day group (0.88 [0.82–0.94]). For ≥5 days of physically and mentally unhealthy days, compared to the almost never group, the ≥120 min/day group showed significantly higher odds ratios (1.11 [1.03–1.20] and 1.16 [1.08–1.25]).

TABLE 1 | Participants' characteristics.

Items	*n* (%)/M (SD)	
N	27,036	(100)
Sex, male	13,814	(51.1)
Age		
20–29	1,905	(7.0)
30–39	4,858	(18.0)
40–49	8,011	(29.6)
50–59	9,012	(33.3)
≥60	3,250	(12.0)
Education		
Junior or senior high school	7,321	(27.1)
Junior college or vocational school	6,544	(24.2)
University or graduate school	13,171	(48.7)
Presence of Illnesses that require hospital treatment.	9,510	(35.2)
Job type		
Desk work	13,468	(49.8)
Hospitality work	6,927	(25.6)
Manual work	6,641	(24.6)
Telecommuting frequency		
≥4 days/week	2,790	(10.3)
2–3 days/week	1,477	(5.5)
≤1 day/week	1,493	(5.5)
None	21,276	(78.7)
Working hours per day		
<8 h/day	5,334	(19.7)
8–9 h/day	14,848	(54.9)
9–11 h/day	5,541	(20.5)
≥11 h/day	1,313	(4.9)
Exercise time in leisure time		
≥60 min/day	3,202	(11.8)
30–59 min/day	4,210	(15.6)
1–29 min/day	6,123	(22.6)
Almost never	13,501	(49.9)
Physical activity time including work		
≥120 min/day	6,843	(25.3)
60–119 min/day	3,062	(11.3)
30–59 min/day	4,257	(15.7)
1–29 min/day	4,770	(17.6)
Almost never	8,104	(30.0)
CDC HRQOL−4		
Self-rated health	3.48	(0.93)
Physically unhealthy days, ≥5 days/month	7,395	(27.4)
Mentally unhealthy days ≥5 days/month	7,010	(25.9)
Days with activity limitation ≥5 days/month	3,686	(13.6)

CDC HRQOL−4: The Centers for Disease Control and Prevention health-related quality of life−4.

DISCUSSION

This study clarified the relationship between HRQOL (self-rated health and unhealthy days), exercise time during leisure, and physical activity time, including work. The relationship between exercise time and HRQOL showed that better self-rated health was associated with an increase in time spent exercising, even after adjusting for personal characteristics and work-related factors. Furthermore, the results suggest that exercise, even for a short time, is associated with fewer physically and mentally unhealthy days. The results of this study are similar to those of previous studies conducted on adults in various regions (Brown et al., 2004; Södergren et al., 2008; Abuladze et al., 2017; Hsieh et al., 2018). For instance, a study has shown that those with poor self-rated health had approximately twice the risk of mortality compared to those with good self-rated health

TABLE 2 | Prevalence of exercise time in leisure time and physical activity time including work.

		Total	Exercise time in leisure time								*p*
			≥60 min/day		30–59 min/day		1–29 min/day		Almost never		
			n	(%)	*n*	(%)	*n*	(%)	*n*	(%)	
Physical activity time including work	≥120 min/day	6,843	938	(13.7)	1,027	(15.0)	1,504	(22.0)	3,374	(49.3)	<0.001
	60–119 min/day	3,062	1,047	(34.2)	565	(18.5)	569	(18.6)	881	(28.8)	
	30–59 min/day	4,257	520	(12.2)	1,570	(36.9)	921	(21.6)	1,246	(29.3)	
	1–29 min/day	4,770	329	(6.9)	596	(12.5)	2,127	(44.6)	1,718	(36.0)	
	Almost never	8,104	368	(4.5)	452	(5.6)	1,002	(12.4)	6,282	(77.5)	

TABLE 3 | Odds ratios of self-rated health for exercise time in leisure time and physical activity time including work.

Parameters	Items/Options	*n*	M	(SD)	Age-sex adjusted			Multivariate*		
					OR	95% CI	*p*	OR	95% CI	*p*
Self-rated health	**Exercise time in leisure time**									
	≥60 min/day	3,202	3.25	(1.01)	0.60	[0.51–0.60]	<0.001	0.56	[0.52–0.60]	<0.001
	30–59 min/day	4,210	3.35	(0.96)	0.71	[0.62–0.71]	<0.001	0.67	[0.63–0.71]	<0.001
	1–29 min/day	6,123	3.44	(0.91)	0.81	[0.72–0.81]	<0.001	0.77	[0.72–0.81]	<0.001
	Almost never	13,501	3.59	(0.90)	Reference			Reference		
	Physical activity time including work									
	≥120 min/day	6,843	3.51	(0.94)	0.99	[0.93–1.05]	0.736	0.93	[0.88–1.00]	0.037
	60–119 min/day	3,062	3.34	(0.97)	0.81	[0.75–0.88]	<0.001	0.8	[0.74–0.87]	<0.001
	30–59 min/day	4,257	3.39	(0.94)	0.85	[0.79–0.91]	<0.001	0.84	[0.78–0.90]	<0.001
	1–29 min/day	4,770	3.45	(0.91)	0.88	[0.82–0.94]	<0.001	0.88	[0.82–0.94]	<0.001
	Almost never	8,140	3.57	(0.91)	Reference			Reference		

OR, odds ratio; CI, confidence interval.
**Multivariate are adjusted for age, sex, education, job type, telecommuting frequency, and working hours per day.*
Self-rated health takes a range from a minimum of 1 to a maximum of 5, with lower scores indicating better self-rated health.

(DeSalvo et al., 2006). This implies that even short exercise sessions may contribute to better health and fewer physically and/or mentally unhealthy days. These results provide valuable information while considering interventions to address exercise habits among workers.

Regarding the relationship between physical activity, including work, and HRQOL, more than 120 min/day had a lower impact on self-rated health compared to <120 min/day; moreover, it was associated with an increase in the number of physically and mentally unhealthy days compared to the almost never group. The results are comparable to a study that found no physical activity, more than 90 min of physical activity, and a high frequency of physical activity associated with an increase in unhealthy days (Brown et al., 2004). Regarding physical activity time and mental health, a previous study found that more exercise time during leisure was negatively associated with depression; however, it was not significantly associated with more work-related physical activity time (Munehiro et al., 2016). Other studies have shown that strenuous exercise negatively affects the immune system, such as IL-2 production and leukocyte responses (Shephard et al., 1994) and that increased physical activity increases the risk of musculoskeletal disorders (Hootman et al., 2001). Therefore, physical activity that exceeds 120 min/day may not be appropriate, as it is associated with reduced HRQOL.

For the days of activity limitation, the results suggest an association between exercise time of fewer than 60 min/day and a decrease in the days of activity limitation. In comparison, no such association was found for exercise time of 60 min or more. This relationship is different from those of other domains of HRQOL (self-rated health, physically unhealthy days, and mentally unhealthy days). This difference may be because daily exercise for a long time increases the risk of injury that may interfere with daily life. Studies have shown that the average recreational runner suffers an injury rate of 2.5–12.1/1,000 h during running, which is one of the most popular forms of exercise (van Mechelen, 1992).

These results indicate that HRQOL may be more strongly related to exercise time during leisure than physical activity time, including work. In particular, having an exercise habit, even for a short time, was associated with good HRQOL. As for physical activity time, including work, longer periods may be associated with lower HRQOL. We found that a large percentage of workers who spend much time in physical activity, including work, tend to do little or no exercise. Therefore, encouraging workers to have a short exercise habit, regardless of their level of

TABLE 4 | Odds ratios of unhealthy days for exercise time in leisure time, and physical activity time including work.

Parameters	Items/Options	*n*	≥5 days	Age-sex adjusted			Multivariate*		
			%	OR	95% CI	*p*	OR	95% CI	*p*
Physically unhealthy days	**Exercise time in leisure time**								
	≥60 min/day	3,202	26.0	0.86	[0.79–0.95]	0.002	0.88	[0.80–0.97]	0.008
	30–59 min/day	4,210	25.3	0.83	[0.77–0.91]	<0.001	0.83	[0.77–0.91]	<0.001
	1–29 min/day	6,123	25.9	0.88	[0.82–0.94]	<0.001	0.88	[0.82–0.95]	0.001
	Almost never	13,501	28.9	Reference			Reference		
	Physical activity time including work								
	≥120 min/day	6,843	30.3	1.18	[1.09–1.27]	<0.001	1.11	[1.03–1.20]	0.007
	60–119 min/day	3,062	27.4	1.09	[0.98–1.19]	0.129	1.05	[0.95–1.18]	0.302
	30–59 min/day	4,257	26.4	1.05	[0.96–1.16]	0.23	1.05	[0.96–1.16]	0.270
	1–29 min/day	4,770	25.0	0.99	[0.91–1.08]	0.832	0.99	[0.91–1.09]	0.883
	Almost never	8,140	26.8	Reference			Reference		
Mentally unhealthy days	**Exercise time in leisure time**								
	≥60 min/day	3,202	23.7	0.81	[0.73–0.88]	<0.001	0.82	[0.74–0.9]	<0.001
	30–59 min/day	4,210	23.6	0.81	[0.75–0.89]	<0.001	0.82	[0.75–0.9]	<0.001
	1–29 min/day	6,123	23.9	0.85	[0.79–0.92]	<0.001	0.85	[0.79–0.93]	<0.001
	Almost never	13,501	28.1	Reference			Reference		
	Physical activity time including work								
	≥120 min/day	6,843	30.1	1.20	[1.12–1.3]	<0.001	1.16	[1.08–1.25]	<0.001
	60–119 min/day	3,062	26.0	1.08	[0.97–1.19]	0.176	1.06	[0.96–1.18]	0.256
	30–59 min/day	4,257	23.8	0.98	[0.89–1.08]	0.701	0.99	[0.89–1.09]	0.768
	1–29 min/day	4,770	22.0	0.91	[0.83–1.00]	0.044	0.92	[0.84–1.01]	0.066
	Almost never	8,140	25.8	Reference			Reference		
Days with activity limitation	**Exercise time in leisure time**								
	≥60 min/day	3,202	14.1	0.97	[0.86–1.10]	0.646	0.99	[0.88–1.12]	0.889
	30–59 min/day	4,210	12.7	0.86	[0.78–0.96]	0.010	0.87	[0.78–0.97]	0.013
	1–29 min/day	6,123	12.1	0.84	[0.76–0.93]	<0.001	0.84	[0.76–0.93]	0.001
	Almost never	13,501	14.5	Reference			Reference		
	Physical activity time including work								
	≥120 min/day	6,843	14.0	0.99	[0.90–1.09]	0.833	0.93	[0.84–1.03]	0.148
	60–119 min/day	3,062	15.1	1.12	[0.99–1.28]	0.063	1.10	[0.97–1.25]	0.142
	30–59 min/day	4,257	13.5	1.04	[0.93–1.18]	0.478	1.04	[0.93–1.18]	0.462
	1–29 min/day	4,770	12.1	0.96	[0.86–1.08]	0.513	0.97	[0.86–1.1]	0.638
	Almost never	8,140	13.7	Reference			Reference		

OR, odds ratio; CI, confidence interval.
**Multivariate are adjusted for age, sex, education, job type, telecommuting frequency, and working hours per day.*
>5 days: Percentage of participants with five or more unhealthy days.

physical activity, including work, could benefit their health and work performance.

