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Correlates of physical activity, sedentary time, and cardiovascular disease risk factors in autistic adults without intellectual disabilities

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ABSTRACT

Background: Emerging evidence indicates that autistic adults without intellectual disabilities (ID) are at elevated risk of developing cardiovascular disease (CVD).
Aims: This cross-sectional survey study aimed to assess the prevalence of physiological and mental health risk factors for CVD and examine how physical activity (PA) and sedentary time (ST) relate to CVD risk in autistic adults without ID.
Methods: An online self-report survey addressing PA, ST, and CVD risk factors was delivered to 229 autistic adults without ID aged 18–55 years. Participants were recruited via direct contact with autism advocacy organizations in the U.S. and autism support groups on social media. Binary logistic regression analyses were used to explain the impact of PA and ST on CVD risk factors.
Results: Higher ST was significantly associated with increased odds for high blood pressure, stroke, and mental health risk factors (depression, anxiety, bipolar, and obsessive-compulsive disorder; all $p < 0.05$). No significant associations were found between PA and CVD risk factors.
Conclusions: Excessive ST in autistic adults without ID is associated with an increased risk for certain CVD factors, particularly those related to poor mental health. Health interventions should focus on breaking up prolonged sitting as a CVD prevention strategy in this population.

What this paper adds?

Recent studies suggest that autistic adults without co-occurring ID are more likely to develop lifestyle-related CVD. This study aimed to understand the relationship between PA, sitting time, and specific physiological and mental health issues as potential causes of CVD in autistic adults without ID. The research team surveyed 229 autistic adults aged 18–55 and found that a high level of ST was linked to an increased risk of experiencing high blood pressure, stroke, depression, anxiety, bipolar disorder, and obsessive-compulsive

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disorder. There was no significant connection between the level of PA and CVD risk factors. These findings show that excessive sitting is correlated with poor mental health in autistic adults without ID. This work highlights the need for effective interventions that reduce sitting time as a preventative health behavior in this population.

1. Introduction

It is well documented that lack of physical activity (PA) and excessive sedentary time (ST) are leading modifiable risk factors for cardiovascular disease (CVD) in the general population (Chomistek et al., 2013; Lavie et al., 2019). Data on PA and ST in people with autism spectrum disorder (ASD) are largely based on studies of autistic children and adolescents with co-occurring intellectual disabilities (ID), highlighting that these individuals tend to become less physically active and more sedentary with age (MacDonald et al., 2011). An earlier study reported the associations between lower PA levels, higher body mass index, and increased arterial stiffness as a critical indicator of CVD risk among autistic children (Heffernan et al., 2018). This study suggests that autistic individuals may be prone to subclinical risk of CVD from early childhood due to lifestyle factors (e.g., physical inactivity and unhealthy weight). Few comparative studies that focused on both autistic adults with and without ID revealed that autistic adults without ID are often more vulnerable to lifestyle-related chronic health conditions, such as obesity, diabetes, high blood pressure, and chronic obstructive pulmonary disease (Gilmore et al., 2021), as well as mental disorders, such as depression, general anxiety disorder, and social phobia (Crowley et al., 2022), as compared to those with co-occurring ID. Furthermore, a recent observational study based on a large sample of autistic adults without ID (n = 545) reiterated previous findings by revealing a remarkably high prevalence of CVD risk factors in this population in which three quarter of the participants had at least one CVD risk factor (Bishop et al., 2023).

The estimated autism prevalence has steadily increased over the past two decades (Maenner et al., 2021), but prevalence data on autistic adults are limited and greatly vary (Robison, 2019). The available surveillance systems focus heavily on young children with an emphasis on those with co-occurring ID, and there is limited knowledge on how preventive health behaviors (e.g., PA participation) evolve among autistic youth without ID as they transition to adulthood, particularly in relation to their increasing autonomy in behavioral decision-making. Autistic adults without ID often face interpersonal and environmental barriers to PA participation, such as lack of intrinsic motivation to move, sensory sensitivities in public settings, and lack of transportation support (Healy et al., 2022). When compared to the general population, autistic adults without ID also have a greater probability of experiencing multiple comorbid health conditions, which can limit their ability to regularly engage in PA and pervasively exacerbate physical and mental well-being (Forde et al., 2022). Croen et al. (2015) used Kaiser Permanente Northern California medical records to compare chronic health conditions between autistic adults ($\geq$ 18 years) and their age and sex matched controls. Autistic adults had significantly higher rates of both psychiatric and medical conditions, including depression, anxiety, obsessive-compulsive disorder (OCD), obesity, dyslipidemia, and hypertension than the control group (Croen et al., 2015). Davignon et al. (2018) analyzed the same dataset and compared transition-aged autistic individuals (14–25 years) to age and sex matched groups with attention deficit/hyperactivity disorder and controls without these diagnoses. Similar to the earlier study, their findings highlighted that there was an increased risk for developing major medical conditions in transition-aged autistic individuals, including dyslipidemia, obesity, and gastrointestinal disorders, compared to the control groups while this burden of disease intensified as they grew (Davignon et al., 2018). There is an imperative need to better understand the underlying reasons for these poor health outcomes in autistic adults and how modifiable behavioral factors such as PA and ST relate to CVD risk in this population.

