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Mentally active but not inactive sedentary behaviors are positively related to adolescents' cognitive-academic achievements, a cross-sectional study — The Cogni-Action Project

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ABSTRACT

Excessive adolescent sedentary behaviors (SBs) may affect cognitive-academic achievements; however, findings vary according to the SB evaluated and their mental requirements. This study aimed to understand the multivariate association between different SBs and diverse cognitive-academic achievements as a primary analysis. As a secondary one, we differentiated between mentally active and inactive SBs. In this study, 1296 Chilean adolescents (10–14 years old) reported their SB via questionnaires. Cognitive performance was assessed with a neurocognitive battery, and academic achievement was based on school grades. Canonical correlation analysis was performed to determine the mode of covariation (MofC) between two sets of variables. The first set accounted for eight SBs (five considered as "active mentally" and three as "inactive mentally"). The second set accounted for 13 cognitive and academic variables (eight cognitive tasks and five school subjects). Several covariates and a cluster (schools, $k = 19$) were also included in the analysis. The primary analysis revealed a single significant MofC, with a small canonical relationship ($r = 0.22$, $p = 0.002$). This MofC indicated that time spent using computers and engaging in scholarly tasks at home was positively correlated with cognitive processing speed as well as with academic scores in English and History. Secondary analysis revealed two significant modes of covariation. The first confirmed the primary result ($r = 0.21$, $p = 0.001$), while the second highlighted the role of time spent playing video games as the sole contributing factor linked to inhibitory control ($r = 0.17$, $p = 0.034$). These findings indicate a small positive relationship between certain mentally active SBs and cognitive-academic achievements, emphasizing the need for further comprehensive research to understand these complex relationships.

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1. Background

Abbreviations

WHO	World Health Organization
SBs	sedentary behaviors
TV	Television
YAP-SL:	Youth Activity Profile-Spain Latin America
SIMCE	Chilean Education Quality Agency Evaluation System
PISA	Programme for International Student Assessment
OECD	Organization for Economic Cooperation and Development
PHV	peak height velocity
SVI	school vulnerability index
CCA	canonical correlation analysis
ADHD	attention deficit/hyperactivity

Improving adolescents' health and well-being positively affects their lives now and in the future as adults and has significant intergenerational health implications, making adolescents a priority population for the World Health Organization (WHO) to achieve the Sustainable Development Goals for 2030 (van Sluijs et al., 2021). Adolescence is a crucial life stage in which behaviors are modified and rooted. However, evidence shows that adolescents accumulate excessive time in diverse daily sedentary behaviors (SBs), impairing their health status (Carson et al., 2016; Tremblay et al., 2017). For instance, SBs have been associated not only with metabolic syndrome and cardiovascular disease development (Tremblay et al., 2011) but also with lower cognitive and academic achievement (Rodriguez-Ayllon et al., 2019; Sánchez-Oliva et al., 2023; Stillman, Esteban-Cornejo, Brown, Bender, & Erickson, 2020). Important to note is that reducing the prevalence of diseases and improving academic attainment are two critical priorities globally (Chaput et al., 2020; van Sluijs et al., 2021).

The recent WHO guidelines on physical activity and sedentary behavior for children and adolescents call for preventing excessive SBs (Chaput et al., 2020), but SB, defined as "any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents, while in a sitting, reclining, or lying posture" (Tremblay et al., 2017), is accumulated in a variety of ways and contexts (e.g., sitting at school, eating, traveling, and television viewing during leisure time). Digital media use (e.g., Internet surfing, using computers and cell phones, television viewing, and video game playing) seems to be the most prevalent SB during leisure time among children and adolescents (Adelantado-Renau, Moliner-Urdiales, et al., 2019; Marshall, Gorely, & Biddle, 2006). Although accumulating excessive SB time is detrimental to several health indicators in a dose-response relationship (i.e., fat storage, glucose levels, and others) (Kerr & Booth, 2022), current evidence shows that it is relevant to consider the SB domain, the social context in which sedentary activities are carried out, and their cognitive requirements (Adelantado-Renau, Moliner-Urdiales, et al., 2019; Bakrania et al., 2018; Guellai et al., 2022; Kesse-Guyot et al., 2012; Loprinzi, 2019; Walsh et al., 2020; Wanders et al., 2021). These suggestions arise because the characteristics of specific SBs may elicit differential responses to cognitive demands depending on whether the activities are "mentally active" (e.g., reading, working, or playing video games or a musical instrument) or "mentally inactive" (e.g., watching TV, transportation, use cell phone) (Wanders et al., 2021), and may affect academic achievement.