According to a study of Japanese workers, 67% do not inculcate the exercise habits recommended by the Ministry of Health, Labor, and Welfare (Matsuo and So, 2021). Another study has shown that public health restrictions related to COVID-19 have further reduced the amount of time spent outdoors (Cindrich et al., 2021). Additionally, approximately 70% of the participants showed a moderate or greater change in physical activity when voluntary restraint of physical movements was recommended (Balanzá-Martínez et al., 2021). Therefore, even as the COVID-19 pandemic continues, it may be a good idea to recommend that exercises be done indoors. For example, interventions—such as sending fitness equipment, watching videos of exercises on YouTube, text messages from health coaches, exercising with home video game consoles, setting up an ergometer at home, and combining home instruction with unsupervised exercise—lead to increased physical activity, continued exercise, and favorable attitudes toward exercise (Halse et al., 2015; Wherry et al., 2019; Tripicchio et al., 2021). Thus, these practices may lead to the formation of exercise habits, thereby resulting in better HRQOL.

LIMITATIONS

This study has several limitations. First, the generalizability of the results is unclear because the CORoNaWork study is an Internet-based survey. However, to reduce sampling bias, sampling was conducted by generation, residence, and occupation. Second, because this was a cross-sectional study, the causal relationship between exercise time, physical activity time, and HRQOL could not be determined. Further research is needed to investigate the causal relationships using experimental designs with workers or employees as the sample population. For example, Emerson et al. (2017) demonstrated that the effects of an exercise and nutrition workplace wellness program reduced stress and improved participants' quality of life. Furthermore, we did not analyze the occupation because we focused on understanding the overall relationship between exercise and physical activity and HRQOL among workers. However, since one study found a negative relationship between sitting time and self-rated health (Wilson et al., 2019), research on the relationship between occupation or job content and HRQOL may be needed in the future. Third, we asked the participants to answer the questions about exercise and physical activity time in a matrix format among the questions about lifestyle. After the question about exercise time, the respondents were asked to answer questions regarding physical activity (including work) to distinguish between exercise and other physical activities. However, since this was a self-administered questionnaire survey, some respondents may have different perceptions of physical activity (e.g., they may have limited their answers about physical activity time to time spent at work). Furthermore, the questionnaire only asked about the duration of exercise during leisure and physical activity, including work, not the intensity of exercise and physical activity. Fourth, this study was conducted during the COVID-19 pandemic. As such, the impact of exercise and physical activity on HRQOL needs to be considered within the environmental context of the pandemic, which might differ under normal circumstances. Considering that the duration of physical activity was affected by the COVID-19 pandemic and that the participants were anxious about the infection, a continuous evaluation is necessary.

CONCLUSIONS

This study investigated the relationship between exercise time during leisure, physical activity time, and HRQOL. These results suggest that exercise time during leisure is associated with better HRQOL than physical activity time, including work. Interventions that encourage workers with no exercise habit to exercise daily, even for a short time, are likely to be associated with better workers' health and work performance.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because, the nature of this research, the participants of this study did not agree to their data being publicly shared, and hence, supporting data was not available. Requests to access the datasets should be directed to Ryosuke Sugano, ryosuke-sugano@med.uoeh-u.ac.jp.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Ethics Committee of the University of Occupational and Environmental Health, Japan (No. R2-079). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

RS wrote the manuscript and analyzed the data. KI reviewed the manuscript, created the questionnaire, analyzed data, and provided advice on interpretation. HE, MT, ST, TN, and SM reviewed the manuscript. YF reviewed the manuscript and contributed to overall survey planning, creating the questionnaire, and securing funding for research. AO reviewed the manuscript, analyzed data, provided advice on interpretation, and secured funding for research. All authors contributed to the article and approved the submitted version.

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What works to reduce sedentary behavior in the office, and could these intervention components transfer to the home working environment?: A rapid review and transferability appraisal

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Background: Working patterns have changed dramatically due to COVID-19, with many workers now spending at least a portion of their working week at home. The office environment was already associated with high levels of sedentary behavior, and there is emerging evidence that working at home further elevates these levels. The aim of this rapid review (PROSPERO CRD42021278539) was to build on existing evidence to identify what works to reduce sedentary behavior in an office environment, and consider whether these could be transferable to support those working at home.

Methods: The results of a systematic search of databases CENTRAL, MEDLINE, Embase, PsycInfo, CINHAL, and SportDiscus from 10 August 2017 to 6 September 2021 were added to the references included in a 2018 Cochrane review of office based sedentary interventions. These references were screened and controlled peer-reviewed English language studies demonstrating a beneficial direction of effect for office-based interventions on sedentary behavior outcomes in healthy adults were included. For each study, two of five authors screened the title and abstract, the full-texts, undertook data extraction, and assessed risk of bias on the included studies. Informed by the Behavior Change Wheel, the most commonly used intervention functions and behavior change techniques were identified from the extracted data. Finally, a sample of common intervention strategies were evaluated by the researchers and stakeholders for potential transferability to the working at home environment.

Results: Twenty-two studies including 29 interventions showing a beneficial direction of effect on sedentary outcomes were included. The most commonly used intervention functions were training ($n = 21$), environmental restructuring ($n = 21$), education ($n = 15$), and enablement ($n = 15$). Within these the commonly used behavior change techniques were instructions on how to perform the behavior ($n = 21$), adding objects to the environment ($n = 20$), and restructuring the physical environment ($n = 19$). Those strategies with the most promise for transferring to the home environment included education materials, use of role models, incentives, and prompts.

Conclusions: This review has characterized interventions that show a beneficial direction of effect to reduce office sedentary behavior, and identified promising strategies to support workers in the home environment as the world adapts to a new working landscape.

Systematic Review Registration: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021278539, identifier CRD42021278539.

KEYWORDS

sitting, occupational, home working, flexible working, behavior change

Introduction

Sedentary behavior is defined as any waking behavior characterized by an energy expenditure ≤1.5 METs while in a sitting, reclining or lying posture (Tremblay et al., 2017). In 2020, the World Health Organization (WHO) recommended that all adults should limit the amount of time they spend being sedentary (World Health Organization, 2020). This recommendation was based on evidence that higher levels of sedentary behavior increase the risk of adverse physical health outcomes including all-cause, cardiovascular disease and cancer mortality, and the incidence of cardiovascular disease, cancer and type 2 diabetes (Dempsey et al., 2020). Importantly, these physical health risks of being highly sedentary are attenuated only with relatively high levels of physical activity (Dempsey et al., 2020). Additional evidence indicates that higher levels of sedentary behavior are also associated with adverse mental health outcomes (Huang et al., 2020; Biddle et al., 2021).

The workplace is a setting associated with high levels of sedentary behavior, with evidence that office-based employees can spend up to 82% of their working day sitting (Parry and Straker, 2013; Hadgraft et al., 2016; Maes et al., 2020; Rosenkranz et al., 2020); equivalent of up to 438 min/day (Parry and Straker, 2013). Consequently, there has been a growth in intervention research designed to support employees to reduce their sitting whilst at work. A recent 2018 Cochrane review of workplace interventions for reducing sitting at work (n = 34 studies; n = 3,397 participants) concluded that there was some evidence for the short-term (i.e., <12 month) benefits of sit-stand desks on reducing time spent sitting (Shrestha et al., 2018). There was insufficient evidence to draw conclusions on the effectiveness of other intervention strategies. The authors highlighted the low quality of the studies and need for further research. However, in the 4 years since this review, there have been a number of other high quality intervention studies, with more beneficial outcomes (e.g., Healy et al., 2016; Edwardson et al., 2018).

Although the findings from these studies are valuable, due to COVID-19 there has been a seismic shift in working patterns in many sectors that requires consideration. In many countries, lockdown restrictions required employees, where possible, to work from home; and there is indication that these restrictions have resulted in permanent changes in working patterns. For example, in the UK it is anticipated that many employees will spend at least a portion of the working week in the home environment through a hybrid home and office working approach, as we adapt to a "new normal" working landscape (British Council for Offices, 2020; BBC News, 2022).

Whilst there are benefits to working at home for some employees (e.g., reduced commuting time and cost, enhanced work-life balance; Vyas and Butakhieo, 2020), there is initial evidence that suggests this shift to working at home has increased sedentary time. For example, compared with not working at home, working at home during COVID-19 was associated with between ∼31 (McDowell et al., 2020) and 110 min (or 24% of working time) (Fukushima et al., 2021) more sitting time per working day. Additionally, in a series of studies in a single workplace evaluating the impact of introducing flexible working (i.e., being able to work remotely away from the office), Olsen and colleagues reported an increase in actual and perceived workplace sitting time when workers were not in the office (Olsen et al., 2018a,b).

Given that working at home appears to have exacerbated already high levels of sitting time exhibited by office-based employees, there is an urgent need to identify potential intervention strategies to support workers as they adapt to this new work setting. The Behavior Change Wheel (BCW) (Michie et al., 2011, 2014) provides a useful framework for intervention

Abbreviations: APEASE, Affordability, Practicability, Effectiveness, Acceptability, Side-Effects, Equity; BCT, Behavior Change Techniques; BCW, Behavior Change Wheel; COM-B, Capability, Opportunity, Motivation-Behavior; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT, Randomized Controlled Trial; ROB, Risk of Bias.

development, which has been successfully used in office-based sedentary research (Munir et al., 2018; Ojo et al., 2019). In short, the BCW involves three stages of intervention development. In the first stage, developers specify the target behavior and identify the sources that influence the behavior. The COM-B model is used to guide identification of the role **C**apability, **O**pportunity and **M**otivation as influential sources on **B**ehavior, and what needs to change. In stage 2, what needs to change is mapped to appropriate intervention functions (e.g., education) and policy categories (e.g., communication/marketing). Finally, in stage 3, developers specify the content of the intervention by identifying which behavior change techniques (BCTs) best serve the intervention functions, and how they should be delivered. A BCT is defined as "an active component of an intervention designed to change behavior" (p. 145). Michie et al. have presented a taxonomy of 93 BCTS, including for example, goal setting and social support (Michie et al., 2013).