The American Heart Association science advisory committee reported that on average, American adults spend 6–8 hours per day sedentary, although the results of the estimated ST may widely differ among the assessment instruments (Young et al., 2016). Epidemiological evidence suggests excess sedentary behavior should be recognized as a standalone risk factor for adverse health outcomes, including CVD-related morbidity and subsequent disease burden in the general population (G. N. Healy et al., 2011; Young et al., 2016). Likewise, previous studies have identified an inverse association between ST and mental health in diverse adults without disabilities and clinical groups while reducing ST, regardless of bout length, can positively change mental health profiles (Ellingson et al., 2018; Rhodes et al., 2012; Van Uffelen et al., 2013). Moreover, a recent meta-analysis of prospective studies called attention to the detrimental role of mentally passive sedentary behaviors such as watching television in increasing the risk of depression in the general population (Huang et al., 2020).

Although the relationship between modifiable health behaviors and CVD risk is well established in the general population (Kaminsky et al., 2022), it remains largely underreported in autistic adults without ID, a subpopulation of autistic individuals who present distinct behavioral patterns and health profiles. Despite their distinct patterns of PA and sedentary behavior, few studies focused on the impact of these modifiable health behaviors on CVD outcomes specifically within this subgroup. Unlike autistic individuals with co-occurring ID, those without ID who live independently may experience greater health disparities due to the gap between their functional abilities and societal expectations. While these individuals possess cognitive and verbal skills that align with typical developmental milestones, they may still encounter challenges in social communication, executive functioning, and sensory discomforts (e.g., sounds and lights), which often hinder their participation in PA within community-based programs or public settings (Blagrave et al., 2021) and their ability to navigate general healthcare effectively (Raymaker et al., 2017).

The heightened CVD risk in autistic adults without ID can be attributed to multiple factors, including interpersonal and environmental barriers (Healy et al., 2022), elevated rates of physiological and mental health conditions (Croen et al., 2015; Crowley et al., 2022), and inactive lifestyle (Gilmore et al., 2021). Drawing from previous research on the relationship between CVD risk and preventive health behaviors in autistic children (Heffernan et al., 2018) and neurotypical adults (Chomistek et al., 2013; Lavie et al., 2019), prolonged sedentary behavior and lower PA levels may further increase the vulnerability of autistic adults without ID to CVD. Despite the ongoing efforts to delineate the prevalence of chronic health conditions in autistic individuals, there is insufficient evidence

for a relation between behavioral outcomes and CVD risk factors in autistic adults without ID. Understanding how modifiable health behaviors influence CVD risk factors in this underrepresented group is crucial for addressing a knowledge gap in the autism literature. Using a cross-sectional survey, this study aimed to 1) assess the prevalence of physiological and mental health risk factors for CVD in a relatively large sample of autistic adults without ID and 2) examine the associations between the levels of PA and ST and CVD risk factors in this population. We hypothesized that a low level of PA and/or a high level of ST would be associated with a high prevalence of CVD risk factors in autistic adults without ID.

2. Material and methods

2.1. Participants

Prospective participants who met the following inclusion criteria were invited to complete a self-report online survey: (a) 18–55 years of age; (b) diagnosis of an ASD by a qualified medical professional; (c) no use of mobility-related assistive devices (e.g., wheelchair or crutches) for walking; and (d) cognitive capacity to process and complete the entire survey independently. Only participants who successfully completed the survey and also met the response validity criteria were provided with a $10 Amazon e-gift card as compensation. All participants provided electronic informed consent prior to study participation, and this study was approved by the Institutional Review Board at Indiana University (Protocol #: 1708965076).

2.2. Survey development

A Qualtrics self-report survey was developed to assess the following topics: (a) demographic information; (b) autism traits using the Autism Spectrum Quotient-10 (AQ 10) (Baron-Cohen et al., 2001); (c) ST using a modified version of the Sedentary Behavior Questionnaire (Rosenberg et al., 2010), with rephrased questions designed to improve their readability and clarity, guided by a survey research expert (d) PA using the International Physical Activity Questionnaire-Short form (IPAQ-SF) (Craig et al., 2003); and (e) health risk factors for CVD. The risk factors for CVD were categorized into physiological (e.g., high blood pressure, diabetes, cholesterol, triglycerides, heart attack, stroke, and cancer) and mental health risk factors (e.g., depression, anxiety, bipolar, and OCD). Survey participants were asked to report their physiological and mental health conditions based on a formal diagnosis from a physician or medical professional. The IPAQ-SF consisted of three main questions on vigorous PA, moderate PA, and walking, each with numeric entry for frequency (i.e., 0–7 days) and duration (i.e., hours and minutes per day). The ST section included nine questions adapted from the Sedentary Behavior Questionnaire, with categorical response options ranging from none to 6 + hours per day. The summed total ST was reported separately for weekdays and weekends. According to the scoring guidelines, weekly estimates were calculated by multiplying the total weekday hours by 5 and the total weekend hours by 2 (Rosenberg et al., 2010).

