Heliyon 10 (2024) e29294

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Effects of substituting sedentary time with physical activity on body mass index in Japanese adults with Down syndrome: A cross-sectional study

Erika Yamanaka [a], Takayo Inayama [b,*], Kazunori Ohkawara [c], Michio Kojima [d], Tsubasa Nakada [c], Ichiro Kita [a]

[a] *Graduate School of Human Health Sciences, Tokyo Metropolitan University, Tokyo, 192-0397, Japan*
[b] *Faculty of Health, and Human Development, The University of Nagano, Nagano, 380-8525, Japan*
[c] *Graduate School of Informatics and Engineering, The University of Electro-Communications, Tokyo, 182-8585, Japan*
[d] *Institute of Human Sciences, University of Tsukuba, Tokyo, 112-0012, Japan*

ARTICLE INFO

Keywords:
Down syndrome
BMI
Physical activity
Sedentary behavior
Isotemporal substitution model

ABSTRACT

Objective: and Rationale: Obesity is a health challenge for adults with Down syndrome. Therefore, a physical activity promotion program is required to prevent or reduce obesity in adults with this condition. However, there is a lack of evidence of useful risk reduction initiatives. The objective of this study was to suggest a rationale for behaviors that should replace time of inactivity to reduce obesity in Japanese adults with Down syndrome.

Methods: The participants were adults with Down syndrome, aged 18–48 years, living in Japan. The snowball sampling method was used. To detect an effect size of 0.20 for body mass index using an F-test, 80 participants were required, generating a statistical power of 0.8 and a risk level of 0.05. Survey items included sex, age, height, weight, body mass index, and physical activity (min/d). Physical activity was categorized by intensity and further divided into ambulatory and non-ambulatory activities. The body mass index categories were compared using analysis of covariance. An isotemporal substitution model was used to confirm the interdependence of behaviors.

Results: Half of the participants were obese, with a body mass index of 25 kg/m^2 or higher. The obese group had significantly fewer light physical activity, moderate-to-vigorous physical activity, and ambulatory moderate-to-vigorous physical activity times than the non-obese group. Replacing 10 min of sedentary behavior with ambulatory moderate-to-vigorous physical activity was significantly associated with a lower body mass index.

Conclusions: This study suggests a rationale for behaviors that should replace time of inactivity to reduce obesity in adults with Down syndrome. Specifically, replacing 10 min of sedentary behavior with ambulatory moderate-to-vigorous physical activity time may contribute to obesity reduction.

* Corresponding author.
E-mail addresses: erichi4y@gmail.com (E. Yamanaka), inayama.takayo@u-nagano.ac.jp (T. Inayama), ohkawara_kazunori@e-one.uec.ac.jp (K. Ohkawara), mkoji-ma@human.tsukuba.ac.jp (M. Kojima), TsubasaNAKADA@uec.ac.jp (T. Nakada), kita-ichiro@tmu.ac.jp (I. Kita).

https://doi.org/10.1016/j.heliyon.2024.e29294
Received 14 September 2023; Received in revised form 4 April 2024; Accepted 4 April 2024
Available online 10 April 2024
2405-8440/

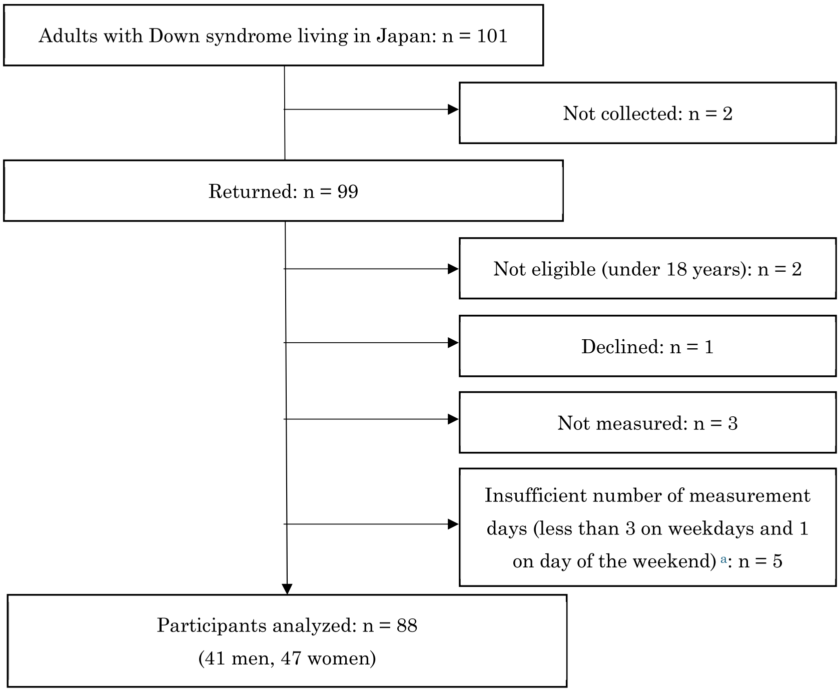

Fig. 1. Participant inclusion criteria flow diagram.
[a]We accepted days in which more than 600 min (10 h) of wear time had accrued.