In addition to using the BCW to design interventions, sedentary behavior researchers have also used the BCW as a framework to retrospectively examine pre-existing interventions and to determine which BCW intervention functions and BCTs were included, and which were most effective (Gardner et al., 2016; Dunn et al., 2018; Curran et al., 2021). For example, Gardner et al. (2016) reported that workplace interventions incorporating environmental restructuring and education were most promising, and that a range of BCTs may be useful. Given the recent growth of high-quality office-based sedentary behavior intervention research, there is considerable value in identifying which BCW intervention functions and BCTs are associated with effectiveness in this setting. This information could provide a useful and efficient starting point for intervention development in the new home working environment. Indeed, several intervention development frameworks (e.g., Michie et al., 2011; Skivington et al., 2021) recognize that interventions from existing contexts may be adaptable to new contexts.

However, it is acknowledged that the home working environment differs from the office environment, and that those interventions effective in an office setting may not be directly transferable to the home. For example, at home the physical space available to move around, and financial and social resources available to support behavior change may be more limited. Therefore, it is important to also evaluate the potential transferability of effective BCW intervention functions and BCTs in the office to the working at home environment. Within the BCW framework, Michie et al. (Michie et al., 2014; West and Michie, 2022) outline the APEASE criteria that may be applied during intervention development to evaluate the application of similar interventions to a different context. Using the criteria, intervention developers assess the **A**ffordability, **P**racticability, **E**ffectiveness, **A**cceptability, **S**ide-effects, and **E**quity of proposed interventions to assess their potential for transferability to a different context (e.g., Jenkins et al., 2018).

In summary, the revolutionary changes in working practices initiated by COVID-19 have led to considerable growth in working at home. However, this environment appears to be a high risk setting for unhealthy sedentary behavior, and there is a need to support workers to reduce prolonged sitting when working at home. Given the lack of intervention research in this context, there is benefit and efficiency in drawing from the growing evidence base on office-based sedentary interventions. Particularly, findings from high quality studies of intervention strategies that show a beneficial effect will enable identification of what types of interventions work in the office environment, and through appraisal, consideration of the transferability to the home working environment.

Therefore, the overall aim of this rapid review was to identify the types of interventions that have been beneficial in reducing sedentary behavior in healthy adult workers in an office environment, and to appraise the opportunity for transferability to the home working environment. There were three objectives:

1. To identify interventions with a beneficial direction of effect in reducing sedentary behavior in office-based settings.
2. To use the BCW to identify and classify the most commonly used intervention functions and BCTs of interventions with a beneficial direction of effect.
3. In consultation with expert stakeholders, to appraise the potential transferability of components of office-based interventions with a beneficial direction of effect to the home working environment using the APEASE criteria.

Methods

This review was pre-registered to the PROSPERO database (reference number CRD42021278539). In the absence of specific guidelines for reporting of rapid reviews, this study was reported in accordance with PRISMA 2020 guidelines (Page et al., 2021) for reporting systematic reviews (see Supplementary File 1 for PRISMA checklist).

Search methods

Consistent with the Cochrane Rapid Reviews Methods Group guidance (Garritty et al., 2021) a stepwise approach was adopted, and an existing relevant Cochrane systematic review was used as our starting point (Shrestha et al., 2018). We incorporated the studies included in the 2018 Cochrane review into our title and abstract screening stage. We then searched the Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE, Embase, PsycInfo, CINHAL, and SportDiscus from the last search date of the Cochrane review, which was 10 August 2017, to 06 September 2021. Table 1 shows the search strategy adopted.

TABLE 1 Rapid review search strategy by database.

CENTRAL

#1 work*
#2 sedentary
#3 sitting
#4 #2 or #3
#5 office
#6 inactiv*
#7 #5 and #6
#8 #4 or #7
#9 #1 and #8
#10 #9 AND trials
LIMITS: August 2017 – Sept 2021; trials

MEDLINE

#1 (work[tw] OR works*[tw] OR work'*[tw] OR worka*[tw] OR worke*[tw] OR workg*[tw] OR worki*[tw] OR workl*[tw] OR workp*[tw] OR occupation*[tw] OR employe*[tw])
#2 (effect*[tw] OR control[tw] OR controls*[tw] OR controla*[tw] OR controle*[tw] OR controli*[tw] OR controll*[tw] OR evaluat*[tw] OR intervention*[tw] OR program*[tw] OR compare*[tw])
#3 (sedentary OR sitting) OR seated posture OR chair[tiab] OR desk[tiab] OR (office AND inactiv*)
#4 (animals [mh] NOT humans [mh])
#5 #1 AND #2 AND #3 NOT #4
LIMITERS: 2017-current; humans; English language

Embase

#1 sedentary—changed to sedentar*
#2 'sitting'/de—changed to sit*
#3 'seated posture'
#4 seated NEAR/1 posture (term rejected) – changed to seated adj3 posture
#5 chair:ab,ti OR desk:ab,ti
#6 chair:ab,ti
#7 desk:ab,ti
#8 office AND inactiv*
#9 #1 OR #2 OR #4 OR #6 OR #7 OR #8
#10 'work'/de OR work
#11 work*
#12 'occupation'/de OR occupation—changed to occupation*
#13 employe*
#14 #10 OR #12 OR #13
#15 effect
#16 control
#17 evaluat*
#18 intervention*
#19 program
#20 compare
#21 #15 OR #16 OR #17 OR #18 OR #19 OR #20
#22 #9 AND #14 AND #21
#23 #22 AND [embase]/lim
#24 #23 AND [humans]/lim AND [embase]/lim

(Continued)

TABLE 1 Continued

LIMITERS: 2017-current; humans; English language; Embase: journal; article; 18-64 years

CINAHL

S10 S1 AND S2 AND S9 Limiters - Exclude MEDLINE records Search modes - Boolean/Phrase
S9 S3 OR S4 OR S5 OR S6 OR S7 OR S8
S8 (office AND inactive*) or TX (office AND inactive*) or MW (office AND inactive*)
S7 Desk or TX desk or MW desk
S6 Sedentary or TX sedentary or MW sedentary
S5 Seated posture or TX seated posture or MW seated posture
S4 Sitting or TX sitting or MW sitting
S3 Chair or TX chair or MW chair
S2 TX randomized controlled trial or TX controlled clinical trial or AB placebo or TX clinical trials or AB randomly or TI trial or TX intervent* or control* or evaluation* or program*
S1 work* OR (offic* OR busines*) OR occupat*
LIMITERS: 2017-current; humans; English language; 19-44 and 45-64 years

PsycINFO

S25 S13 AND S17 AND S24
S24 S18 OR S19 OR S20 OR S21 OR S22 OR S23
S23 compare
S22 program
S21 intervention*
S20 evaluat*
S19 control
S18 effect
S17 S14 OR S15 OR S16
S16 employe*
S15 occupation
S14 work
S13 S1 OR S2 OR S4 OR S8 OR S11 OR S12
S12 office AND inactive*
S11 S9 OR S10
S10 ab(desk)
S9 ti(desk)
S8 S6 OR S7
S7 ti(chair)
S6 ab(chair)
S5 ab(chair) OR ti(chair)
S4 seated NEAR/1 posture – changed to seated adj3 posture
S3 seated posture
S2 sitting
S1 sedentary
LIMITERS: 2017 – current; English; humans

SportDiscus

S10 S1 AND S2 AND S9
S9 S3 OR S4 OR S5 OR S6 OR S7 OR S8
S8 (office AND inactive*) or TX (office AND inactive*) or MW (office AND inactive*)

(Continued)

TABLE 1 Continued

S7 Desk or TX desk or MW desk
S6 Sedentary or TX sedentary or MW sedentary
S5 Seated posture or TX seated posture or MW seated posture
S4 Sitting or TX sitting or MW sitting
S3 Chair or TX chair or MW chair
S2 TX randomized controlled trial or TX controlled clinical trial or AB placebo or TX clinical trials or AB randomly or TI trial or TX intervent* or control* or evaluation* or program*
S1 work* OR (offic* OR busines*) OR occupat*
LIMITERS: 2017-2021; ENGISH, ACADEMIC JOURNALS

Eligibility criteria

The inclusion criteria for eligible studies were peer reviewed publications in English language that included: (a) healthy (i.e., not recruited to a study focusing on a specific health-related condition, such as back-pain or obesity) adults aged 18 and over; (b) interventions to reduce occupational sitting in office-based settings; (c) a true control arm comparison (i.e., control condition for cross-over design or control group for between subject design; (d) an outcome assessing sedentary behavior during the normal working day reported using either self-reported measures (e.g., activity log, questionnaire) or device measured (e.g., accelerometer) or both, including changes in at least one of: time spent sitting, time spent standing, posture, and number of sitting breaks; (e) a randomized controlled trial (RCTs), cross-over RCT, or cluster RCT design. We only included interventions that showed a beneficial direction of effect for at least one sedentary behavior outcome in comparison to the control at any post-baseline time point, whether or not statistically significant. This criterion was adopted at the full-text stage of screening to be inclusive of interventions with potential, and due to the known shortcomings of relying on statistical significance to make judgements of effectiveness, especially when there are data from low numbers of participants (Wasserstein et al., 2019).

Screening and identification of interventions with a beneficial direction of effect

Covidence review software was used to facilitate study identification. References were imported (including publications associated with the 34 studies from the 2018 Cochrane review), and duplicates identified and removed prior to commencing screening. All five reviewers (AN, SM, CF, DS, and DSi) were involved at each step. Each title and abstract was independently screened by two of the five reviewers. Where titles and abstracts met the eligibility criteria, full texts were located. Screening of a sample of five full text articles was conducted by all team members to calibrate and test the review form. Subsequently, all full-text papers were independently screened by two of the five reviewers, and any disagreements were resolved through discussion within the research team.

Data extraction of study characteristics and assessment of risk of bias

For each included study the data were extracted by one reviewer (SM) to a bespoke excel spreadsheet. The extracted data were subsequently reviewed and checked by one of the four other reviewers (AN, CF, DS, and DSi). Extracted data included general study information, information on study participants (including those included in the analysis of the intervention with a beneficial direction of effect), sedentary behavior measurement instrument, intervention characteristics, and changes in occupational sedentary behavior at assessed time-points post-baseline.