Evidence on this matter in children and adolescents is scarce and previous studies have shown equivocal results (Li, Guo, Zheng, Shi, & Huang, 2022). For instance, increased sedentary time has been associated with better (Aadland et al., 2017), negative (van der Niet et al., 2015), and neutral (Fairclough et al., 2021; Mora-Gonzalez et al., 2019; Syväoja, Tammelin, Ahonen, Kankaanpää, & Kantomaa, 2014) executive functions in children and adolescents. In addition, when SB domains are analyzed individually, some discrepancies can be found. For example, research has shown that video games are negatively associated with working memory (Dubuc, Aubertin-Leheudre, & Karelis, 2020; Syväoja et al., 2014) and positively associated with working memory and general cognition (Chaarani et al., 2022; Walsh et al., 2020). Computer use (for playing games, such as emailing, chatting, surfing the Internet, or doing homework) has been negatively related to inhibitory control, sifting, flexibility of attention, and working memory (Syväoja et al., 2014; Verburgh, Scherder, Van Lange, & Oosterlaan, 2016); however, a systematic review concluded that it appears to favorably influence memory compared to other SB domains (Loprinzi, 2019). At the academic level, similar divergences were found. For example, some SBs (i.e., reading and doing homework) were associated with higher academic achievements (Carson et al., 2016), while the total time spent on overall screen media use was not (Adelantado-Renau, Moliner-Urdiales, et al., 2019). Thereby, exposure to numerous SBs is constant in adolescence, and participation in one sedentary activity can influence subsequent ones, creating a pattern (e.g., watching TV may lead to engaging with video games, computers, and cell phones) (Patnode et al., 2011). Consequently, the SB profile represents a cumulative, interdependent, and interconnected effect, influencing cognitive and academic achievement (Khan, Lee, Janssen, & Tremblay, 2022; Sánchez-Oliva et al., 2023; Walsh et al., 2020).

Therefore, this study aimed to understand the multivariate association between a set of SBs and cognitive/academic variables in a large sample of adolescents as primary analysis. As a secondary one, we explored the differences according to mentally active and inactive SBs. Our hypothesis postulated that mentally active SBs positively correlate with cognitive-academic achievements, whereas mentally inactive SBs negatively correlate.

2. Methods

2.1. Study design

This cross-sectional study is part of the Cogni-Action Project, which aimed to determine associations of physical activity, sedentary behavior, and physical fitness with brain structure and function, cognitive performance, and academic achievement in Chilean adolescents. A detailed description of the design and methodology has been published previously (Solis-Urra et al., 2019). The project was conducted between March 2017 and October 2019, and was performed according to the guidelines of the Declaration of Helsinki for human research. The Bioethics and Biosafety Committee of the Pontificia Universidad Católica de Valparaíso approved the project (BIO-EPUCV-H103–2016), and school principals, parents, and participants voluntarily provided signed written informed consent before participation. This project was retrospectively registered in the Research Registry (ID: researchregistry5791) and was reported in accordance with the STROBE guidelines for cross-sectional studies (Supplementary Material).

2.2. Participants

A total of 1296 Chilean adolescents aged 10–14 from 19 urban public, subsidized (i.e., schools that receive partial governmental and private economic support), and private schools of the Valparaiso region participated in this study. The total sample size and power calculations were based on the total enrolment of schoolchildren in the Valparaiso region (5th to 8th grades), as indicated by the Chilean Ministry of Education in 2016 (Solis-Urra et al., 2019). An alpha error of 5%, a confidence interval of 99%, a heterogeneity of 50%, and a dropout rate of 20% were considered. It is important to acknowledge that this method may not have been the most suitable, and that there is a need to recognize the potential biases associated with it. This project and study defined adolescence as the period between 10 and 24 years of age (Sawyer, Azzopardi, Wickremarathne, & Patton, 2018). The inclusion and exclusion criteria and details of other measurements can be found in the Cogni-Action protocol (Solis-Urra et al., 2019).