Certain items in the Sedentary Behavior Questionnaire were rephrased to align with contemporary terminology and improve participant comprehension. For example, in the original questionnaire, one item assesses time spent "doing paperwork or computer work (office work, emails, paying bills, etc.)". In our modified version, this item was reworded as "During the typical five weekdays, about how much time do you usually spend doing the following activity per day? – Sitting while doing schoolwork, job tasks, or computer work." These modifications were informed by a piloting process to ensure clarity while maintaining the original questionnaire's structure and intent. The data reported in this paper were collected as part of a large survey that investigated the correlates of PA, ST, technology use, and their associations with CVD risk factors in autistic adults without ID.

Content validity of survey questions was examined, and the pilot survey was tested and revised according to the feedback from experts in the fields of survey methodology and autism, including one parent/advocate. Two survey research experts led the validation and revision process that elaborated on wording, formatting, and other survey mechanics. Also, visual aids, along with detailed descriptions of sample activities, were incorporated into the PA and sedentary behavior questions to facilitate comprehension by the autistic respondents who often prefer visual communication and rely on visual mental representations to process information (Bled et al., 2021). Logic metrics of the survey questions and multiple-choice scales were customized to calculate the estimated response time and clarify available choice options.

Six autistic adults without ID recruited through convenience sampling pretested the survey to examine quality indicators, such as response time, readability, structural flow of questions, and survey design format. Follow-up interviews were conducted with these individuals to gain detailed feedback on the clarity and appropriateness of the questions. The survey was revised according to the provided feedback and completed a second time by the same autistic volunteers for additional clarification. The finalized survey was accessible through commonly used digital devices (e.g., computers, smartphones, and tablets), consisted of 80 questions with 5 subquestions depending on the response metrics. The survey methodology experts determined that minimum 15 minutes were required to properly comprehend and respond to all questions included in the survey.

2.3. Procedure

Participants were recruited via direct contact with regional and national autism advocacy organizations in the U.S. and autism support groups on social media. Online community groups in Facebook and Reddit that aggregate autism-related issues in adulthood and share discussion on conversation topics were specifically targeted because it was reasoned that most group members are autistic individuals who are cognitively capable of participating in a self-administered survey. Invitation messages with the study description and survey link were posted in public sources of the autism advocacy organizations and accessible feed pages of social media sites.

Eligibility criteria along with the purpose of the study were highlighted in the first page of the survey. To ensure the quality of responses and minimize the influence of a biased sampling, response validity criteria were established based on the Checklist for Reporting Results of Internet E-Surveys (Eysenbach, 2004) as a measure to prevent data contamination. The criteria included a $\geq$ 15-minute survey completion time as a cut-off threshold, evidence of autism identification, and exclusion of duplicate entries.

We leveraged Qualtrics' timestamping feature to measure the times between a survey is commenced and completed. Cases with the total survey completion time less than 15-minute were excluded. The level of autism traits was assessed by the AQ 10 score. The overall AQ 10 score was divided into two categories (i.e., less severe 0–5 and severe 6–10), where individuals in a severe category can be