Risk of Bias (RoB) assessment was completed in Covidence using the Cochrane RoB tool and guidance (Higgins et al., 2011). Again, one reviewer (SM) independently conducted RoB for all included studies, and then allocated studies equally across the rest of the team (AN, CF, DS, DSi), each of whom completed the same RoB process independently, then met with SM to discuss and agree final assessments. Included studies were assessed according to (i) sequence generation; (ii) allocation concealment; (iii) blinding of outcome assessments; (iv) incomplete outcome data; (v) selective reporting; (vi) validity of outcome reporting; (vii) baseline comparability/imbalance for age, gender, and occupation of study groups. Each potential source of bias was graded as either high risk (i.e., if there was sufficient detail to demonstrate procedures leading to high risk of bias), unsure (i.e., if there was insufficient detail to make a decision), or low risk (i.e., if there was sufficient detail that high quality procedures had been followed).

Using the BCW to identify and classify the most commonly used intervention functions and BCTs

In order to systematically classify the content of each effective intervention, individual components were extracted and mapped to the BCW intervention functions, and this was undertaken at study level. The intervention functions were defined as articulated by Michie et al. (2014) and included education, persuasion, incentivisation, coercion, training, restrictions, environmental restructuring, modeling, and enablement. We then identified the individual BCTs (Michie et al., 2013) within each BCW intervention component, and the delivery mechanism. These steps were undertaken by one reviewer, checked by a second, and discussed until consensus was reached. Three reviewers (AN, CF, and SM) had undertaken BCT Taxonomy training (bct-taxonomy.com), and at least one of these was involved in each step. Given the potential presence of up to 93 BCTs, in order to adopt a parsimonious approach we focused primarily on those BCTs previously identified as being most commonly used to address the different intervention functions (Michie et al., 2011, 2014).

Using the APEASE criteria to appraise the potential transferability of intervention components

The APEASE criteria were applied by one reviewer and checked by a second for each study to evaluate the transferability of interventions from an office to a home working environment. For each study, we rated the transferability of the included BCTs as transferable, possibly transferable, or not transferable across each of the APEASE criteria.

Following this step, we engaged with seven expert stakeholders to invite their feedback on the potential transferability of the identified intervention functions. These stakeholders had already been invited to be part of a larger research project focusing on developing interventions to reduce sedentary behavior when working at home. These experienced stakeholders were included because they had a remit for workplace health in Scotland, were likely to be involved in the delivery of any resultant intervention (Skivington et al., 2021), and were willing to be involved. Our stakeholders included a senior development officer, and a development officer in workplace health from a Scottish charity that promotes walking for health, employees of The Scottish Government [who had a remit for occupational health ($n = 2$) and for strategy ($n = 1$)], a representative from the health promotion service in Public Health Scotland, and an active travel project officer from a UK charity with a remit for walking and cycling. Initially, we hosted an online meeting with the stakeholders to provide an overview of the context and guidance on applying the APEASE framework. The stakeholders then completed an online questionnaire that listed all of the BCW intervention functions used in the included studies, and associated examples of how the intervention had been delivered in practice. Experts were asked to provide a score of 1, 2, or 3 for each APEASE criteria to indicate transferability from an office environment to a home working environment. A score of 1 indicated transferable; 2 indicated possibly transferable; 3 indicated not transferable. The majority score for each example was identified. Following research team discussion, SM then completed scoring on behalf of the research team. This was checked and discussed with another reviewer (DSi) until consensus was reached. The criterion of effectiveness was excluded since it is based on an evaluation of the intervention in a specific setting, and these interventions have not yet been tested in the home working environment. For ease of presentation and interpretation, the 1–3 scoring was translated as follows: 1 to "+" to represent transferable; 2 to "?" for potentially transferable, and 3 was translated to "–" to represent not transferable.

Results

Inclusion of studies

The PRISMA study flow diagram (Page et al., 2021; Figure 1) details the process of identifying the included studies. A total of 11,557 references were identified during the initial search of six databases, and we also included 43 papers (from 34 studies) included in the 2018 Cochrane review of office-based interventions (Shrestha et al., 2018). We imported 11,600 titles to Covidence for screening. After duplicates were removed, 10,382 titles and abstracts were screened, and 59 reports retrieved for full text screening. Of these, we excluded 37 papers and included 22 in this review. Five studies had more than one intervention arm demonstrating a beneficial direction of effect, consequently 29 interventions arms were included in the review. Of the 34 studies included in the Cochrane review, 11 were included in our review (Chau et al., 2014; Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017).

Characteristics of studies demonstrating a beneficial direction of effect on sedentary behavior

Participants

Table 2 describes the characteristics of the 22 included studies. A total of 1,577 participants were included across the 29 intervention arms, with sample sizes at baseline ranging from 6 (Li et al., 2017) to 196 (Blake et al., 2019) participants, and with an average of 49 (±46) participants in each intervention arm. All participants worked in an office-based role (e.g., administrative, financial services, managerial, customer services) from public and private sectors including universities, government, an environmental agency, a health promotion unit, construction services, an energy company, and a national health service. The studies were undertaken in 13 countries including China, Australia, Netherlands, Denmark, Greenland, Belgium, South Africa, USA, Canada, England, India, Spain, or New Zealand. Sixteen studies reported the gender composition of the sample, and in 14 of these studies there was a higher proportion of

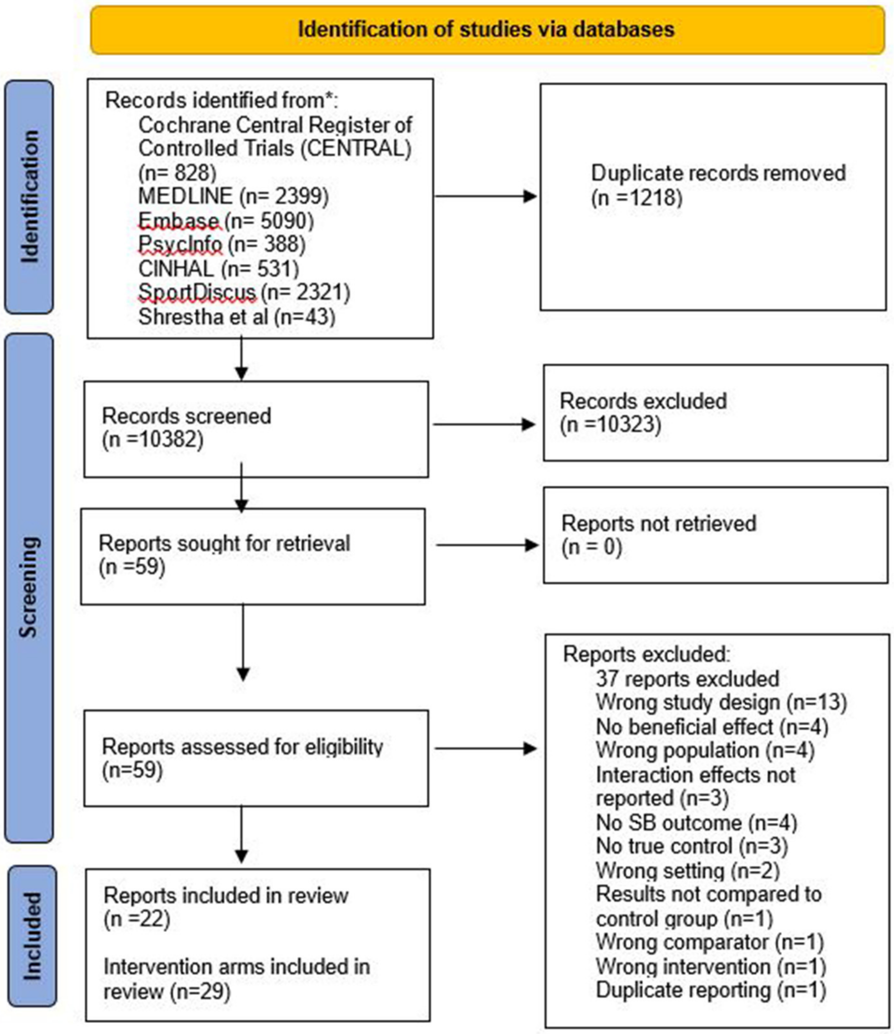

FIGURE 1
PRISMA flow diagram obtained from Covidence showing the study selection process.

female participants. All participants were of working age 18–65 years old, and the mean age of the participants was 40.86 (±3.81) years. All participants were healthy and spent most of the working day in a seated posture, for example at a desk, computer, or workstation.

Sedentary behavior outcomes

In terms of sedentary behavior outcomes, seven studies used only a self-report outcome measure, for example, questionnaire (Coffeng et al., 2014; Graves et al., 2015; Puig-Ribera et al., 2015; Blake et al., 2019; Lithopoulos et al., 2020; Rollo and Prapavessis, 2020; Patel et al., 2021), four used a device-based measure, for example, an ActivPAL (Neuhaus et al., 2014; Tobin et al., 2016; Carter et al., 2020; Weatherson et al., 2020), and 11 used a combination of self-report and device-based measure (Chau et al., 2014; Dutta et al., 2014; De Cocker et al., 2016; Healy et al., 2016; Danquah et al., 2017; Li et al., 2017; Dunning et al., 2018; Edwardson et al., 2018; Maylor et al., 2018; Mantzari et al., 2019; Pierce et al., 2019).

All included studies showed a beneficial direction of effect on at least one sedentary behavior outcome (i.e., number of breaks, sitting time, posture change, standing time) compared with control condition (further detail in Supplementary File 2). Six studies showed changes in number of breaks (Coffeng et al., 2014; De Cocker et al., 2016; Mantzari et al., 2019; Carter et al., 2020; Rollo and Prapavessis, 2020; Patel et al., 2021). All studies showed changes in sitting time (Chau et al., 2014; Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017; Dunning et al., 2018; Edwardson et al., 2018; Maylor et al., 2018;

Blake et al., 2019; Mantzari et al., 2019; Pierce et al., 2019; Carter et al., 2020; Lithopoulos et al., 2020; Rollo and Prapavessis, 2020; Weatherson et al., 2020; Patel et al., 2021). Seventeen studies showed changes for increased standing (Chau et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017; Edwardson et al., 2018; Maylor et al., 2018; Mantzari et al., 2019; Pierce et al., 2019; Carter et al., 2020; Rollo and Prapavessis, 2020; Weatherson et al., 2020; Patel et al., 2021).