1. Introduction

Down syndrome is a congenital disorder caused by trisomy 21. It is characterized by short stature, hypotonia, and mild intellectual disabilities [1,2]. Obesity is a health challenge in children and adults with Down syndrome [3–5]. Moreover, as the life expectancy of individuals with Down has increased [6–8], efforts to prevent obesity at an early age have become increasingly important [9–11].

Promoting physical activity (PA) is important in reducing obesity. According to the WHO guidelines on PA and sedentary behavior [12], adults living with disabilities should engage in at least 150–300 min/week (21–43 min/d) of moderate physical activity (MPA), at least 75–150 min/week (11–21 min/d) of vigorous physical activity (VPA), or an equivalent combination of moderate-to-vigorous physical activity (MVPA) for substantial health benefits. However, studies quantitatively assessing PA in adults with Down syndrome are limited [13–15]. In some studies, adults with Down syndrome do not meet the guideline recommendations [13,14], and obesity in adults with Down syndrome is associated with light physical activity (LPA) [14].

Programs promoting PA aimed at reducing obesity in adolescence and adulthood are needed to promote lifelong health. However, there is a lack of evidence for such useful initiatives.

Previous studies reporting the association between the duration of PA or inactivity and health point to the need to consider the interdependence of behaviors [16,17]. The day is finite (24 h) and performing one behavior (e.g., exercise) requires a reduction in another behavioral time (e.g., sedentary behavior). Recent studies in adults employing a statistical method called the isotemporal substitution (IS) model to test for interdependence suggest that substitution of sedentary behavior (SB) with PA is effective for body composition and coronary artery disease risk factors such as body mass index (BMI) [18–21]. Previous studies in Japanese adults have also suggested that replacing 30 min of SB with MVPA is associated with improved mental health in office workers [22]. Thus, showing that replacing SB with physical activities reduces obesity in Japanese adults with Down syndrome can help provide a PA program plan for health promotion.

We hypothesized that adults with Down syndrome are more likely to be obese, that their obesity is associated with more SB time or less MVPA time, and that replacing SB time with more active time may reduce obesity.

The objective of this study was to suggest a rationale for behaviors that should replace time of inactivity to reduce obesity in Japanese adults with Down syndrome. Specifically, this study will identify obesity among Japanese adults with Down syndrome, identify differences in activity time by PA intensity between the obese and non-obese groups, and identify the interdependence of BMI replacing sitting time and other PA intensity times. The interdependence of BMI on sedentary time and other PA intensity times. Furthermore, these results can be used to plan PA promotion programs to reduce obesity in adults with Down syndrome.

2. Materials and methods

2.1. Research design

The research design is a cross-sectional study.

2.2. Participants and research procedures

The participants consisted of 101 adults with Down syndrome (aged 18–48 years) living in Japan who belong to the Japanese Down Syndrome Society [23]. Of these, 88 participants (41 men and 47 women) were included in the analysis, excluding two whose data had not been returned, two who were not age-eligible, one who had requested to withdraw from the study, three who had faulty equipment, and five who had an insufficient number of days. A flowchart of the participants is shown in Fig. 1.

The survey period was set to run from September 2021 to December 2022, and the sampling method was snowball sampling. The survey was conducted in cooperation with the Japanese Down Syndrome Society [23], which is organized by individuals with Down syndrome living in Japan and their families. Because it is a voluntary organization, not all individuals with Down syndrome living in Japan are registered. There are 50 chapters throughout Japan, and members belong to the chapter in their area of residence.

The recruitment process was initially via telephone or email from the branch heads of prefectural chapters of the Japanese Down Syndrome Society. Additionally, branch managers who expressed interest in the research were briefed on the survey via the web and telephone and branch managers recruited other branch members to participate in the survey. Two researchers visited and held information sessions in the three regions with the highest numbers (TY, NR, and NG). Parents (i.e., family members) and participants attended the information sessions. Measurement kits (e.g., study instructions, consent form, activity meter, cloth cover, belt, safety pin, activity recording form, and return envelope) were distributed to participants. The purpose of the study and measurement methods were explained, informed consent was obtained, and participant and parental consent forms were also obtained. If the participant was unable to complete the consent form, a guardian (e.g., a family member) completed the consent form as a surrogate after confirming the participant's willingness to participate. In areas where it was difficult to meet as a group, parents (i.e., family members) who wished to participate were asked to disclose their contact details, and the date and time were set up for an individual phone call or email explaining the study. Arrangements were made for the measurement kits (ibid.) to be delivered to the participants before the explanation process. The purpose of the study was explained and informed consent was obtained via the web or telephone at the appointed date and time. The parent/guardian then explained the situation to the participant and written informed consent was obtained from the participant and parent/guardian. If the participant was unable to complete the consent form, a guardian (e.g., a family member) completed the consent form as a surrogate after confirming the participant's willingness to participate.