2.3. Data collection

All measurements occurred within schools over two 4-h visits spaced eight days apart. During the initial visit, cognitive performance and anthropometry tests (i.e., sex, biological maturation, body mass index, and others) and physical activity questionnaires (including SBs) were administered. The subsequent visit focused on the evaluation of sleep issues and physical fitness. Finally, the data on adolescents' grade point average scores at the end of the academic school year were obtained from school records, and the school vulnerability index was sourced from the Education Ministry.

2.4. Sedentary behaviors

SBs domains were evaluated through two questionnaires. The first was a Chilean validated and self-administered questionnaire from the INTA (in Spanish "Instituto de Nutrición y Tecnología de los Alimentos"), which measured movement behaviors during the last week (Monday to Friday). This instrument presents a test/retest reliability of 0.58–0.94 (Lin coefficient for continuous values) and kappa coefficient = 0.58 to 0.84 (for no continuous values) (Godard et al., 2008). This questionnaire included five categories: sleeping time, number of streets walked per day, daily time participating in outdoor recreational activities, time per week participating in exercise or scheduled sports, and daily time engaged in seated activities or SB. The last category included five domains: time sitting 1) in the classroom at school, 2) doing school tasks, drawing, or reading at home, 3) eating, 4) transport (i.e., cars, buses), and 5) TV, video games, and computers per day. The last question was not included because it involved more than one SB and some could be considered mentally active or inactive.

The second questionnaire was the Youth Activity Profile-Spain Latin America (YAP-SL), a Spanish-validated and self-administered recall questionnaire that showed adequate reliability for activities at school, out-of-school, and sedentary behaviors (kappa coefficient = 0.61–0.77; intraclass correlation coefficient = 0.77–0.89) in children and adolescents (Segura-Díaz et al., 2021). The YAP-SL contains 15 items on in-school and out-of-school activities and sedentary habits (Saint-Maurice & Welk, 2015; Segura-Díaz et al., 2021). Sedentary habits included different behavioral domains such as (1) time watching television, (2) playing video games, (3) using a computer, (4) using a cell phone, and an overall sedentary time item. Each question uses a 5-point Likert scale.

In summary, our study involved a total of eight SBs. Based on the existing literature (Khan et al., 2022; Wanders et al., 2021), we categorized five of these behaviors as mentally active, which included sitting: (1) in the classroom at school, (2) doing school tasks, drawing, or reading at home, (3) eating, (4) playing video games, and (5) using the computer). Moreover, three behaviors were categorized as mentally inactive, which included sitting: (1) in transport (i.e., cars, buses), (2) watching television, and (3) using a cell phone).

2.5. Cognitive performance and academic achievements

The NeuroCognitive Performance Test (NCPT, Lumus Labs, Inc.) is a brief and web-based platform to measure different cognitive performance domains (Morrison, Simone, Ng, & Hardy, 2015). The NCPT has demonstrated adequate reliability and validity to measure cognitive performance and good concordance with pencil-paper assessments in adults (Morrison et al., 2015). While it is important to note that specific validation studies for children and adolescents are lacking, it is noteworthy that the Grand Index score, which is derived from the summation of a student's normalized scores across NCPT tasks, demonstrates good test-retest reliability (r = 0.78) within this particular population aged 8–15 years (unpublished data) (Ng, Sternberg, Katz, Hardy, & Scanlon, 2013).

Briefly, the NCPT included: "Trail Making A and B″ for attention, cognitive flexibility, and processing speed; "Forward and Reverse Memory Span" for short-term visual memory and working memory; "Go/No-Go" for inhibitory control and processing speed; "Balance Scale" for quantitative and analogical assessment; "Digit Symbol Coding" for processing speed; and "Progressive Matrices" for problem-solving and reasoning intelligence (Cristi-Montero et al., 2021). A description of each task, the main cognitive functions involved, and a graphical representation are provided in the Supplementary Material (Fig. S1). Tests were scaled according to a normal inverse transformation of the percentile rank; thus, we obtained scaled scores derived from the same normal distribution with a mean of 100 and standard deviation of 15 (Morrison et al., 2015). Negative scores were reverted to obtain a positive score for all (Table 1).