Risk of bias

Table 3 summarizes the risk of bias (RoB) assessment for each study. A mix of ratings was evident, and although no individual study was rated as having low RoB across all criteria, there were relatively few high-risk ratings. Only two studies had more than two (i.e., three) criteria rated as high risk (Coffeng et al., 2014; Blake et al., 2019). Eight studies were rated as unsure on three or more criteria for RoB (Dutta et al., 2014; Neuhaus et al., 2014; Puig-Ribera et al., 2015; De Cocker et al., 2016; Mantzari et al., 2019; Pierce et al., 2019; Lithopoulos et al., 2020; Patel et al., 2021). Across the studies, the criterion blinding of outcome assessment had the highest RoB, with nine studies assessed as high risk on this measure (Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017; Blake et al., 2019; Carter et al., 2020). The criteria with the highest number of low RoB assessments were validity of outcome assessment ($n = 16$) and sequence generation ($n = 15$).

Intervention functions and BCTs evident in interventions demonstrating a beneficial direction of effect

For each intervention arm with a beneficial direction of effect we mapped the intervention content to the relevant BCW intervention function (Michie et al., 2011) and identified the included BCTs (Michie et al., 2013). Table 4 presents a synthesis of the BCW intervention functions and BCTs evident in the included studies (see Supplementary File 3 for individual studies). Of the nine BCW intervention functions, restrictions and coercion were not evident.

Education

Education was defined as increasing knowledge or understanding (Michie et al., 2014), and 15 of the 22 included studies used education as part of the intervention strategy (Neuhaus et al., 2014; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Danquah et al., 2017; Edwardson et al., 2018; Maylor et al., 2018; Blake et al., 2019; Mantzari et al., 2019; Carter et al., 2020; Lithopoulos et al., 2020; Rollo and Prapavessis, 2020; Weatherson et al., 2020; Patel et al., 2021). The most common educational strategy was providing information about the benefits and health consequences of sedentary behavior and physical activity. Several methods were adopted to communicate these messages including bespoke websites, posters around the office, text messages, and some studies used lectures and workshops. Feedback on behavior was also used, and this comprised individual and group feedback on sitting activity delivered *via* emails and coaching sessions. Prompts and cues were an additional educational strategy evident in these interventions. We coded education strategies as reflecting the BCTs 2.2 feedback on behavior, 5.1 information about health consequences, and 7.1 prompts/cues.

Persuasion

Persuasion was defined as using communication to induce positive or negative feelings or stimulate action (Michie et al., 2014), and four of the 22 included studies used persuasion as part of the intervention strategy (Healy et al., 2016; Edwardson et al., 2018; Blake et al., 2019; Patel et al., 2021). This included targeted messaging highlighting health consequences (e.g., "Break in sitting, make better working"; Patel et al., 2021). Additionally, this included supportive communication from senior colleagues to encourage engagement with the intervention (e.g., allowing time for activities and encouraging managers to filter the message down through the staff body). We coded these as reflecting the BCTs 5.1 information about health consequences and 9.1 credible source.

Incentivization

Incentivisation was defined as creating an expectation of reward (Michie et al., 2014), and one study used incentivisation as part of the intervention strategy (Coffeng et al., 2014). This one study encouraged participants to consider self-delivered rewards for achieving target behavior (i.e., reducing sitting time during the workday). Incentivisation strategies were coded to the BCT 10.3 non-specific reward.

Training

Training was defined as imparting skills (Michie et al., 2014), and 21 of the 22 included studies used training as part of the intervention strategy (Chau et al., 2014; Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017; Dunning et al., 2018; Edwardson et al., 2018; Maylor et al., 2018; Blake et al., 2019; Mantzari et al., 2019; Pierce et al., 2019; Carter et al., 2020; Rollo and Prapavessis, 2020; Weatherson et al.,

TABLE 2 Characteristics of included studies showing a beneficial direction of effect.

References	Participants of intervention group				Measurement tool	Beneficial direction of effect in occupational sedentary behavior			
	Sector	Country	Age	Number and gender		Number of breaks	Sitting	Posture change	Standing
Blake et al. (2019)	Private sector IT	China	X	Baseline: $n = 196$, 49.5% F 27% loss to follow-up $n = 143$ % F not reported	Self-report weekday sitting hours	Not reported	✓	Not reported	Not reported
Carter et al. (2020)	University	England	42.5 (± 10.0)	Baseline: $N = 14$ 57.1% F $N = 6$ intervention completed post assessment $N = 9$ crossover intervention completed post assessment; % F not reported	ActivPAL	Not reported	✓	✓	✓
Chau et al. (2014)	Non-government health agency	Australia	38 (±11)	Baseline: $N = 42$ 86% F Pre-INT 1 $n = 33$ Pre-INT 2 $n = 39$ Post-INT $n = 38$	ActivPAL OSPAQ [1] WSQ [2]	Not reported	✓	Not reported	✓
Coffeng et al. (2014)	Financial services	Netherlands			Unvalidated self-report: estimate the total amount of minutes spend at work on computer use, meetings and other sedentary activities during a usual working day				
a) Social and physical environmental intervention			38 (±10.5)	Baseline: $N = 92$ 44.6% F $N = 63$ at 6 mths $N = 63$ at 12 mths		Not reported	✓	Not reported	Not reported
b) Social environment intervention			43.6 (±10.3)	Baseline: $N = 118$ 38.1% F $N = 100$ at 6 mths $N = 94$ at 12 mths		Not reported	✓	Not reported	Not reported
c) Physical environmental intervention			42.2 (±10.5)	Baseline: $N = 96$ 37.5% F $N = 76$ at 6 mths $N = 76$ at 12 mths		Not reported	✓	Not reported	Not reported

(Continued)

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TABLE 2 Continued

References	Participants of intervention group				Measurement tool	Beneficial direction of effect in occupational sedentary behavior			
	Sector	Country	Age	Number and gender		Number of breaks	Sitting	Posture change	Standing
Danquah et al. (2017)	Municipalities and private workplaces	Denmark and Greenland	46 (±10)	Baseline: $N = 173$ 61% F	ActiGraph GT3X+ accelerometer (+log) – workdays (work time and leisure time)	Not reported	✓	✓	✓
De Cocker et al. (2016)	University and environmental agency	Belgium			WSQ [2], ActivPAL, day log				
a) Tailored intervention			40.5 (±8.6)	Baseline: $N = 78$ 67.9% F $N = 43$ at 1 mth $N = 36/38$ at 3 mths		✓	✓	Not reported	✓
b) Generic intervention			40.7 (±9.7)	Baseline: $N = 84$ 67.9% F $N = 75/41$ at 1 mth $N = 67/42$ at 3 mths		✓	✓	Not reported	✓
Dunning et al. (2018)	University and CBD	South Africa	27.9 (±5.4)	Baseline: $n = 11$ 64%F Follow up: $n = 7$	ActivPAL, ActiGraph GT3X+	Not reported	✓	Not reported	✓
Dutta et al. (2014)	Not reported	USA	40.4	$N = 28$ 67.8% F	Modular Signal Recorder (MSR) accelerometer; OSPAQ [1]	Not reported	✓	Not reported	✓
Edwardson et al. (2018)	National Health Service Trust	England	41.7 (±11.0)	Baseline: $N = 77$ $N = 62$ at 12 mths % F not reported (for final analysis)	ActivPAL micro	Not reported	✓	Not reported	✓
Graves et al. (2015)	University	England	38.8 (± 9.8)	Baseline: $N = 26$ 89% F (23) $N = 26$ at 4 wks $N = 25$ at 8 wks	Ecological momentary assessment (EMA) diaries	Not reported	✓	Not reported	✓
Healy et al. (2016)	Government organization	Australia	44.6 (±9.1)	Baseline: $N = 135$ 65.4% F $N = 123$ at 3 mths $N = 100$ at 12 mths	ActivPAL3	Not reported	✓	Not reported	✓

(Continued)

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TABLE 2 Continued

References	Participants of intervention group				Measurement tool	Beneficial direction of effect in occupational sedentary behavior			
	Sector	Country	Age	Number and gender		Number of breaks	Sitting	Posture change	Standing
Li et al. (2017)	Health Promotion Unit	Australia			ActivPAL, OSPAQ				
a) Group 2: 40 min sitting/20 min standing			46 (4)	Baseline and follow up: $N = 6$ 83% F		Not reported	✓	Not reported	✓
b) Group 3: 30 min sitting/30 min standing			40 (13)	Baseline and follow up: $N = 5$ 60% F		Not reported	✓	Not reported	✓
c) Group 4: 20 min sitting/40 min standing			41 (14)	Baseline and follow up: $N = 6$ 100% F		Not reported	✓	Not reported	✓
Lithopoulos et al. (2020)	Local workplaces	Canada			Adapted version of sitting portion of IPAQ [3]—self reported	Not reported		Not reported	Not reported
a) Affective			41.87 (±10.35)	$N = 28$ 42.9% F			✓		
b) Instrumental			42.42 (±11.78)	$N = 43$ 72.1% F			✓		
Mantzari et al. (2019)	Genomics company and an NHS Foundation Trust consisting of two hospitals	England	Not reported	$N = 9$ in intervention arm at (Phase 3) (and full data) % F not reported	ActivPAL	Not reported	✓	✓	✓
Maylor et al. (2018)	National property, residential, construction, and services group organization	England	43.0 (39.4–46.7)	For workplace sitting and activity outcomes, Baseline $N = 46$ 54% F 8-week $N = 38$	ActivPAL	Not reported	✓	✓	✓
Neuhaus et al. (2014)	University	Australia			ActivPAL				
a) Multi-component group			37.3 (±10.7)	Baseline: $N = 16$ 100% F $N = 12$ at 3 mths		Not reported	✓	✓	✓

(Continued)

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TABLE 2 Continued

References	Participants of intervention group				Measurement tool	Beneficial direction of effect in occupational sedentary behavior			
	Sector	Country	Age	Number and gender		Number of breaks	Sitting	Posture change	Standing
b) Workstations only group			43.0 (±10.2)	$N = 14$ 78.6% F $N = 13$ at 3 mths		Not reported	✓	✓	✓
Patel et al. (2021)	University	India	38.35 (±12.27)	Baseline: $n = 29$ Post-test $N = 27$ %F = 44.4%	SITBRQ [4], OSPAQ [1]	✓	✓	Not reported	✓
Pierce et al. (2019)	Energy Company	New Zealand	39.8 [10] (28 to 58)	Baseline: $N = 12$ 58.3% F	Pedometer, physical activity diary (PADs), self-report questionnaire	Not reported	✓	Not reported	✓
Puig-Ribera et al. (2015)	University	Spain	Not reported	Baseline: $N = 129$ % F not reported Ramping phase: $n = 112$ Maintenance phase: $n = 91$ Follow up phase: $n = 88$	Paper diary log recording occupational sitting time	Not reported	✓	Not reported	Not reported
Rollo and Prapavessis (2020)	Large businesses, office spaces, and academic institutions	Canada	46.59 (±11.13)	Baseline: $N = 29$ 93.1% F	OSPAQ [1], SBQ [5], SIT-Q 7d	✓	✓	Not reported	✓
Tobin et al. (2016)	Non-government organization and University	Australia	34.8 (±10.5)	Baseline: $N = 26$ $N = 18$ at 5 wks 89% F (16)	ActivPAL	Not reported	✓	✓	✓
Weatherson et al. (2020)	University	Canada	40.96 (±10.82)	Baseline: $N = 24$ 95.8% F $N = 20$ at 3 mths $N = 17$ at 6 mths % F not reported	ActivPAL3	Not reported	✓	Not reported	✓

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TABLE 3 Risk of bias summary by study.