2.3. Measurement items and methods

2.3.1. Physical characteristics

In cases where the description was provided at a group venue, the height and weight were measured immediately by two researchers. In cases where individual explanations were provided, participants were asked to report their height measured within the past year at a hospital or facility with medical staff. Weight was measured at the hospital or in a facility with medical staff within one month before and after the activity measurement, or a scale was sent directly to the patient's home, and the patient's weight was reported.

Researchers calculated the BMI (kg/m^2). In Japan, a person with a BMI of 25 kg/m^2 or higher is considered obese [24]. Obesity was determined according to the Japanese criteria for obesity and classified into two groups: BMI of 25 kg/m^2 or more (obese group) and BMI of less than 25 kg/m^2 (non-obese group).

2.3.2. Sedentary behavior and physical activity

Sedentary behavior and PA were measured using a validated [25,26] triaxial accelerometer (Active style Pro HJA-750C; Omron Healthcare, Inc., Kyoto, Japan). The triaxial accelerometer was placed on a special cover and worn on the lower back using a safety pin. The wearing period was two consecutive weeks. The wearing time excluded activities in which they could not be worn, such as swimming, changing clothes, bathing, and sleeping. The triaxial accelerometer data were imported into a computer once the device returned at the end of the monitoring period. Data were analyzed only if it was available for more than 3 weekdays and more than 1 day of the weekend, during which the device was worn for at least 600 min/d (and removed for less than 60 min).

Physical activity was measured every 10 s and totaled daily. Activity intensity was classified into SB (PA $<$ 1.6 METs), LPA (1.6 METs $\leq$ PA $<$ 3.0 METs), MPA (3.0 METs $\leq$ PA $<$ 6.0 METs), VPA (6.0 METs $\leq$ PA), and MVPA (3.0 METs $\leq$ PA). Behavioral patterns were classified into ambulatory and non-ambulatory activities for each intensity category [26] and expressed in min per day. Interval measures are presented as the mean (standard deviation: SD). No data were missing.

2.4. Statistical analysis

The sample size was enough to detect an effect size of 0.20 for BMI using an F-test. Eighty participants were required to obtain a statistical power of 0.8 and a risk level of 0.05.

Physical characteristics were analyzed using the interval scale as mean (SD) and the nominal scale as counts (percentage). Physical activity (min/day) according to intensity was tabulated using macros provided free of charge by the Japan Physical Activity Research Platform [27]. The average values were calculated by weighting 5 weekdays and 2 weekend days {weighted data = [(average for weekdays × 5 days) + (average for weekend days × 2 days)]/7} (SD).

Physical activity was compared using analysis of covariance (ANCOVA) in the BMI categories (obese and non-obese groups). Moreover, BMI and PA were covariates, as they were influenced by sex and age.

Multiple regression analyses with single-factor, partition, and IS models were conducted to examine the association of SB, LPA, and MVPA times, and their replacements with BMI. The independent variables were behavioral variables with a 10-min unit to facilitate the interpretation of the results. Sex and age were used as the covariates. The variance inflation factor (VIF) was calculated to confirm multicollinearity among variables. A VIF greater than 5 indicates moderate or high multicollinearity; none of the variables in this study exceeded this threshold.

2.4.1. Single-factor model

In the single-factor model, the time of SB, ambulatory and non-ambulatory LPA, ambulatory and non-ambulatory MVPA, accelerometer wearing time, and covariates were fed into the model to check the overall relevance of each behavior.

2.4.2. Partition model

In the partition model, all action times and covariates for SB, ambulatory and non-ambulatory LPA, and ambulatory and non-ambulatory MVPA were fed into the model to confirm the independent association of each action variable.

2.4.3. IS model

In the IS model, SB, ambulatory and non-ambulatory LPA, and ambulatory and non-ambulatory MVPA action times were fed into the regression model with the exception of SB, and acceleration attachment times and covariates were further fed into the model. For example, when examining the relationship between SB replacement and ambulatory LPA/BMI, ambulatory and non-ambulatory LPA, ambulatory and non-ambulatory MVPA, time spent wearing the accelerometer, and covariates were fed into the model. This allowed us to examine the association with BMI when 10 min of SB per day was replaced with 10 min of ambulatory LPA.