Academic achievement was assessed using school records, which included grades in five subjects (Mathematics, Language, Science, History, and English), expressing grades on a national scale ranging from 1 to 7. Most of these subjects are included in the Chilean Education Quality Agency Evaluation System (SIMCE) and the Programme for International Student Assessment (PISA) by the Organization for Economic Cooperation and Development (OECD). In summary, 13 variables were included, eight cognitive tasks and five academic subjects.

2.6. Covariates

Several variables available in the Cogni-Action Project (i.e., sex, biological maturation, school vulnerability index, body mass index, physical activity levels, global fitness, and sleep problems) were identified as confounders due to their potential relationship with SB and cognitive-academic achievements.

Sex and biological maturation are known to be associated with SB and cognitive-academic achievements (Lloyd, Oliver, Faigenbaum, Myer, & De Ste Croix, 2014; Machado Rodrigues et al., 2010). Specifically, peak height velocity (PHV) was calculated as a maturity indicator, computing the subtraction of PHV age from chronological age (Moore et al., 2015); then, the difference was established as a maturity offset value.

The Chilean school vulnerability index (SVI) was used as a proxy for socioeconomic status. The SVI includes information on the family, parent tutors' educational level, student health condition, physical and emotional well-being, and school location (Cristi-Montero et al., 2021). Schools were classified as low (<10), middle (≥10 to <60), or high (≥60) SVI, whereas a zero value was assigned to private schools.

Obesity has been positively associated with SB in children (Tanaka et al., 2018) and lower cognitive-academic achievements (Esteban-Cornejo et al., 2020; Schwartz et al., 2013); hence, weight was measured using a digital scale OMRON (HN-289-LA, Kyoto, Japan) and height with a portable stadiometer SECA (model 213, GmbH, Germany). The body mass index z-score was calculated and used as an indicator of adiposity in accordance with the WHO growth reference for school-age children (De Onis et al., 2007).

Physical activity is inversely associated with SB (Pearson, Braithwaite, Biddle, van Sluijs, & Atkin, 2014) and positively associated with cognitive-academic achievements (Donnelly et al., 2016; Singh et al., 2019). Thus, total physical activity scores assessed by the two questionnaires used to determine SBs were included (Godard et al., 2008; Segura-Díaz et al., 2021). Nonetheless, we computed news scores for each questionnaire without SBs in order to avoid duplicate SBs in the analyses.

Physical fitness is a relevant factor that has been associated with both SB and cognitive-academic achievements (Cristi-Montero et al., 2021;

Table 1
Descriptive characteristics of adolescents.

Variable	n = 1296
Age (years)	11.89 (1.19)
Sex	
Girls	648 (50.0%)
Boys	648 (50.0%)
School type	
Public	456 (35.2%)
Subsidized	514 (39.7%)
Private	326 (25.2%)
Years from peak height velocity point (maturation)	−0.41 (1.26)
School vulnerability index	
Low	326 (25.2%)
Middle	360 (27.8%)
High	610 (47.1%)
Global physical fitness	−0.02 (2.77)
Body mass index (kg/m^2)	21.52 (3.78)
Godard total score	3.58 (1.29)
YAP total score	0.11 (4.07)
Sleep self-report score	11.22 (5.06)
CCA Components	
Sedentary behavior mode (First latent factor)	
Sitting in the classroom (min/day)	345.29 (132.78)
Sitting doing school tasks (min/day)	102.80 (91.93)
Sitting eating (min/day)	62.25 (51.70)
Sitting in passive transportation (min/day)	45.00 (49.29)
Watching television (scale ranging from 1 to 5)	2.21 (1.03)
Playing videogames (scale ranging from 1 to 5)	2.08 (1.29)
Using a personal computer (scale ranging from 1 to 5)	1.60 (1.08)
Using a cell phone (scale ranging from 1 to 5)	3.15 (1.30)
Cognitive-Academic mode (Second latent factor)	
Trial making test A – reverted (attention, cognitive flexibility, and processing speed)	100.00 (14.70)
Trial making B – reverted (attention, cognitive flexibility, and processing speed)	100.00 (14.70)
Digit symbol coding (processing speed)	100.00 (14.68)
Forward memory span (visual short-term memory)	100.01 (14.37)
Reverse memory span (working memory)	99.95 (14.34)
Go/no-go – reverted (inhibitory control and processing speed)	100.00 (14.70)
Balance scale (quantitative and analogical reasoning)	100.06 (14.49)
Progressive matrices (problem-solving and fluid reasoning/ intelligence)	100.10 (14.25)
Language (grades)	5.40 (0.79)
English (grades)	5.62 (0.90)
Mathematics (grades)	5.35 (0.95)
Science (grades)	5.45 (0.83)
History (grades)	5.45 (0.79)

Data are presented as Mean (SD) or n (%) according to its variable characteristic. CCA: Canonical Correlation Analysis. A description of each task, the main cognitive functions involved, and a graphical representation are provided as supplementary material (Fig. S1).