References	Sequence generation	Allocation concealment	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Validity of outcome reporting	Baseline comparability
Blake et al. (2019)	+	+	−	−	?	+	−
Carter et al. (2020)	+	?	−	+	?	+	+
Chau et al. (2014)	+	−	?	+	?	+	+
Chau et al. (2014)	+	+	?	−	−	−	?
De Cocker et al. (2016)	?	?	?	?	?	+	+
Danquah et al. (2017)	+	+	−	+	?	+	+
Dunning et al. (2018)	+	+	?	−	?	+	+
Dutta et al. (2014)	?	−	−	−	−	+	+
Edwardson et al. (2018)	+	+	+	−	+	+	+
Graves et al. (2015)	+	+	?	+	+	−	+
Healy et al. (2016)	+	?	−	+	?	+	+
Li et al. (2017)	+	+	−	+	+	+	?
Lithopoulos et al. (2020)	+	+	?	−	?	−	?
Mantzari et al. (2019)	+	?	?	+	?	+	?
Maylor et al. (2018)	+	+	?	+	+	+	?
Neuhaus et al. (2014)	?	?	−	+	?	+	+
Patel et al. (2021)	?	?	+	?	?	?	?
Pierce et al. (2019)	?	?	?	+	?	−	?
Puig-Ribera et al. (2015)	?	?	?	−	+	−	?
Rollo and Prapavessis (2020)	+	?	?	+	+	+	+
Tobin et al. (2016)	?	−	−	−	+	+	+
Lithopoulos et al. (2020)	+	+	?	+	?	+	+

− High risk of bias; + Low risk of bias; ? Unclear risk of bias.

2020; Patel et al., 2021). Examples of delivery included provision of guided exercise sessions at regular intervals throughout the day, including feedback from an instructor (e.g., led by team leader/visuals/videos); provision of strategies to break up sitting, such as using the sit-stand desk, remembering to raise the sit-stand desk each morning, walking/standing meetings, workplace challenges (e.g., step count challenge); dissemination of a training manual to support team leaders to facilitate and encourage engagement with the intervention; delivery of one-to-one coaching sessions by a health coach to identify and set goals and individual behavior change strategies including training to "listen to body" and advice about changing posture regularly; and, an individual health check report with follow up meetings. Training strategies were coded to the BCTs 2.2 feedback on behavior, 2.3 self-monitoring of behavior, 2.7 feedback on outcome(s) of behavior, 4.1 instruction on how to perform the behavior, 6.1 demonstration of the behavior, 8.1 behavioral practice/rehearsal, 8.2 behavior substitution, 8.3 habit formation, 8.7 graded task.

Enablement

Enablement was defined as increasing means or reducing barriers to increase capability or opportunity (Michie et al., 2014), and 15 of the 22 included studies used enablement as part of the intervention strategy (Chau et al., 2014; Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Danquah et al., 2017; Li et al., 2017; Edwardson et al., 2018; Maylor et al., 2018; Blake et al., 2019; Carter et al., 2020;

TABLE 4 The BCW intervention functions and BCTs evident in the included studies.

BCW Intervention Function and definition	BCT and studies	Number of studies including BCTs
Education (Increasing knowledge or understanding)	2.2 Feedback on behavior (Neuhaus et al., 2014; De Cocker et al., 2016; Maylor et al., 2018)	3
	5.1 Information about health consequences (Chau et al., 2014; Neuhaus et al., 2014; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Danquah et al., 2017; Edwardson et al., 2018; Maylor et al., 2018; Blake et al., 2019; Mantzari et al., 2019; Carter et al., 2020; Lithopoulos et al., 2020; Rollo and Prapavessis, 2020; Weatherson et al., 2020; Patel et al., 2021)	15
	7.1 Prompts/cues (Neuhaus et al., 2014; Danquah et al., 2017; Maylor et al., 2018; Carter et al., 2020; Rollo and Prapavessis, 2020)	5
Persuasion (Using communication to induce positive or negative feelings or stimulate action)	5.1 Information about health consequences (Blake et al., 2019; Patel et al., 2021)	2
	9.1 Credible source (Healy et al., 2016; Edwardson et al., 2018; Blake et al., 2019)	3
Incentivization (Creating an expectation of reward)	10.3 Non-specific reward (Coffeng et al., 2014)	1
Training (Imparting skills)	2.2 Feedback on behavior (Chau et al., 2014; Healy et al., 2016; Edwardson et al., 2018; Blake et al., 2019)	4
	2.3 Self-monitoring of behavior (Healy et al., 2016)	1
	2.7 Feedback on outcomes(s) of behavior (Healy et al., 2016)	1
	4.1 Instruction on how to perform the behavior (Chau et al., 2014; Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017; Dunning et al., 2018; Edwardson et al., 2018; Maylor et al., 2018; Blake et al., 2019; Mantzari et al., 2019; Pierce et al., 2019; Carter et al., 2020; Rollo and Prapavessis, 2020; Weatherson et al., 2020; Patel et al., 2021)	21
	6.1 Demonstration of the behavior (Graves et al., 2015; Healy et al., 2016; Danquah et al., 2017; Li et al., 2017; Blake et al., 2019; Mantzari et al., 2019; Patel et al., 2021)	7
	8.1 Behavioral practice/rehearsal (Patel et al., 2021)	1
	8.2 Behavior substitution (Dunning et al., 2018; Mantzari et al., 2019)	2
	8.3 Habit formation (Blake et al., 2019)	1
	8.7 Graded task (Puig-Ribera et al., 2015; Blake et al., 2019)	2
Enablement (Increasing means/reducing barriers to increase capability or opportunity)	1.1 Goal setting (behavior) (Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Danquah et al., 2017; Edwardson et al., 2018; Maylor et al., 2018)	9
	1.2 Problem solving (Neuhaus et al., 2014; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Edwardson et al., 2018; Maylor et al., 2018; Rollo and Prapavessis, 2020; Patel et al., 2021)	8
	1.4 Action planning (De Cocker et al., 2016; Healy et al., 2016; Li et al., 2017; Edwardson et al., 2018; Rollo and Prapavessis, 2020)	5
	1.5 Review behavior goal(s) (Coffeng et al., 2014; Neuhaus et al., 2014; Puig-Ribera et al., 2015; Healy et al., 2016; Edwardson et al., 2018; Maylor et al., 2018)	6
	2.3 Self-monitoring of behavior (Puig-Ribera et al., 2015; Edwardson et al., 2018; Patel et al., 2021)	3
	3.1 Social support (unspecified) (Coffeng et al., 2014; Neuhaus et al., 2014; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Danquah et al., 2017; Li et al., 2017; Edwardson et al., 2018; Maylor et al., 2018; Carter et al., 2020; Rollo and Prapavessis, 2020)	11
	3.2 Social support (practical) (Blake et al., 2019)	1
	8.2 Behavior substitution (Edwardson et al., 2018; Patel et al., 2021)	2
	8.3 Habit formation (Li et al., 2017)	1
	8.7 Graded tasks (Puig-Ribera et al., 2015)	1

(Continued)

TABLE 4 Continued

BCW Intervention Function and definition	BCT and studies	Number of studies including BCTs
	12.1 Restructuring the physical environment (Chau et al., 2014; Healy et al., 2016; Li et al., 2017; Carter et al., 2020)	4
	12.5 Adding objects to the environment (Chau et al., 2014; Coffeng et al., 2014; Puig-Ribera et al., 2015; Healy et al., 2016; Danquah et al., 2017; Li et al., 2017; Maylor et al., 2018; Carter et al., 2020; Rollo and Prapavessis, 2020)	9
Modeling (Providing an example for people to aspire to or imitate)	6.1 Demonstration of the behavior (Healy et al., 2016; Danquah et al., 2017; Blake et al., 2019; Mantzari et al., 2019; Patel et al., 2021)	5
Environmental restructuring (Changing the physical or social context)	7.1 Prompts/cues (Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Danquah et al., 2017; Li et al., 2017; Dunning et al., 2018; Edwardson et al., 2018; Maylor et al., 2018; Blake et al., 2019; Rollo and Prapavessis, 2020; Patel et al., 2021)	14
	12.1 Restructuring the physical environment (Chau et al., 2014; Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017; Dunning et al., 2018; Maylor et al., 2018; Blake et al., 2019; Mantzari et al., 2019; Pierce et al., 2019; Carter et al., 2020; Weatherson et al., 2020; Patel et al., 2021)	19
	12.2 Restructuring the social environment (Blake et al., 2019)	1
	12.5 Adding objects to the environment (Chau et al., 2014; Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; Puig-Ribera et al., 2015; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017; Dunning et al., 2018; Edwardson et al., 2018; Maylor et al., 2018; Blake et al., 2019; Mantzari et al., 2019; Pierce et al., 2019; Carter et al., 2020; Rollo and Prapavessis, 2020; Weatherson et al., 2020; Patel et al., 2021)	20
Restrictions (Using rules to reduce the opportunity to engage in the target behavior)	Not used	-
Coercion (Creating an expectation of punishment or cost)	Not used	-

Rollo and Prapavessis, 2020; Patel et al., 2021). Examples of delivery included goal setting strategies (group and individual) recorded using an activity tracker or personal log or activity planning sheet (incl. coping strategies); telephone calls at regular time points delivered by an appropriate professional to support goal attainment including assessment of progress toward goals, problem-solving, action planning, adjustment/progression of goals and related behavior change strategies; an e-health programme to support reduction of sedentary behavior and goal attainment (the software remotely installed onto a work computer/laptop); and, motivational interviewing comprising discussions around participant progress toward goals, problem-solving, and adjustment of goals and behavior change strategies as necessary. Enablement strategies were coded to the BCTs 1.1 goal setting (behavior), 1.2 problem solving, 1.4 action planning, 1.5 review behavior goal(s), 2.3 self-monitoring of behavior, 3.1 social support (unspecified), 3.2 social support (practical), 8.2 behavioral substitution, 8.3 habit formation, 12.1 restructuring the physical environment, and 12.5 adding objects to the environment.