Statistical analysis was performed using IBM SPSS Statistics (version 23.0; IBM Co., Tokyo, Japan), with a statistical significance level of 5 %.

3. Ethics statement

This study was approved by the Ethics Committee of the University of Nagano (E21-10).

4. Results

The physical characteristics of the participants are presented in Table 1. Overall, 44 participants (50.0 %) had a BMI of 25 kg/m^2. Sixteen of the 41 men (39.0 %) and 28 of the 47 women (59.6 %) had a BMI of 25 kg/m^2.

SB and intensity category-specific PA time and its breakdown (e.g., ambulatory and non-ambulatory) for the participants as a whole and for the obese and non-obese groups by group are shown in Table 2. Overall, MVPA time was 73.4 min/d.

The comparison between the two groups showed no significant differences in SB or VPA times; however, LPA ($p = 0.040$), MPA ($p = 0.004$), and MVPA times ($p = 0.009$) were significantly shorter in the obese group than in the non-obese group.

Table 1
Participants physical characteristics (n = 88).

		All (Men 41, Women 47)	
		Mean	(SD)
Age		27	(7.0)
Height (cm)		147.4	(8.8)
Weight (kg)		55.4	(10.5)
BMI[a] (kg/m^2)		25.6	(5.1)
		n	(%)
BMI category[b]	−1	3	(3.4)
	0	41	(46.6)
	+1	26	(29.5)
	+2	13	(14.8)
	+3	5	(5.7)
	+4	0	–

Results are presented as mean (SD) for interval scale and as number (%) for Age category and body mass index category.
[a] BMI: body mass index (kg/m^2).
[b] BMI category: −1 = BMI < 18.5, 0 = 18.5 ≤ BMI < 25, +1 = 25 ≤ BMI < 30, +2 = 30 ≤ BMI < 35, +3 = 35 ≤ BMI < 40, +4 = 40 ≤ BMI.

Table 2
Physical activity (min/d) in obesity and non-obesity groups of people with Down syndrome in adulthood (n = 88).

Physical activity status in intensity	All n = 88		Obesity group n = 44[a]		Non-obesity group n = 44[b]		
specific categories[c]	Mean	(SD)	Mean	(SD)	Mean	(SD)	*P*[d]
SB (min/d)	512.3	(92.7)	530.3	(84.9)	494.3	(97.5)	0.096
LPA (min/d)	259.4	(82.0)	240.3	(83.6)	278.6	(76.6)	0.040
Ambulatory (min/d)	44.0	(21.2)	39.3	(16.9)	48.7	(24.1)	0.043
Non-ambulatory (min/d)	215.4	(70.4)	201.0	(74.4)	229.8	(63.7)	0.075
MPA (min/d)	70.4	(33.6)	59.2	(28.2)	81.6	(35.0)	0.004
Ambulatory (min/d)	31.8	(19.4)	24.7	(16.9)	39.0	(19.2)	0.003
Non-ambulatory (min/d)	38.6	(21.5)	34.5	(17.8)	42.6	(24.2)	0.061
VPA (min/d)	3.0	(3.7)	3.2	(4.8)	2.7	(2.0)	0.423
Ambulatory (min/d)	1.8	(2.9)	1.9	(3.7)	1.6	(1.8)	0.330
Non-ambulatory (min/d)	1.2	(2.1)	1.3	(2.9)	1.1	(0.8)	0.950
MVPA (min/d)	73.4	(35.4)	62.4	(31.7)	84.3	(35.9)	0.009
Ambulatory (min/d)	33.6	(20.7)	26.6	(19.3)	40.6	(19.8)	0.010
Non-ambulatory (min/d)	39.8	(22.6)	35.8	(20.0)	43.7	(24.5)	0.076
Steps (steps/d)	5336	(2487)	4446	(2301)	6225	(2367)	0.002
Wearing times (min/d)	845.0	(75.0)	832.9	(71.9)	857.2	(76.8)	0.222

Results are presented as mean (SD) for interval scale. The table shows unadjusted values.
[a] Obesity group is body mass index (BMI) ≥ 25 kg/m^2. There were 25 men and 19 women.
[b] Non-obesity group is BMI< 25 kg/m^2. There were 16 men and 28 women.
[c] SB: Sedentary behavior: physical activity (PA) < 1.6METs. LPA: light physical activity: 1.6METs ≤ PA< 3.0METs. MPA: moderate physical activity: 3.0METs ≤ PA< 6.0METs. VPA: vigorous physical activity: 6.0METs ≤ PA. MVPA: moderate-to-vigorous physical activity: 3.0METs ≤ PA.
[d] Analysis of covariance with sex and age as covariates.