Kulinski et al., 2014), even greater than physical activity. Therefore, a global fitness score was calculated according to three fitness tests (i.e., cardiorespiratory, muscular, and speed-agility fitness) through the ALPHA fitness test battery (Ruiz et al., 2011), standardizing each component by age and sex. The three z-scores were then summed to compute the Global Fitness Score (Solis-Urra et al., 2021).

Finally, the sleep problem score was included due to its association with increased SBs and negative association with cognitive-academic achievements ((Adelantado-Renau, Beltran-Valls, et al., 2019; Pesonen et al., 2022). The "Sleep Self-Report," a questionary validated in the Spanish population was employed (Orgilés, Owens, Espada, Piqueras, & Carballo, 2013; Owens, Maxim, Nobile, McGuinn, & Msall, 2000). This questionnaire includes 16 items and four subscales: sleep quality, sleep anxiety, bedtime refusal, and sleep routines. It is important to acknowledge that this validation includes schoolchildren aged 10–12 years old but does not encompass those aged 13–14, potentially introducing a methodological bias.

2.7. Statistical analysis

Prior to all statistical testing, missing data were imputed based on the nonparametric missing value method using random forest through the "missForest" R package (Stekhoven & Bühlmann, 2012). This function successfully imputes large and complex mixed-type datasets (quantitative and/or categorical variables), including complex interactions and non-linear relations, by a random forest trained on the observed values predicting the missing values. Missing data ranged from 1.2% (PHV) to 45.2% (physical activity by YAP-SL). The differences between the imputed and non-imputed databases are provided in Supplementary Material (Table S2).

A common limitation among most studies is that they did not explore multiple SBs through multivariate analyses, focusing mainly on a single domain or multiple domains separately. Canonical correlation analyses (CCA) could help overcome this limitation by establishing a link between two sets of variables or latent factors (mode of covariation) with multiple intercorrelated outcome variables (canonical loading) and determining the contribution of each variable to the opposite variate (canonical cross-loading) (Fig. 1). This approach identifies the mode of covariation (Pearson's r), making no prior assumptions about relationships, given the canonical cross-loading or strength of correlation that each variable exerts on its opposite canonical variate. Each mode of covariation is characterized by a pair of CCA variates, which are maximally correlated and orthogonal by construction; hence, they are independent of each other. The possible total number of modes of covariation always equals the number of variables in the smaller dataset (eight modes; SBs). For the primary analysis, we ran a CCA to characterize modes of covariation relating to two sets of latent factors, the first, accounting for the eight SBs (sitting: watching TV, in the classroom, using cellphones, transporting, doing school tasks at home, using computers, playing video games, and eating), and the second by the 13 cognitive and academic variables (i.e., eight cognitive tasks and five school subjects). Moreover, a secondary analysis was performed to characterize the modes of covariation between SBs considered active or inactive mentally with the cognitive/academic latent factor.

The CCA was adjusted for several covariates and a cluster. To achieve this, the PermCCA MATLAB function was employed (Winkler, Renaud, Smith, & Nichols, 2020), which can be found at https://github.com/andersonwinkler/PermCCA. Adjustments were made for variables, such as age, biological maturation, SVI, body mass index, physical activity levels, global fitness, and sleep problems. Additionally, this function allows the inclusion of a cluster in the analysis, while preserving the dependencies outlined by the hierarchical structure of the data (Winkler, Webster, Vidaurre, Nichols, & Smith, 2015). Here, the cluster pertains to adolescent schools ($k = 19$). All variables included in the analysis were previously standardized. The significance of the CCA modes was calculated via nonparametric inference testing through 1000 permutations among subjects within schools. Family-wise error correction (FWE-corr) was applied across all CCA modes to correct for multiple comparisons. A CCA (covariation, loading, and cross-loading) was deemed significant at FWE-corr $p < 0.05$ and a minimal association of r values ≥ 0.10 (small effect size) (Akoglu, 2018; Schober, Boer, & Schwarte, 2018). Sensitivity analyses are provided in the Supplementary Material, which includes CCAs conducted with both imputed and non-imputed data, as well as an analysis performed with complete data (without missing values).