Modeling

Modeling was defined as providing an example for people to aspire to or imitation (Michie et al., 2014), and five of the 22 included studies used modeling as part of the intervention strategy (Healy et al., 2016; Danquah et al., 2017; Blake et al., 2019; Mantzari et al., 2019; Patel et al., 2021). Examples of delivery included provision of role models (e.g., ambassadors/team leaders/managers/team champs) who provided or demonstrated examples for participants to aspire to, to enable them to achieve goals and to implement the intervention strategies into their workday. Modeling strategies were coded to the BCT 6.1 demonstration of the behavior.

Environmental restructuring

Environmental restructuring was defined as changing the physical or social context, and 21 of the 22 included studies used environmental restructuring as part of the intervention strategy (Chau et al., 2014; Coffeng et al., 2014; Dutta et al., 2014; Neuhaus et al., 2014; Graves et al., 2015; Puig-Ribera et al., 2015; De Cocker et al., 2016; Healy et al., 2016; Tobin et al., 2016; Danquah et al., 2017; Li et al., 2017; Dunning et al., 2018; Edwardson et al., 2018; Maylor et al., 2018; Blake et al., 2019; Mantzari et al., 2019; Pierce et al., 2019; Carter et al., 2020; Rollo and Prapavessis, 2020; Weatherson et al., 2020; Patel et al., 2021). Examples of how environmental restructuring was delivered included provision of regular prompts encouraging staff to participate/engage in movement (daily/twice a week/weekly/based on individual dosage) with reminders/suggestions to move (e.g. onscreen/text message/stickers/step challenges); goal setting mechanisms (e.g. activity log/goal setting booklet); sit-stand desk (e.g. standard/electric/desk mount) including appropriate assessment for safe usage and provision of information about how to use safely; a device (Darma cushion) used to track sitting and provide prompts to move; and specially designed zones to encourage standing and moving (e.g. coffee bar with chairs and large plant, exercise balls, room with standing table and relaxing poster, footsteps promoting stair walking). These strategies were coded to the BCTs 7.1 prompts/cues, 12.1 restructuring the physical environment, 12.2 restructuring the social environment, and 12.5 adding objects to the environment.

Judging the transferability of effective office-based interventions to the working at home environment using the APEASE criteria

Supplementary File 3 details the researchers' APEASE (Michie et al., 2011; West and Michie, 2022) ratings for all of the BCTs identified in each study. Table 5 shows the scores for stakeholders and research team in relation to the transferability of the intervention functions used in the included studies, and associated examples of how the intervention had been delivered in practice. Scores vary across all intervention types and examples of delivery, with most being scored as possibly transferable.

Education

For education, the stakeholders indicated that materials about sedentary behavior and physical activity were transferable, except in terms of safety and equity, which they indicated was potentially transferable. The research team scored this as transferable. For feedback on behavior, stakeholders indicated this to be possibility transferable, with the exception of practicability, which was indicated to be transferable. The research team scored as potentially transferable, with the exception of safety and equity, which was scored as transferable.

Persuasion

For persuasion, stakeholders felt that support for the intervention from senior management was potentially transferable, with the exception of acceptability, which they scored as transferable. The research team indicated this was a transferable strategy, with the exception of affordability and practicability, which was scored as potentially transferable.

Incentivization

The stakeholders indicated that provision of an incentive was potentially transferable. The research team scored this as transferable.

Training

For almost all examples of how training could be delivered, stakeholders indicated these to be potentially transferable, except for strategies to break up sitting which they scored as transferable in terms of acceptability. For the training manual, there was split opinion on equity, and one-to-one coaching sessions and individual health checks were scored as transferable in terms of equity. The research team scored the one-to-one coaching sessions and individual health checks as not transferable in terms of affordability, but possibly transferable for the practicability, acceptability, and safety. Otherwise, the training manual was scored as transferable across all constructs, and all other examples were considered to be potentially transferable.

Enablement

The scores for enablement were the most varied for the stakeholder group. For goal setting strategies, stakeholders were completely divided between transferable and potentially transferable in terms of practicability, side effects, and equity. But agreed this was transferable from an acceptability perspective. Regular telephone calls to support engagement with strategies to break up sitting were considered to be potentially transferable for the most part, however in terms of practicability and acceptability, this type of strategy was considered not transferable to the work at home environment. E-health programmes were considered transferable in terms of practicability, side-effects, and equity, but considered only potentially transferable in terms of affordability and acceptability. Motivational interviewing was mostly considered to be potentially transferable, however stakeholders were split on equity. For all constructs except telephone calls, the research team considered enablement strategies to be potentially transferable, with the exception of equity, which was considered to be transferable.

TABLE 5 Summary of APEASE scoring for stakeholders and research team.

Intervention type	Example of how it could be delivered	APEASE score expert stakeholders						APEASE score research team					
		A	P	E	A	S	E	A	P	E	A	S	E
Education	Materials about SB and physical activity — including benefits, health consequences, how to reduce SB, facts, tips, etc. (e.g. website/poster/leaflet/text message/lecture)	+	+		+	?	?	+	+		+	+	+
	Feedback on sitting activity along with a suggestion to break up sitting (email/coaching session)	?	+		?	?	+/?	?	?		?	+	+
Persuasion	Support for the intervention from senior management — encouraging staff involvement, allowing time for activities and encouraging managers to filter the message down through the staff body	?	?		+	?	?	?	?		+	+	+
Incentives	Self—delivered rewards for achieving target behavior	?	?		?	?	?	+	+		+	+	+
Training	Exercise sessions at regular intervals throughout the day incl. feedback from instructor (e.g led by team leader/visuals/videos)	?	?		?	?	?	?	?		?	?	+
	Strategies to break up sitting e.g. using the desk, remembering to raise the desk each morning, Walking/standing meetings, challenges	?	?		+	?	?	?	?		?	?	+
	Training manual to support team leaders to facilitate/deliver/encourage engagement with the intervention	?	?		?	?	+/?	+	+		+	+	+
	One—to—one coaching sessions delivered by a health coach to identify and set goals and individual—behavior change strategies incl. training to 'listen to body' and advice about changing posture regularly	?	?		?	+	+	–	?		?	?	+
	Individual health check report with follow up meetings	?	?		?	+	+	–	?		?	?	+
Enablement	Goal setting strategies (group and individual) recorded using an activity tracker/personal log/activity planning sheet (incl. coping strategies)	?	+/?		+	+	+/?	?	?		?	?	+
	Telephone calls at regular time points delivered by an appropriate professional to support goal attainment involving assessment of progress toward goals, problem—solving, action planning, adjustment/progression of goals and related behavior change strategies.	?	–		–	?	?	–	?		?	?	+
	e—health programme to support reduction in SB, goal attainment (Software remotely installed onto work computer/laptop)	?	+		?	+	+	?	?		?	?	+
	Motivational interviewing comprising discussions around participant progress toward goals, problem—solving, and adjustment of goals and behavior change strategies as necessary	?	?		?	+	+/?	?	?		?	?	+

(Continued)

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TABLE 5 Continued

Intervention type	Example of how it could be delivered	APEASE score expert stakeholders						APEASE score research team					
		A	P	E	A	S	E	A	P	E	A	S	E
Modeling	Role models (e.g. ambassadors/team leaders/managers/team champs) to provide social support to achieve goals and to implement the intervention strategies	+	+		+	?	+	?	?		?	+	+
Environmental restructuring	Regular prompts encouraging staff to participate/engage in movement (daily/twice a week/weekly/based on individual dosage) with reminders/suggestions to move (e.g. onscreen/text message/stickers/step challenges)	+/?	+		+	?	+	?	?		?	?	+
	Goal setting mechanisms (e.g. activity log/goal setting booklet)	+/?	+		+	?	+/?	?	?		?	?	+
	Sit – stand desk (e.g. standard/electric/desk mount) incl. appropriate assessment for safe usage	?	?		+	?	?	–	–		?	?	+
	Darma cushion to track sitting and prompt movement	–	?/–		?	?	?	–	?		?	?	+
	Zones to encourage standing and moving (e.g. Coffee bar with chairs and large plant, Exercise balls, room with standing table and relaxing poster, Footsteps promote stair walking)	?	+/?		?	?	?	–	–		–	–	+

+, transferable; –, not transferable; ?, possibly transferable; +/?, split decision between respondents on transferable and possibly transferable; ?/–, split decision between respondents on not transferable and possibly transferable.

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Modeling

For modeling, one example of delivery was through role models, e.g., ambassadors/team leaders/managers demonstrating the behavior and providing support and encouragement to engage with the intervention. The stakeholder group felt this was a transferable strategy, except for side effects. The research team felt this was a potentially transferable strategy except for side effects and equity, which were scored as transferable.

Environmental restructuring

Overall, examples of environmental restructuring were shown to have the most transferable scores by stakeholders. Prompts were considered to be transferable, except in terms of affordability, which was split between transferable and potentially transferable, and side effects, which was scored as potentially transferable. Goal setting was scored the same except for side effects, which was split between transferable and potentially transferable. Sit-stand desks were considered potentially transferable, except in terms of acceptability which was considered to be transferable. The Darma cushion was considered not transferable in terms of affordability, experts were split between not transferable and potentially transferable for practicability. Otherwise, this was considered potentially transferable. Zones to encourage standing and moving were considered potentially transferable, except for practicability that was split between transferable and potentially transferable. Scoring for the research team was more toward the potentially transferable category, however, researchers indicated sit-stand desks and the Darma cushion to be not transferable in terms of affordability. Desks were also not transferable in the context of practicability. Setting up zones for movement were not considered to be transferable at all, except for equity.

Discussion

Working at home for at least part of the week is likely to become increasingly common for many employees. However, initial evidence suggests that working at home is likely to exacerbate already high levels of workplace sedentary behavior evident in office settings (McDowell et al., 2020; Fukushima et al., 2021). The purpose of this rapid review was to build on the growing evidence base of intervention strategies that have been effective in reducing sedentary behavior in office settings to inform intervention development to support workers in the home environment. We identified 22 high quality RCT studies, including 29 intervention arms that showed a beneficial direction of effect for at least one outcome measure of sedentary behavior in the intervention group(s) compared to the control conditions. From these studies we identified that the most common intervention functions were environmental restructuring, training, enablement and education. The most common BCTs were information on health consequences, instructions on how to perform the behavior, and restructuring the physical environment. Finally, our assessment of potential transferability of the interventions to the home working environment highlighted that educational materials, role models, incentives, and regular prompts were the most promising interventions transferable to supporting reduced sedentary behavior when working at home.