When PA was divided into ambulatory and non-ambulatory activities, the obese group had significantly shorter ambulatory LPA ($p = 0.043$), ambulatory MPA ($p = 0.003$), and ambulatory MVPA times ($p = 0.010$) than the non-obese group.

In the IS model, BMI was significantly lower when 10 min of SB per day was replaced with equal-time ambulatory MVPA ($p = 0.005$). The LPA time showed no 10-min replacement effect in either ambulatory or non-ambulatory patients.

5. Discussion

This study aimed to suggest a rationale for actions that should replace physical inactivity time to reduce obesity in Japanese adults with Down syndrome. We found that replacing 10 min of SB with MVPA may reduce obesity. To our knowledge, this is the first report of behavioral interdependence that suggests that replacing 10 min of SB with MVPA in adults with Down syndrome has the benefit of reducing obesity. These results provide useful evidence-based resources for planning PA promotion programs to maintain BMI and reduce obesity in adults with Down syndrome.

As shown in Table 1, more adults with Down syndrome were obese (BMI of 25 kg/m^2) than their Japanese peers. In the National Health and Nutrition Examination Survey of Japan [28], 26.7 % of men and 12.6 % of women aged 20–39 years had a BMI of 25 kg/m^2 or higher, indicating that men are more likely to be obese than women. In contrast, the results of this study suggest that it may be necessary to raise more awareness about obesity in adults with Down syndrome among women than among men. In any case, men and women with Down syndrome are at high risk of obesity, and there is an urgent need to prevent or ameliorate this problem.

As shown in Table 2, although the study participants had a high risk of obesity, their PA was not necessarily low. The WHO guidelines on physical activity and sedentary behavior (2020) [12] recommend that adults living with disabilities perform at least 150–300 min/week (21–43 min/d) of MPA, at least 75–150 min/week (11–21 min/d) of VPA, or an equivalent combination of MVPA. However, previous studies have reported that individuals with Down syndrome may have difficulty achieving the PA volume guidelines. In a report by Oreskovic et al. [14] of individuals with Down syndrome attending a general hospital in Massachusetts, USA (aged 18–60 years, n = 52, mean BMI = 30.2 kg/m^2, 75 % with BMI 25 kg/m^2 or higher), MPA averaged 10.1 (SD, 13.5), VPA averaged 1.7 (SD, 9.8), and MVPA averaged 11.7 (SD, 22.4) min/d. In addition, Shields et al. [15] reported the PA of adults with Down syndrome living in Australia (aged 18–48 years, n = 12, mean BMI = 33.7 kg/m^2, all with BMI >25 kg/m^2); MPA averaged 22.3 (IQR 11.5–38.7) min/d, VPA averaged 5.0 (IQR 1.4–13.6) min/d, and MVPA averaged 27.2 (IQR 13.7–53.5) min/d. The participants in this study reached the PA guidelines for MPA (70.4 min/d) and MVPA (73.4 min/d), but not for VPA (3.0 min/d). Furthermore, when differences were checked by obesity status, there were not only significantly less LPA and MPA in the obese group, but also significant differences in ambulatory rather than non-ambulatory PA. In a previous study, Dodd et al. [13] reported an association between PA and BMI in two groups of people with Down syndrome living in Kansas, USA: obese people with a BMI of 30 kg/m^2 or more (n = 43) and others (n = 35). There were no significant differences in SB, LPA, or MVPA between the two groups, and no association was observed between BMI and PA. One factor that may have contributed to the different results from our study is the difference in the cutoff values for BMI. However, as many of the participants in our study were physically active, it cannot be said that the difference in cutoff values was the only factor. Given the physical characteristics of muscle hypotonia, maintaining BMI or improving obesity by promoting PA in adults

Table 3
Associations between BMI[a] and sedentary behavior, physical activity using single, partition and isotemporal substitution models by multiple regression analysis (n = 88).

Models	SB[b]		Ambulatory LPA[c]		Non-ambulatory LPA[c]		Ambulatory MVPA[d]		Non-ambulatory MVPA[d]	
	β (95%CI)	*p*	β (95%CI)	*p*	β (95%CI)	*p*	β (95%CI)	*p*	β (95%CI)	*p*
Single	0.223 (0.017, 0.228)	0.023	−0.148 (−0.822, 0.114)	0.137	−0.152 (−0.260, 0.040)	0.148	−0.252 (−1.081, −0.161)	0.009	−0.110 (−0.669, 0.172)	0.244
Partition	−0.123 (−0.206, 0.070)	0.332	−0.089 (−0.709, 0.283)	0.395	−0.317 (−0.414, −0.045)	0.015	−0.335 (−1.333, −0.317)	0.002	0.064 (−0.393, 0.684)	0.593
Isotemporal substitution										
Replace SB	Dropped		−0.061 (−0.647, 0.357)	0.567	−0.223 (−0.339, 0.016)	0.074	−0.307 (−1.276, −0.238)	0.005	0.094 (−0.290, 0.716)	0.402