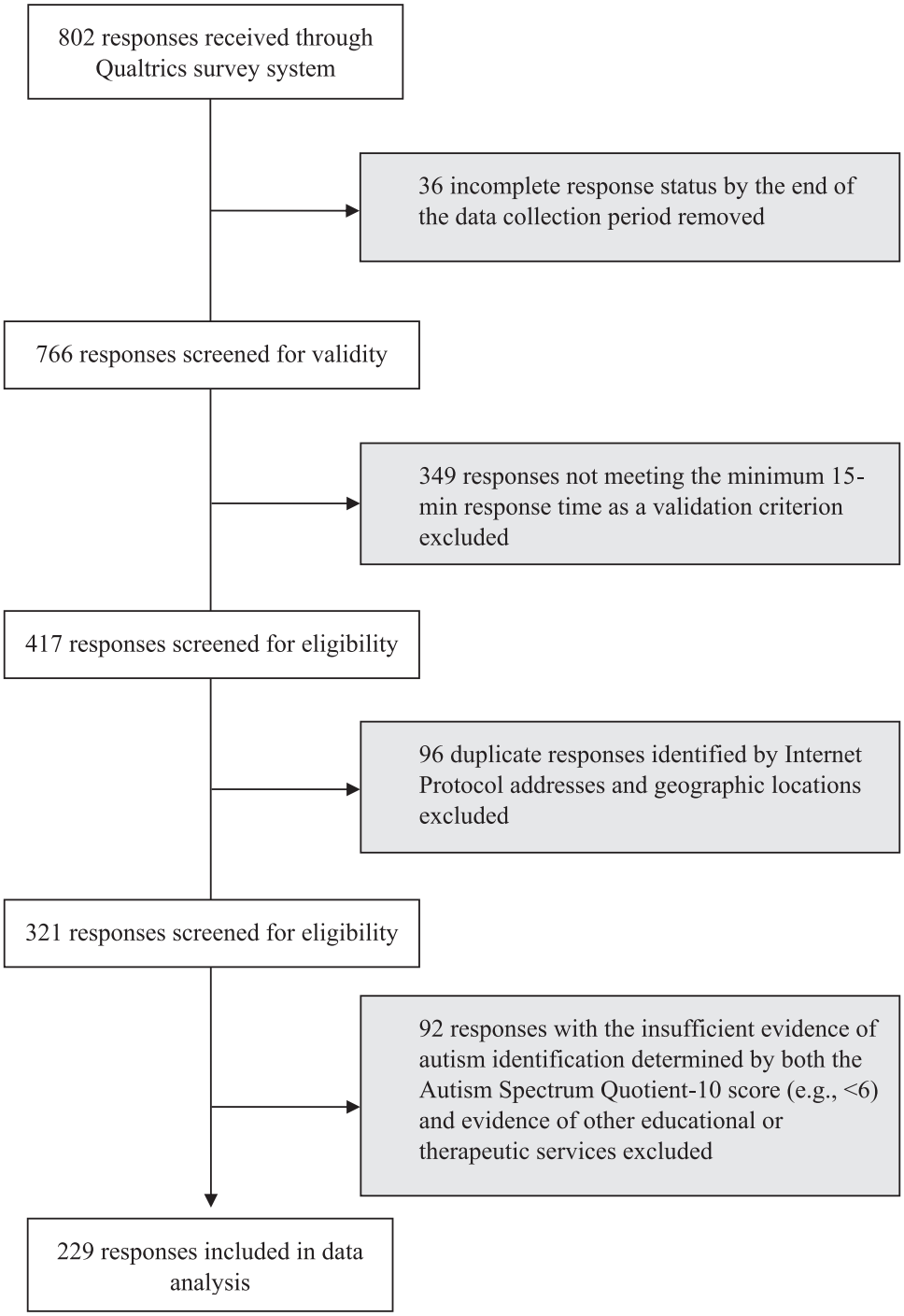

Fig. 1. Response validation flowchart.

referred for a formal diagnostic assessment (Baron-Cohen et al., 2001; Wheelwright et al., 2006). Evidence of autism identification was further assessed by service history, such as having an Individualized Education Program (IEP) during school years, experiencing school-based services due to an ASD diagnosis, and receiving therapeutic services for autism-related symptoms. Duplicate survey entries were excluded by using Qualtrics-supported geographic location and Internet Protocol (IP) address-tracking features. Of the 802 responses received, 573 were excluded due to not meeting the response validation criteria, such as atypical timestamp for survey completion, duplicate entries, or insufficient evidence of autism identification. Detailed response validation process is illustrated in Fig. 1.

2.4. Data cleaning

We calculated metabolic equivalent of task (MET) values for PA intensities according to the IPAQ guidelines (i.e., vigorous PA (VPA) = 8.0 METs x time reported; moderate PA (MPA) = 4.0 METs x time reported; and walking = 3.3 METs x time reported) (International Physical Activity Questionnaire Research Committee, 2005). The following data cleaning process was employed to detect and remove unreliable records from responses: (1) exclude cases if the sum total of all walking, MPA and VPA time variables was greater than 960 min/day (>16 hours per day) and (2) all walking, MPA and VPA time variables exceeding 180 min/day were truncated to be equal to 180 min/day (International Physical Activity Questionnaire Research Committee, 2005). According to the 2018 PA guidelines for Americans, adults may achieve 75 minutes of VPA per week (Piercy et al., 2018), and its reasonable equivalent can be 500–1000 MET-minutes/week (Ross et al., 2016). As such, we eliminated (1) cases with > 3000 MET-minutes/week for each PA category, (2) cases where the total MET-minutes/week of walking, MPA and VPA was > 6000 MET-minutes/week, and (3) cases higher than 180 min/day on average for both MPA and VPA. We also defined and identified ST outliers based on the following criteria: (1) cases with a total ST of $\geq$ 17 hours/day, considering 7–9 hours/day and 15–17 hours/day as the average sleep and awake times respectively and (2) cases with a ST of $\leq$ 1 hour/day. Following the Mahalanobis distance criterion, two multivariate outliers were detected in the PA variables and body mass index (BMI) score, but they were already accounted by the PA data cleaning procedure.

2.5. Data analysis

We performed descriptive analyses to summarize demographic characteristics and prevalence of PA, domain-specific ST, and CVD risk factors among the study participants. Total PA and ST were presented as median and interquartile range (IQR) due to the violation of normal distribution assumption. Related-Samples Wilcoxon Signed Rank Tests were executed to compare median differences of ST between the two time periods in a week (i.e., weekday vs. weekend day). Entries with missing values on PA and/or ST were discarded for further analyses. Independent samples t-tests were performed to compare differences in ST by the existence of CVD risk factors. Binary logistic regression was employed to examine the associations between PA, ST, and CVD physiological and mental health risk factors. Regression analyses were sequentially conducted for total PA time, which consisted of times spent for moderate-to-vigorous PA and walking. Regression models were adjusted for age, sex, physical and mental health satisfaction, quality of life, and existence of co-occurring functional limitations for PA participation. Functional limitations related to PA participation were identified using the question “Would you describe yourself as having a disability or health condition that limits your ability to participate in physical activity? If yes, please describe.” The research team analyzed the responses and converted them into a yes/no format for analysis. Decision for including covariates in the models was made based on the extent of correlation between predictor and outcome variables. Data analysis was conducted using IBM Statistical Package for the Social Sciences for Windows version 26, and p value less than 0.05 denoted statistical significance.