The mode of covariation is the correlation between the two latent factors. Each latent factor is composed of canonical loadings (coefficients between each variable and their corresponding variates). Canonical cross-loadings are the correlation coefficients of each variable and opposite variate.

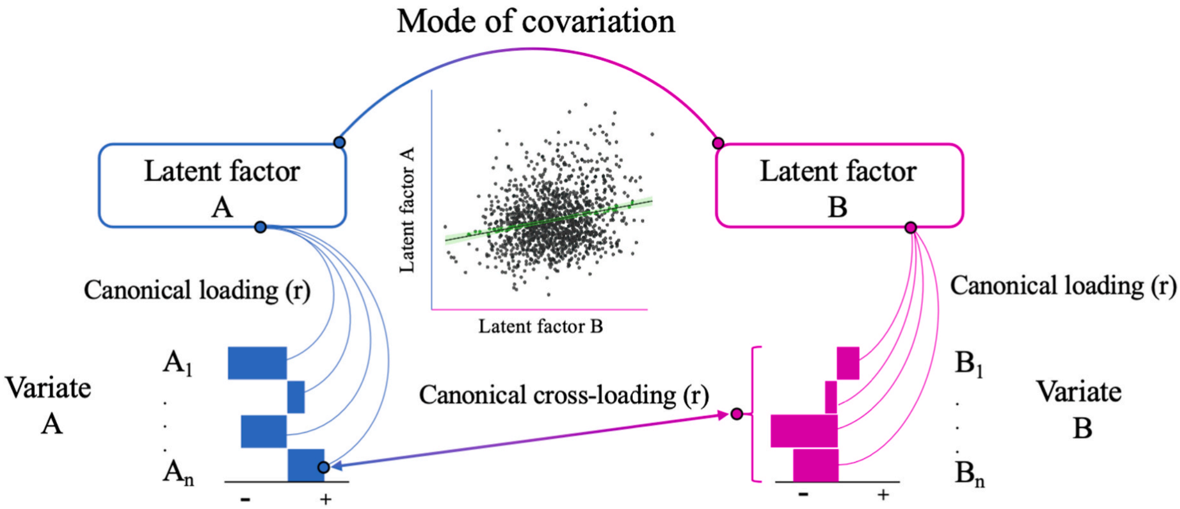

Fig. 1. Schematic of canonical correlation analysis and its components.

3. Results

The descriptive characteristics of the adolescents are displayed in Table 1. Some differences were observed between imputed and non-imputed variables (Supplementary Material, Table S1). The data presented a 1:1 proportion of boys and girls, and no differences were found in the school-type distribution.

3.1. Canonical correlation analysis (CCA)

3.1.1. Primary analysis

CCA was conducted between SBs and cognitive-academic achievements, and out of the eight possible combinations, only one mode of covariation was statistically significant. Thus, only this mode of covariation was analyzed further (Fig. 2).

Fig. 2 depicts three blocks. At the center, it is possible to see a small but significant correlation coefficient between the two latent factors, representing the mode of covariation between sets of variables ($r = 0.23$; $p = 0.015$). On the sides, the canonical loadings and cross-loading for each component are observed. In detail, two of the eight SBs exceeded r values ≥ 0.10 (i.e., adolescents using computers and doing scholarly tasks at home), showing a positive correlation with one cognitive task and two academic achievements (i.e., cognitive processing speed, English, and History). All inactive mental SBs showed a negative and insignificant association.

Canonical correlation analysis (CCA) adjusted for sex, biological maturation, school vulnerability index, body mass index, physical activity levels, global fitness, sleep problems, and the random effect of schools. Purple: CCA cross-loadings (r) for Sedentary Behavior variables. Yellow: CCA cross-loadings (r) for cognitive-academic variables ($n = 1296$). The central correlation shows an association between the two latent factors.