The independent variables were behavioral variables with a 10-min unit to facilitate the interpretation of the results . Sex and age were used as the covariates.
[a] BMI: body mass index (kg/m^2).
[b] SB: Sedentary behavior: physical activity (PA) < 1.6 METs.
[c] LPA: light physical activity: 1.6 METs ≤ PA < 3.0 METs.
[d] MVPA: moderate-to-vigorous physical activity: 3.0 METs ≤ PA.

with Down syndrome requires the planning of specific programs that focus on MPAs, especially those involving walking. This can be practiced without difficulty in daily life, rather than VPA.

In this study, the time difference in PA between the obese and non-obese groups was approximately 40, 20, and 10 min for LPA, MVPA, and ambulatory MVPA, respectively (Table 2). To examine the benefits of increasing PA by 10 min, given the physical characteristics of low muscle tone in adults with Down syndrome and in light of feasibility, we examined the replacement of time for each activity category within the total time of SB, LPA, and MVPA (within the wearing time) (Table 3). The results revealed that replacing 10 min of SB with ambulatory MVPA may be associated with lower obesity. Previous studies on the general adult population have also suggested that replacing SB time with other PA times may have a favorable effect on BMI [18–21] and reported that MVPA was associated with a lower BMI in 445 healthy Caucasian individuals of European origin (49.6 % female, mean age: 66 ± 6 years, mean BMI: 25.9 ± 4.1 kg/m^2) when 10 min of SB was replaced with MVPA. The duration of SB replacement, as shown in this study and related to the BMI, was 10 min. The Japanese Active Guide (Health Japan 21) [29] recommends to "move your body for 10 min more every day than you do now." In adults with Down syndrome, 10 min is a highly feasible and important resource for planning specific PA promotion programs.

This study had some limitations. First, this was a cross-sectional study, meaning that causal relationships could not be established. Second, the sample size was small, which limited the number of control variables; additionally, there is a possibility of residual confounding. Third, there was participant bias because the participants were adults with Down syndrome living in Japan who came forward and were willing to participate. However, the fact that the study was not biased toward one region and was conducted with the cooperation of parent associations in various parts of Japan, likely contributes to the usefulness of the results. Thus, although generalizations should be made with caution, this is the first report to consider the behavioral interdependence of the benefits of replacing 10 min of SB with ambulatory MVPA to reduce obesity in adults with Down syndrome.

Children with Down syndrome are physically active at school and are less obese [30–32]. However, adults with Down syndrome are more likely to be obese. Therefore, a program that promotes PA and prevents or improves obesity is required. A program to promote PA based on the results of this study would encourage an increase in daily activities that involve walking for 10 min, at least three METs, in the daily routine. People with Down syndrome are said to have characteristics such as love for social interactions, friendliness, and a good sense of music [1,23]. An example of a device that can encourage participation and continuity is the substitution of daily activities, such as walking to work or shopping (i.e., behavior substitution method) or placing a favorite game console in a separate room and performing activities that would otherwise require standing and walking at home (i.e., nudge theory). Other possible approaches include game-like activities such as aiming to achieve a target number of steps with peers or encouraging individuals to dance while listening to music. The use of application tools to promote PA and the creation of community-based mechanisms involving surrounding supporters and others are also expected to be sustainable. The verification of the usefulness and effectiveness of the program developed based on the results of this study will be the focus of future research.

6. Conclusions

Adults with Down syndrome may be at higher risk of developing obesity than their Japanese counterparts. The PA of adults with Down syndrome suggests that those with obesity may engage in less LAP, MPA, and MVPA, as well as less activity involving walking than those who are not obese. Replacing 10 min of SB with walking-based MVPA may reduce obesity.

Data availability statement

Data associated with this study been not deposited into a publicly available repository. The datasets supporting our findings are presented in the article.

Funding

This work was supported by JSPS KAKENHI Grant Number JP20K02326.

CRediT authorship contribution statement

Erika Yamanaka: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Takayo Inayama:** Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Kazunori Ohkawara:** Writing – review & editing, Supervision, Software, Methodology, Formal analysis, Conceptualization. **Michio Kojima:** Writing – review & editing, Methodology, Conceptualization. **Tsubasa Nakada:** Software, Resources, Formal analysis, Data curation. **Ichiro Kita:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to express our sincere gratitude to the Japan Down syndrome Society for conducting this study as well as to our research collaborators, their families, and everyone involved.