3. Results

A total of 229 responses from autistic adults without ID were included in the analyses. Characteristics of study participants are presented in Table 1. The majority of respondents were Caucasian males under 35 years of age and diagnosed with an autism spectrum condition during childhood (before age 12). Domain-specific STs based on the Sedentary Behavior Questionnaire calculation are presented in Table 2. Autistic adults without ID spent more time sitting on weekdays compared to weekends, largely due to work-related tasks. The estimated total median PA was 1812 MET-minutes/week (IQR = 1723.5), and the seven-day median ST was 9.1 hours/day (IQR = 5.1).

Participants who reported the existence of certain physiological and mental health risk factors for CVD tended to show higher ST than those who were asymptomatic. Specifically, the seven-day ST was significantly higher among those with physiological conditions, including high blood pressure ($\bar{x}$ = 11.3 vs. 9.1 hours/day), elevated triglycerides ($\bar{x}$ = 12.2 vs. 9.3 hours/day), heart attack ($\bar{x}$ = 11.3 vs. 9.3 hours/day), stroke ($\bar{x}$ = 13.2 vs. 9.2 hours/day), and cancer ($\bar{x}$ = 13.5 vs. 9.3 hours/day) (p values ranged from <0.001–0.027), as well as mental health conditions, including depression ($\bar{x}$ = 11.4 vs. 8.9 hours/day), anxiety ($\bar{x}$ = 10.9 vs. 8.7 hours/day), bipolar ($\bar{x}$ = 14.0 vs. 9.2 hours/day), and OCD ($\bar{x}$ = 12.4 vs. 9.1 hours/day) (all $p < 0.001$).

Tables 3 and 4 show the adjusted odds ratios for CVD risk factors explained by ST and total PA time. Sitting time with age and sex covariates (Model 1) significantly predicted the odds of high blood pressure, diabetes, heart attack, cancer, stroke, depression, anxiety, bipolar and OCD (p values ranged from <0.001–0.04). These factors accounted for more than 30 % of the variance in stroke, cancer and bipolar disorder, and between 10 % and 20 % variance in the other variables. ST with age and sex did not significantly predict the odds of high triglycerides or cholesterol. When additional covariates of physical and mental health satisfaction, quality of life, and functional limitations were added in Model 2, the coefficient of determination increased an average of 43 % (range 32–63 %) in the

Table 1
Characteristics of study participants (N = 229).

Variable	n	%
Age		
18-24	58	25.3
25-34	113	49.3
35-44	46	20.1
45-55	12	5.3
Age at diagnosis		
Early childhood (birth to age 5)	65	28.4
Later childhood (ages 6 -11)	75	32.8
Adolescence (ages 12 -18)	42	18.3
Adulthood (ages ≥18)	47	20.5
Prefer not to answer	0	0
Sex		
Male	147	64.1
Female	78	34.1
Other (e.g., nonbinary)	2	0.9
Prefer not to answer	2	0.9
Ethnicity		
Caucasian	154	67.2
African-American	21	9.2
Hispanic/ Latino	34	14.8
Asian	7	3.1
Native American/ Pacific Islander/ Native Alaskan	4	1.7
Other or more than one	7	3.1
Prefer not to answer	2	0.9
Highest level of education		
Did not complete high school	8	3.5
High school/GED	53	23.1
Some college	56	24.6
2-year college degree	31	13.5
4-year college degree	62	27.1
Master's degree	9	3.9
Professional degree (JD, MD)	4	1.7
Prefer not to answer	6	2.6
Student status		
Enrolled as a full-time student	41	17.9
Enrolled as a part-time student	14	6.1
Not a student	166	72.5
Prefer not to answer	8	3.5
Relationship status		
Married	109	47.6
Widowed	3	1.3
Divorced/separated	2	0.9
In a domestic partnership or civil union	7	3.1
Single, cohabitating with significant other	8	3.5
Single, but in a relationship, not cohabitating	8	3.5
Single, never married	86	37.5
Prefer not to answer	6	2.6
Autism traits		
Less severe	73	31.9
Severe	153	66.8
Prefer not to answer	3	1.3
BMI (kg/m^2)		
Underweight (<18.5)	10	4.4
Normal (18.5-24.9)	146	63.7
Overweight (25.0-29.9)	46	20.1
Obese, classes 1 and 2 (30.0-39.9)	11	4.8
Extremely obese (≥40)	3	1.3
Prefer not to answer	13	5.7
CVD risk factors[a]		
High blood pressure	27	11.8
Diabetes (Type 1 or 2)	8	3.5
Elevated cholesterol	13	5.7
Elevated triglycerides	7	3.1
Heart attack	15	6.6
Stroke	12	5.2
Cancer	5	2.2
Depression	49	21.4

(*continued on next page*)

Table 1 (*continued*)

Variable	n	%
Anxiety	73	31.9
Bipolar	9	3.9
Obsessive-compulsive disorder	20	8.7

Note. GED = general education development; JD = juris doctor; MD = doctor of medicine; hrs/wk = hours per week; BMI = body mass index; CVD = cardiovascular disease.
[a] Multiple choices allowed.

Table 2
Sedentary time assessed by Sedentary Behavior Questionnaire.