3.1.2. Secondary analysis

Two separate CCAs were conducted, one for mentally active SBs and another for inactive SBs. Regarding the first CCA, out of the five possible combinations, two modes of covariation were statistically significant (Fig. 3). The first mode of covariation showed a small positive correlation ($r = 0.21$; $p = 0.001$). Canonical loading and cross-loading showed a similar trend pattern; adolescents spending more time in computers and doing scholarly tasks at home were related to higher results on inhibitory control, English, and History (notably, the canonical loading for all three cognitive-academic variables was $r = 0.09$). Regarding the second mode of covariation, a small positive correlation was observed ($r = 0.17$; $p = 0.034$). This covariation showed a small positive correlation between adolescents spending more time playing video games and inhibitory control (both $r \geq 0.10$). Regarding the second CCA no mode of covariation was found for inactive SBs.

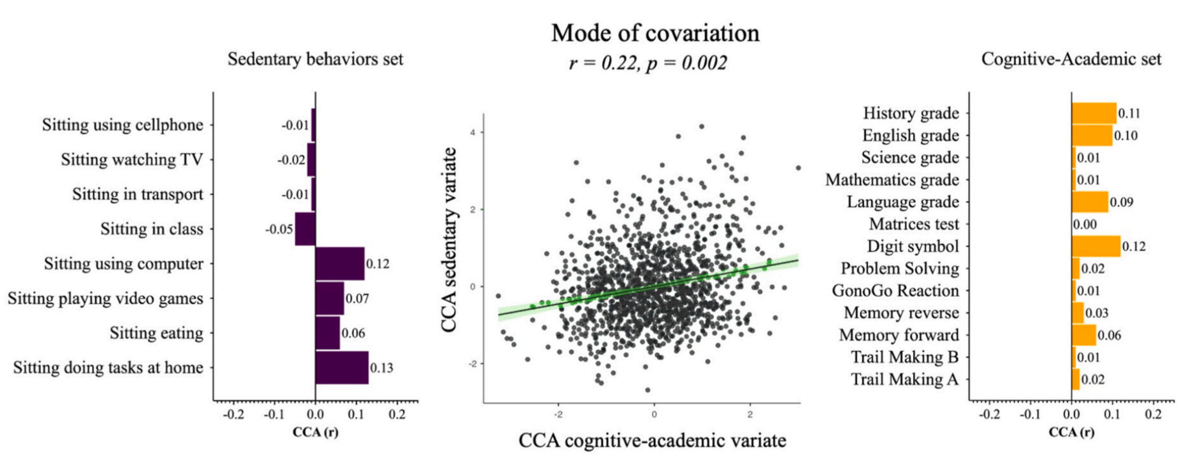

Fig. 2. Modes of covariation linking sets of sedentary behaviors with sets of cognitive/academic variables in adolescents.