References

[1] M. Suwa, All about Down Syndrome, Revised second ed., Chugai Igaku-sha, Tōkyō, 2021 (In Japanese).
[2] J. Carr, S. Collins, 50 years with Down syndrome: a longitudinal study, Res. Intell. Disabil. 31 (2018) 743–750, https://doi.org/10.1111/jar.12438.
[3] Y. Kanbara, C. Takeuchi, Y. Mochizuki, M. Osako, M. Sasaki, H. Miyake, Medical needs of adults with Down syndrome presenting at a regional medical and rehabilitation center in Japan, J. Nippon Med. Sch. 90 (2023) 210–219, https://doi.org/10.1272/jnms.JNMS.2023_90-211.
[4] F. Bertapelli, K. Pitetti, S. Agiovlasitis, G. Guerra-Junior, Overweight and obesity in children and adolescents with Down syndrome-prevalence, determinants, consequences, and interventions: a literature review, Res. Dev. Disabil. 57 (2016) 181–192, https://doi.org/10.1016/j.ridd.2016.06.018.
[5] A. Soler Marín, J.M. Xandri Graupera, Nutritional status of intellectual disabled persons with Down syndrome, Nutr. Hosp. 26 (2011) 1059–1066, https://doi.org/10.1590/S0212-16112011000500021.
[6] A.P. Presson, G. Partyka, K.M. Jensen, O.J. Devine, S.A. Rasmussen, L.L. McCabe, E.R.B. McCabe, Current estimate of Down syndrome population prevalence in the United States, J. Pediatr. 163 (2013) 1163–1168, https://doi.org/10.1016/j.jpeds.2013.06.013.
[7] A.H. Bittles, C. Bower, R. Hussain, E.J. Glasson, The four ages of Down syndrome, Eur. J. Publ. Health 17 (2007) 221–225, https://doi.org/10.1093/eurpub/ckl103.
[8] E.J. Glasson, S.G. Sullivan, R. Hussain, B.A. Petterson, P.D. Montgomery, A.H. Bittles, Comparative survival advantage of males with Down syndrome, Am. J. Hum. Biol. 15 (2003) 192–195, https://doi.org/10.1002/ajhb.10132.
[9] R.M. Martínez-Espinosa, M.D. Molina Vila, M. Reig García-Galbis, Evidences from clinical trials in Down syndrome: diet, exercise and body composition, IJERPH 17 (2020) 4294, https://doi.org/10.3390/ijerph17124294.
[10] A. García-Hermoso, A.P. Quintero, E. Hernández, J.E. Correa-Bautista, M. Izquierdo, A. Tordecilla-Sanders, D. Prieto-Benavides, C. Sandoval-Cuellar, K. González-Ruíz, E. Villa-González, R. Ramírez-Vélez, Active commuting to and from university, obesity and metabolic syndrome among Colombian university students, BMC Publ. Health 18 (2018) 523, https://doi.org/10.1186/s12889-018-5450-5.
[11] K. Hsieh, J.H. Rimmer, T. Heller, Obesity and associated factors in adults with intellectual disability: obesity and ID, J. Intellect. Disabil. Res. 58 (2014) 851–863, https://doi.org/10.1111/jir.12100.
[12] World Health Organization, WHO Guidelines on Physical Activity and Sedentary Behaviour, 2020, pp. 22–23. https://www.who.int/publications/i/item/9789240015128 (Accessed 15 August).
[13] D. Dodd, B. Helsel, A.E. Bodde, J.C. Danon, J.R. Sherman, J.E. Donnelly, R.A. Washburn, L.T. Ptomey, The association of increased body mass index on cardiorespiratory fitness, physical activity, and cognition in adults with down syndrome, Disabil. Health J. 101497 (2023), https://doi.org/10.1016/j.dhjo.2023.101497.
[14] N.M. Oreskovic, C. Cottrell, A. Torres, V. Patsiogiannis, S. Santoro, D. Nichols, C. Moore, B.G. Skotko, Physical activity patterns in adults with Down Syndrome, J. Appl. Res. Intellect. Disabil. 33 (2020) 1457–1464, https://doi.org/10.1111/jar.12773.
[15] N. Shields, S. Plant, C. Warren, D. Wollersheim, C. Peiris, Do adults with Down syndrome do the same amount of physical activity as adults without disability? A proof of principle study, J. Appl. Res. Intellect. Disabil. 31 (2018) 459–465, https://doi.org/10.1111/jar.12416.
[16] J. Grgic, D. Dumuid, E.G. Bengoechea, N. Shrestha, A. Bauman, T. Olds, Z. Pedisic, Health outcomes associated with reallocations of time between sleep, sedentary behaviour, and physical activity: a systematic scoping review of isotemporal substitution studies, Int. J. Behav. Nutr. Phys. Activ. 15 (2018) 69, https://doi.org/10.1186/s12966-018-0691-3.
[17] R.A. Mekary, W.C. Willett, F.B. Hu, E.L. Ding, Isotemporal substitution paradigm for physical activity epidemiology and weight change, Am. J. Epidemiol. 170 (2009) 519–527, https://doi.org/10.1093/aje/kwp163.
[18] I.K. Dahl-Petersen, S. Brage, P. Bjerregaard, J.S. Tolstrup, M.E. Jørgensen, Physical activity and abdominal fat distribution in Greenland, Med. Sci. Sports Exerc. 49 (2017) 2064–2070, https://doi.org/10.1249/MSS.0000000000001337.
[19] N. Gupta, M. Heiden, M. Aadahl, M. Korshøj, M.B. Jørgensen, A. Holtermann, What is the effect on obesity indicators from replacing prolonged sedentary time with brief sedentary bouts, standing and different types of physical activity during working days? A cross-sectional accelerometer-based study among blue-collar workers, PLoS One 11 (2016) e0154935, https://doi.org/10.1371/journal.pone.0154935.
[20] G.N. Healy, E.A.H. Winkler, N. Owen, S. Anuradha, D.W. Dunstan, Replacing sitting time with standing or stepping: associations with cardio-metabolic risk biomarkers, Eur. Heart J. 36 (2015) 2643–2649, https://doi.org/10.1093/eurheartj/ehv308.
[21] M. Hamer, E. Stamatakis, A. Steptoe, Effects of substituting sedentary time with physical activity on metabolic risk, Med. Sci. Sports Exerc. 46 (2014) 1946–1950, https://doi.org/10.1249/MSS.0000000000000317.
[22] Y. Onodera, N. Kitano, T. Kuchiki, Y. Kai, T. Nagamatsu, S. Machida, Isotemporal substitution of sedentary time with physical activity and its associations with mental health of Japanese office workers, Jpn. J. Phys. Fit. Sports Med. 68 (2019) 261–268, https://doi.org/10.7600/jspfsm.68.261.
[23] Japan Down Syndrome Society. https://www.jdss.or.jp/family/index.html. (Accessed 15 August 2023) (In Japanese).
[24] W. Ogawa, S. Miyazaki, Diagnosis criteria for obesity and obesity disease, JHEP 42 (2015) 301–306, https://doi.org/10.7143/jhep.42.301.