Sedentary Behavior	Weekday (n=222, hr/d)Median (IQR)	Weekend day (n=228, hr/d)Median (IQR)	*p* value
Sitting while watching television or movies	1 (1.38)	2 (2)	<0.001**
Sitting while playing computer, video or board games	1 (1.5)	2 (2)	<0.001**
Sitting while doing schoolwork, job tasks or computer work	3 (4.5)	0.25 (1)	<0.001**
Sitting while reading	1 (1)	0.5 (1)	0.709
Sitting for motorized transport	1 (0.25)	0.25 (0.5)	0.008**
Sitting while talking on the phone	0 (0.25)	0.25 (0.5)	0.274
Sitting while listening to music	1 (1)	0.5 (1)	0.526
Sitting while playing a musical instrument	0 (0.25)	0 (0.5)	0.044*
Sitting while doing artwork or crafts	0 (0.5)	0 (0.5)	0.178
Sitting while being engaged in social interactions	1 (1.75)	0.5 (1.75)	0.401
Total	**10 (6.75)**	**8 (4.75)**	**0.005****

Note. hr/d = hours/day; IQR = interquartile range. A Likert-type scale was used with 9 different response options: none, 15 min, 30 min, 1 hr, 2 hrs, 3 hrs, 4 hrs, 5 hrs, and 6 hrs or more. Related-Samples Wilcoxon Signed Rank tests were performed to compare median differences.
* $p < 0.05$,
** $p < 0.01$.

Table 3
Adjusted odds ratios for CVD risk factors explained by ST.

Variable	Model 1[a]			*p* value	Model 2[b]			*p* value
	OR	95% CI	R^2		OR	95% CI	R^2	
High blood pressure	1.24	1.08-1.42	0.158	0.002**	1.28	1.07-1.52	0.413	0.007**
Diabetes (type 1 or 2)	1.25	1.01-1.55	0.131	0.04*	1.31	0.97-1.78	0.48	0.08
Elevated cholesterol	1.03	0.86-1.24	0.079	0.739	0.96	0.75-1.21	0.368	0.713
Elevated triglycerides	1.22	0.97-1.54	0.064	0.088	1.04	0.73-1.48	0.641	0.823
Heart attack	1.25	1.04-1.51	0.125	0.019**	1.29	0.99-1.69	0.367	0.056
Stroke	1.47	1.19-1.82	0.335	<0.001**	1.93	1.17-3.19	0.633	0.01*
Cancer	1.46	1.03-2.08	0.338	0.036*		N/A[c]		
Depression	1.30	1.17-1.46	0.192	<0.001**	1.29	1.13-1.48	0.343	<0.001**
Anxiety	1.20	1.09-1.31	0.140	<0.001**	1.17	1.05-1.31	0.319	0.006**
Bipolar	1.68	1.24-2.27	0.316	0.001**	1.69	1.12-2.56	0.504	0.013*
OCD	1.31	1.13-1.52	0.162	<0.001**	1.32	1.10-1.58	0.404	0.003**

Note. OCD = obsessive-compulsive disorder; OR = odds ratio; CI = confidence interval; R^2 = Nagelkerke R^2.
* $p < 0.05$,
** $p < 0.01$
[a] Adjusted for age and sex.
[b] Also adjusted for physical and mental health satisfaction, quality of life, and functional limitation.
[c] Model did not fit due to small cases observed.

variables that were significant in Model 1. However, the odds of having diabetes or heart attack were no longer significant in Model 2. The variance in triglycerides increased from 6 % to 64 % in Model 2, but this was not statistically significant. Total PA time failed to predict the odds of having any of the CVD risk factors in both models, despite the relatively high amount of variance accounted for variables in Model 2 (average of 39 %). Odds ratios with 95 % confidence intervals (CI) for CVD risk factors explained by ST were estimated and visualized using a forest plot (see Fig. 2).

Table 4
Adjusted odds ratios for CVD risk factors explained by total PA time.

Variable	Model 1[a]			*p* value	Model 2[b]			*p* value
	OR	95% CI	R^2		OR	95% CI	R^2	
High blood pressure	1.02	0.92-1.14	0.071	0.657	1.00	0.89-1.13	0.352	0.989
Diabetes (type 1 or 2)	1.05	0.89-1.24	0.066	0.548	1.05	0.85-1.30	0.429	0.642
Elevated cholesterol	1.00	0.86-1.15	0.077	0.95	0.92	0.76-1.11	0.377	0.373
Elevated triglycerides	1.11	0.92-1.33	0.027	0.276	1.10	0.79-1.53	0.646	0.583
Heart attack	1.11	0.97-1.27	0.076	0.134	1.12	0.96-1.31	0.34	0.159
Stroke	0.90	0.75-1.08	0.158	0.251	0.88	0.64-1.21	0.5	0.421
Cancer	1.01	0.81-1.28	0.199	0.904		N/A[c]		
Depression	1.02	0.94-1.11	0.023	0.579	1.03	0.94-1.13	0.255	0.536
Anxiety	1.02	0.95-1.10	0.051	0.566	1.03	0.94-1.11	0.279	0.564
Bipolar	1.13	0.96-1.32	0.053	0.136	1.15	0.94-1.41	0.364	0.182
OCD	0.98	0.86-1.11	0.026	0.72	0.94	0.79-1.12	0.316	0.506

Note. OCD = obsessive-compulsive disorder; OR = odds ratio; CI = confidence interval; R^2 = Nagelkerke R^2.
[a] Adjusted for age and sex.
[b] Also adjusted for physical and mental health satisfaction, quality of life, and functional limitation.
[c] Model did not fit due to small cases observed.