Consistent with the rapid review guidance (Garritty et al., 2021), we included only studies with a robust study design incorporating both randomization and control conditions. Further, the relatively few ratings of high risk of bias in these studies further increased our confidence in the findings. The 22 studies identified were conducted in 13 different countries reflecting the international interest in reducing workplace sedentary behavior. There was limited research in low-middle income countries, potentially limiting transferability of the findings to this context. This review included eleven studies that were also included in the 2018 Cochrane Review (Shrestha et al., 2018), but it is notable that there were eleven additional studies since the 2018 review, highlighting the growth of research in this area and that our review of promising interventions is timely.

From the 29 intervention arms, there were 1,577 participants included at baseline assessment points. The sample sizes ranged from 6 to 196, and future research should aim to recruit sufficient participants to adequately power analysis. We included studies with participants aged 18–65 years, although the average age of participants was 40 years with a relatively small variance potentially limiting the findings to this target group. This finding may suggest that this age group are most interested in reducing their sedentary behavior, and indeed, previous research has highlighted early to middle-aged adults as a high-risk group for sedentary behavior due to high workplace sedentary behavior (Strain et al., 2018). There was a range of work settings included from both public and private sectors.

In all but seven studies, sedentary behavior outcomes were assessed using device-based measurement with twelve studies also using self-report measures. Devices provide a more valid and reliable assessment of sedentary behavior (Byrom et al., 2016), and a combination of both device and self-report is recommended (Bakker et al., 2020), therefore, the prevalence of use of these measurement tools increases confidence in the findings. Every intervention showed a beneficial change in sitting time and, where reported, there was also evidence of beneficial changes in number of breaks and time spent standing. Collectively, these included interventions provide a robust body of evidence to consider in this rapid review of what type of intervention works in an office-based setting to enhance sedentary behavior.

The BCW (Michie et al., 2011) and BCT taxonomy (Michie et al., 2013) provided a useful framework to systematically classify the identified interventions. Environmental restructuring was one of the most commonly identified intervention functions, present in 21 of the studies included in our review. A previous review of interventions to reduce sitting, also noted the frequency and promise of environmental restructuring to reduce sitting in the workplace (Gardner et al., 2016). Further, workers have reported this as an acceptable and feasible approach (Hadgraft et al., 2018). The most frequently used BCTs were restructuring the physical environment and adding objects to the environment, which were implemented in a number of ways including sit-stand desks and adapting spaces to encourage standing and movement. However, in judging the potential transferability of these strategies to the home working environment, neither the stakeholders nor the researchers rated them as directly transferable across the APEASE criteria. The perceived lack of transferability is most likely because the home office is considerably different to the traditional office environment with limited space and resources. Additionally, in contrast to the office environment where employees typically have a similar environment, home office facilities can vary considerably. A 2020 study (Davis et al., 2020) exploring ergonomic set ups of employees working at home during COVID-19 found a range of "workstations" including, as examples, at dining tables, on the couch, in bed, at a treadmill. Nevertheless, it is notable that the stakeholders more consistently rated these strategies as being possibly transferable than the researchers, perhaps reflecting that some organizations are in a position to provide an enhanced home working environment.

The BCT prompts and cues was also used frequently within the environmental restructuring function, and included reminders to move using methods such as on-screen (computer) and text messages, and stickers. In their review, Gardner et al. (2016) reported that prompts and cues had relatively limited use within workplace settings, so these findings likely reflect a more recent growth in the use of such strategies, potentially due to increased availability of technology, such as apps (Dunn et al., 2018). Stakeholders evaluated this strategy as transferable, with researchers flagging "possibly transferable" indicating the potential of prompts and cues for supporting reduced sedentary behavior in the home working environment.

The intervention function of training was also evident in 21 of the 22 studies. The most commonly occurring BCTs were instruction on how to perform the behavior, and demonstration of the behavior and there were a wide range of strategies used to deliver this training. This finding differs from a previous review, which reported limited evidence of training in workplace studies (Gardner et al., 2016). However, these authors did report substantial evidence of the BCT instruction on how to perform a behavior, which we have classified as "training" (Michie et al., 2011) and this discrepancy may reflect different coding approaches. The stakeholders and researchers had similar ratings on the potential transferability of the training examples, although researchers saw greater potential in the use of a training manual. It is likely that training in how to change behavior will be important in supporting participants but there will be a need to carefully design this strategy so that it is adaptable to a home working environment.

The intervention function enablement was evident in 15 studies and included the BCTs social support (unspecified), goal setting (behavior), problem solving, and adding objects to the environment. These findings are consistent with the Gardner et al. (2016) review, in which enablement was the most frequently reported intervention function, and the same BCTs were present in workplace interventions highlighting the frequency of these approaches in the workplace. Gardner et al evaluated enablement and several of the BCTs as not promising strategies because they were included in more non-promising than promising interventions. However, the findings of this rapid review report the inclusion of enablement and these BCTs in interventions with a beneficial direction of effect, indicating the need to consider further their promise. Although the APEASE ratings were mixed, overall, both stakeholders and researchers scored enablement strategies to be at least potentially transferable. Notably, the stakeholders evaluated goal setting strategies and e-health programmes to be the most promising for transferring to the home working environment.

The intervention function of education was also evident in 15 studies. This finding is consistent with a previous review (Gardner et al., 2016), that also noted education as one of the most commonly used and promising intervention functions in workplaces, and further supports the importance of this approach. Within this intervention function, three BCTs were identified, the most frequently used being information about health consequences, and less frequently used were feedback on behavior, and prompts and cues. Although none of the education components were considered to be directly transferable across all of the APEASE criteria by both the stakeholders and researchers, there was generally an indication that this intervention function had potential to be transferred, especially materials about sedentary behavior. It is likely that the content of educational materials will be the same for workers in the workplace or in the home environment, however the delivery mechanism may need to be adapted. Specifically, posters and leaflets, may be useful in an office environment but would likely not be appropriate to deliver to employees while they are working at home. Alternatively, websites and text messages may be more useful.

The intervention functions that were less frequently used included persuasion, incentivisation, and modeling. This finding is consistent with Gardner et al. (2016) who reported that these functions were only evident in one study each in their 2016 review. Collectively, these findings indicate that there has been limited consideration of these intervention functions to reduce occupational sedentary behavior. Nevertheless, based on the stakeholder and researcher scoring there was indication that these types of intervention strategies could be transferable to the home working environment. For example, support from senior management to support behavior change interventions was evaluated as a form of persuasion that was potentially transferable. Similarly, a previous review also noted that employees perceived a "top-down" supportive approach from managers was important to provide permission to reduce sedentary behavior and facilitate culture change (Hadgraft et al., 2018). Future research could consider how best to support managers to support employees in their behavior change.

Incentivisation was only evident in one study where participants were encouraged to reward themselves for the target behavior, and this strategy was perceived as potentially transferable by the stakeholders and transferable by the researchers. Although there is limited evidence of use of this strategy in effective workplace sedentary behavior interventions, there has been increased interest in the role of incentives, and specifically financial incentives, in promoting physical activity, with some evidence that they may lead to sustained behavior change (Luong et al., 2020; Mitchell et al., 2020). Further research would be valuable to explore the potential of incentives for facilitating improvements in occupational sedentary behavior. Finally, modeling was evident in five studies and typically involved role models (e.g., ambassadors or team leaders) providing an example of how to engage in the behavior, and thus providing encouragement and support. The value of role models to support workplace behavior change has been previously noted (Hadgraft et al., 2018), and it is encouraging that the use of role models was considered transferable by the stakeholders, and potentially transferable by the researchers. In the home working environment role models will need to model the behavior in a different way from the office (e.g., modeling and encouraging standing and stretching during online meetings).

It is important to note that all but one study used a combination of intervention functions and associated BCTs, which is consistent with previous findings that suggested multi-component interventions are most effective in reducing workplace sedentary behavior (Chu et al., 2016). In transferring to the home working environment, it is also likely that a combination of intervention strategies will be most effective, and required in order to facilitate the stages of behavior change (Schwarzer and Hamilton, 2020).

Based on what is evident to work in the office environment, this study has made recommendations on what promising strategies could potentially support employees to reduce sedentary time when working at home. Clearly, further research is needed to build on these recommendations. Consistent with contemporary guidance on developing and evaluating complex interventions (Skivington et al., 2021), appropriate next steps would be to assess the feasibility and acceptability of the intervention, and then evaluate the effectiveness of the intervention using appropriate methods. Incorporating a process evaluation would also be important to answer questions around how an intervention is or is not effective (e.g., which intervention elements were most effective).

Strengths and limitations

A strength and novel aspect of this study was the integration of expert stakeholder input into judging the transferability of the identified intervention strategies using a recognized defined framework. However, the level of agreement between the stakeholders and researchers was inconsistent. Future research adopting a more in-depth qualitative approach would be valuable in order to explore better the nuance of different contexts to understand what types of intervention strategies may work best. Such research would facilitate consideration of the impact of worker characteristics and type of work on potential transferability, rather than the more general evaluation undertaken in the current study. Further, it is acknowledged that the stakeholders did not include the full spectrum of workplace roles, and it is possible that stakeholders with different backgrounds and characteristics may perceive transferability differently. Nevertheless, it is a strength that these stakeholders had highly pertinent experience and expertise in promoting workplace health, and represented national level organizations.

In order to respond to the transformational changes in work patterns, we adopted a rapid review methodology, which necessarily meant that some steps were abbreviated. Finally, our last database search was in September 2021, and although it takes time to robustly identify, review and evaluate studies, further studies will have been published in that timeframe that can add value to this review.

Conclusion

This rapid review makes an important and novel contribution to our understanding of what works to reduce occupational office-based sedentary behavior, and identifies potential strategies to support workers in the home environment as the world adapts to a new working landscape. Environmental restructuring, training, enablement and education were the most common interventions, but not all aspects will be easily transferable to the home working environment. Intervention strategies judged to be most promising for the home working environment were identified, including educational materials, role models, incentives, and regular prompts. Future intervention development research is needed to further adapt and evaluate these strategies in this new context.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

AN, SM, CF, and RJ conceived the study. AN, SM, CF, DSi, and DSa designed the study, analyzed, and interpreted the data. AN, SM, CF, and DSi drafted and substantively revised the article. All authors have approved of the submitted version, and have agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fspor.2022.954639/full#supplementary-material

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