[25] Y. Hikihara, S. Tanaka, K. Ohkawara, K. Ishikawa-Takata, I. Tabata, Validation and comparison of 3 accelerometers for measuring physical activity intensity during nonlocomotive activities and locomotive movements, J. Phys. Activ. Health 9 (2012) 935–943, https://doi.org/10.1123/jpah.9.7.935.
[26] K. Ohkawara, Y. Oshima, Y. Hikihara, K. Ishikawa-Takata, I. Tabata, S. Tanaka, Real-time estimation of daily physical activity intensity by a triaxial accelerometer and a gravity-removal classification algorithm, Br. J. Nutr. 105 (2011) 1681–1691, https://doi.org/10.1017/S0007114510005441.
[27] Japan Physical Activity Research Platform. Available online. http://paplatform.umin.jp (accessed on 15 August 2023). (In Japanese).
[28] National Health and Nutrition Examination Survey of Japan, Ministry of Health, Labour and Welfare, 2019. Available online: https://www.nibiohn.go.jp/eiken/kenkounippon21/download_files/eiyouchousa/2019.pdf, 21 februsry 2024.
[29] The Japanese Active Guide (Health Japan 21), Ministry of Health, Labour and Welfare. https://www.mhlw.go.jp/stf/houdou/2r9852000002xple.html (accessed on 15 August 2023). (In Japanese).
[30] E. Yamanaka, T. Inayama, K. Okazaki, T. Nakada, M. Kojima, I. Kita, K. Ohkawara, The amount of light to vigorous physical activity (Met's-Hours/Day) in children with and without Down syndrome attending elementary school in Japan, IJERPH 20 (2023) 1293, https://doi.org/10.3390/ijerph20021293.
[31] E. Yamanaka, T. Inayama, K. Okazaki, I. Kita, K. Ohkawara, Differences in the amount of moderate to vigorous physical activity during school term and summer vacation among children, Japan Society of Health Promotion and adolescents with Down's syndrome 23 (2021) 187–194, 874288EE8E52976C2D328D5A2D8D5A97B92E696E6464> (umin.jp) (In Japanese).
[32] E. Yamanaka, T. Inayama, K. Ohkawara, K. Okazaki, I. Kita, The association between obesity and sedentary behavior or daily physical activity among children with Down's syndrome aged 7-12 years in Japan: a cross-sectional study, Heliyon 6 (2020) e04861, https://doi.org/10.1016/j.heliyon.2020.e04861.