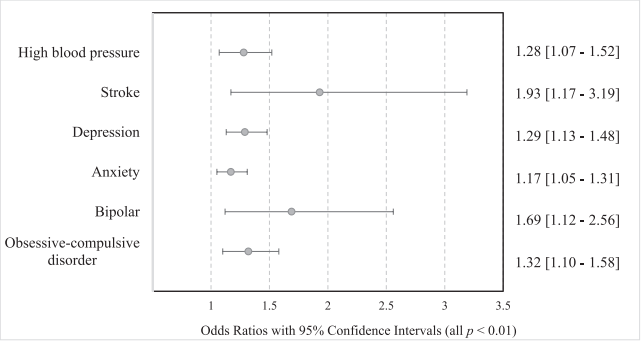

Fig. 2. Forest plot of adjusted odds ratios for CVD risk factors explained by ST.

4. Discussion

This study sought to examine the prevalence of physiological and mental health risk factors for CVD and the relationships of these variables with ST and PA as preventive health behaviors among autistic adults without ID. Our findings indicate that high blood pressure, anxiety, and depression were the most prevalent physiological and mental health conditions in our sample, all of which are recognized as risk factors for CVD. The relationship between PA and CVD risk factors was inconclusive, but ST was significantly associated with the increased CVD risk factors, particularly with all mental health conditions, including depression, anxiety, bipolar, and OCD. This study provides critical insights into the detrimental impact of high levels of ST on mental health in autistic adults without ID and contributes to the literature on preventive health outcomes in this underrepresented population segment.

Approximately one-third to one-fifth of autistic adults without ID in our sample reported having a diagnosis of anxiety (31.9 %) or depression (21.4 %). The high prevalence of these mental health conditions is similar to previous clinical reports regarding the rates of psychiatric symptoms in autistic adults with and without ID. An earlier study examined the overall health status of autistic adults across the wide range of intellectual functioning (n = 1507) and found that the rate of depressive condition was 2.9 times higher in autistic adults than neurotypical counterparts, while 29 % of the autistic sample were diagnosed with comorbid anxiety (Croen et al., 2015). A recent population-based study in Sweden found similar results among autistic adults with and without ID in that the relative risk for a diagnosis of anxiety disorder in this population was nearly three times higher than neurotypical adults (Nimmo-Smith et al., 2020). Furthermore, Bishop-Fitzpatrick & Rubenstein (2019) analyzed de-identified Medicaid claims data from middle-aged and older autistic adults with and without ID in the United States (n = 143), comparing physical and mental health conditions between the two groups. While the prevalence of physical health conditions, including immune conditions (70.6 %), CVD (49.0 %), and sleep disorders (85.3 %), was similar between the two groups, the prevalence of anxiety and depression was relatively higher among middle-aged and older autistic adults without ID compared to those with co-occurring ID (Bishop-Fitzpatrick & Rubenstein, 2019). Although the symptoms and severity may vary, it is evident that autistic adults, regardless of the level of intellectual functioning, commonly experience anxiety and depression over the course of their lives, highlighting the imperative need for effective and timely mental health interventions in this population (Buck et al., 2014; Croen et al., 2015; Eaves and Ho, 2008; Lugnegård et al., 2011).

Our findings moderately support that an increased ST is associated with the existence of high blood pressure and stroke among autistic adults without ID when the regression model was adjusted for participants' physical and mental health satisfaction, quality of

life, and functional limitation. It is well understood that prolonged, uninterrupted ST has a deleterious impact on physiological health that often leads to the development of CVD in general adult population (Carter et al., 2017; Ford and Caspersen, 2012). In a large cohort study based on nearly 6000 healthy adults, significant associations were observed between sedentary behavior and traditional CVD risk factors, including BMI, high-density lipoprotein cholesterol, and high blood pressure (Stamatakis et al., 2012). Similarly, an early systematic review reported that objective accelerometer-measured ST was negatively associated with type 2 diabetes and higher triglyceride levels in the general adult population (Brocklebank et al., 2015). Interestingly, none of the CVD risk factors was affected by the levels of PA engagement within our sample regardless of the type of covariates. This result may in part align with a growing body of research in which ST unfavorably elevates the risk of CVD, independent of the level of light or moderate-to-vigorous PA in general populations (Hamilton et al., 2008; Matthews et al., 2012). Although the observed association between ST and physiological risk factors for CVD is inconclusive due to a relatively small sample size that represents each factor, sedentary behavior may be a leading causative factor for developing CVD in autistic adults without ID.

It should be noted that ST was significantly associated with high odds for all mental health risk factors for CVD in autistic adults without ID, including depression, anxiety, bipolar, and OCD. This result adds to the evidence of available research examining the association between ST and mental health in the general population. An earlier review highlighted that despite the methodological heterogeneity, prolonged sedentary behavior significantly contributes to developing a risk of depression in the general population (Teychenne et al., 2010). Similar results were reported in a large-scale, multi-national study of the general adult population, suggesting that higher ST (e.g., $\geq$11 hours/day) is linked to an increased risk of depression in adults, with mobility limitations, sleep/energy impairments, and age being key factors that exacerbate this relationship (Stubbs et al., 2018). Moreover, a reciprocal association between anxiety and sedentary behavior was found among adults. Anxious adults tend to spend more time in sedentary behaviors (Vancampfort et al., 2018) while less ST is also associated with the favorable perception of mental health and quality of life (Gibson et al., 2017). Considering the mounting evidence that numerous physiological, psychological, and environmental factors, such as diet (Jacka et al., 2011), social and emotional support (Bovier et al., 2004), access to green spaces (Xu et al., 2023), shape one's unique mental health profile, future research is needed to better understand the influential factors and mechanism underlying the association between sedentary behavior and mental health in autistic adults. Sedentary lifestyle and inactive behavioral patterns tend to begin in childhood in autistic individuals (Must et al., 2014). Also, a natural affinity for technology use and excessive screen time are increasingly observed in autistic youth. Recent longitudinal research highlights disparities in PA and screen time behaviors between autistic youth and their neurotypical peers. With age, autistic youth tend to become less physically active while increasingly engaging in distinct patterns of screen time (e.g., video gaming), which often results in prolonged ST during pivotal developmental stages (Dahlgren et al., 2021). This inactive or sedentary lifestyle, coupled with unique behavioral preferences, may contribute to the high prevalence of mental health conditions observed in autistic individuals.

There are several inherent limitations that restrict the generalizability of our study's findings. One of the study limitations is the use of the self-administered online survey to assess levels of ST and PA, which requires appropriate judgement and retrospective time estimation. When compared to objective measures such as accelerometry, the self-report method is subject to recall bias and can include estimation errors for quantifying ST and PA (Atkin et al., 2012). Both neurotypical and autistic adults tend to underestimate their ST and overestimate PA in self-reports compared to objective measures (Celis-Morales et al., 2012; Lee et al., 2023; Prince et al., 2020). Nonetheless, by describing specific domains of physical behaviors and enabling a relative comparison with other populations, the self-report method is a valuable tool to characterize the contexts of physical behaviors in a large sample. Further investigation using a combination of objective and subjective measures is warranted to produce more comprehensive estimates of ST and PA in autistic adults without ID (Urda et al., 2017). Importantly, the observed correlations between ST and mental health risk factors are likely unidirectional and thus, our findings may not imply the reciprocal relationships between the reported outcomes. The directionality of these correlations cannot be fully determined from our study design, and ST may also be influenced by other health conditions, such as anergia or other physical symptoms. Despite the rigorously established response validation criteria, it was also possible that a few reliable responses were eliminated due to the $\geq$ 15-minute survey completion time as a cut-off threshold. However, identifying inattentive survey respondents and eliminating their responses from the dataset became increasingly critical in Internet-based self-report surveys as the improper validation of responses can result in inaccurate estimates of the prevalence and significant attenuation of meaningful correlations (Alvarez et al., 2019; Berinsky et al., 2014). Lastly, the majority of participants were Caucasian males, and the sample only included autistic adults who could independently provide informed consent and complete the survey without assistance. As a result, this study may not fully represent the broader autism community, including those with minority status (e.g., non-Caucasian or non-binary individuals) or those with co-occurring ID. Research indicates that females, particularly those without ID, are often underdiagnosed or receive a formal diagnosis later in life compared to males (Gesi et al., 2021; Ratto et al., 2018). It should also be noted that the AQ-10 may not fully capture the full spectrum of autism traits (Taylor et al., 2020), and reliance on AQ-10 scores and the history of educational accommodations (e.g., IEP) may have inadvertently excluded individuals with underrecognized presentations of autism. The adult population on the autism spectrum is highly diverse, but selection bias is relatively common in autism research due to under-inclusion of those with ID (Russell et al., 2019). As such, the interpretation of our study findings should be made with caution as they lack generalizability. Future research should strive to address the context-specific health outcomes according to different age groups and levels of intellectual function or support needs.

5. Conclusions

Anxiety and depression were the most common mental health risk factors for CVD among autistic adults without ID in this study. Too much sitting is a prevalent public health concern worldwide, and as distinct from the level of PA engagement, sedentary behavior

has become a primary factor for elevating CVD risk in the general population. Similar results were observed in autistic adults without ID as their high level of ST was significantly associated with both physiological and mental health risk factors for CVD, including high blood pressure, stroke, depression, anxiety, bipolar, and OCD. Our study's cross-sectional design limits the ability to determine temporal precedence between PA, ST, and CVD risk factors. To address this gap, future longitudinal research is warranted to clarify the directionality of these associations over time. Despite the methodological limitations, our findings highlight the urgent need for accessible preventive health interventions to reduce persistent health disparities in autistic adults.

CRediT authorship contribution statement

Kennedy John M: Validation, Methodology. **Lee Daehyoung:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Frey Georgia C:** Writing – review & editing, Writing – original draft, Supervision, Resources, Conceptualization. **Dickinson Stephanie:** Visualization, Software, Methodology, Formal analysis. **Golzarri-Arroyo Lilian:** Visualization, Software, Methodology, Formal analysis. **Cothran Donetta J:** Writing – review & editing, Writing – original draft, Supervision, Resources, Conceptualization. **Shih Patrick C:** Writing – review & editing, Writing – original draft, Supervision, Resources, Conceptualization.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

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Data Availability

Data will be made available on reasonable request.

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