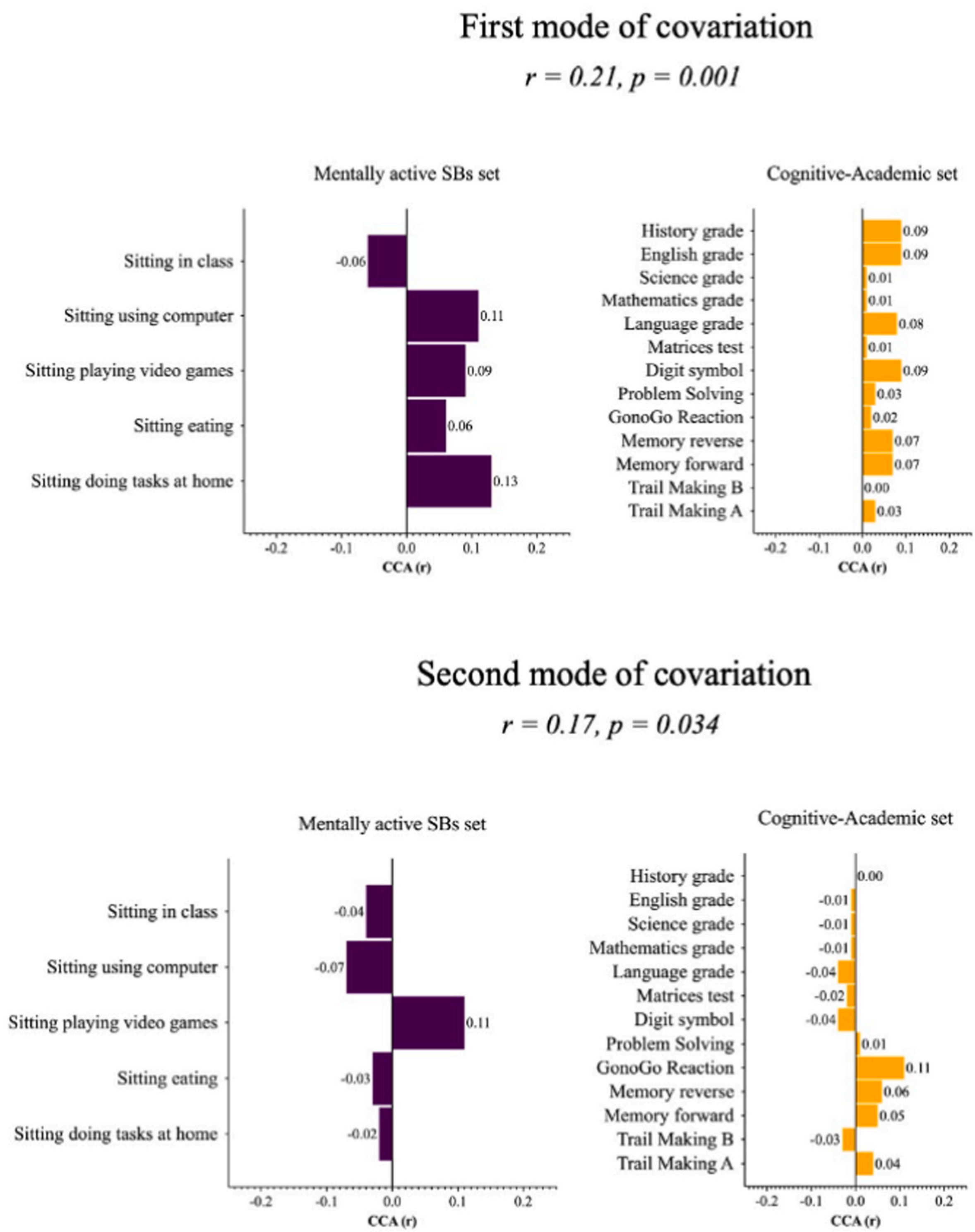

Fig. 3. Modes of covariation linking only mentally active sedentary behaviors with sets of cognitive/academic variables in adolescents. Canonical correlation analysis (CCA) adjusted for sex, biological maturation, school vulnerability index, body mass index, physical activity levels, global fitness, sleep problems, and the random effect of schools. Purple: CCA cross-loadings (r) for Sedentary Behavior variables. Yellow: CCA cross-loadings (r) for cognitive-academic variables ($n = 1296$). The central correlation shows an association between the two latent factors.

4. Discussion

This study aimed to investigate the multivariate associations between SBs and cognitive/academic achievements. The primary analysis revealed a single, albeit small, yet statistically significant mode of covariation between the two sets of latent factors. Adolescents who spent more time using computers and engaging in scholarly tasks at home were linked to higher levels of cognitive speed processing as well as higher academic achievement in English, and History. In the secondary analysis, two modes of covariation were identified only within mentally active SBs. The first mode exhibits a similar trend pattern to that of the primary analysis. The second mode revealed that spending more time playing video games was associated with higher inhibitory control. These results suggest that mentally active, but not inactive, SBs may have a subtle link to cognitive and academic outcomes. Further research is required to elucidate the mechanisms underlying these associations and their clinical implications for cognitive and academic well-being.

Some reviews and cross-sectional studies have shown that prolonged time in several SBs, especially screen-based sitting time, is associated with unfavorable brain microstructure, levels of brain-derived neurotrophic factor (BDNF), and cognitive and academic achievements (Adelantado-Renau, Moliner-Urdiales, et al., 2019; Felin Fochesatto et al., 2023; Li et al., 2022; Yang et al., 2022). They also suggest that the available evidence is inconclusive for children and adolescents and recommend that each domain be analyzed individually (Adelantado-Renau, Moliner-Urdiales, et al., 2019; Li et al., 2022). However, although singular differences could emerge from each SB, adolescents are exposed to more than one sedentary activity daily (Ferreira, Rombaldi, Ricardo, Hallal, & Azevedo, 2016; Mielgo-Ayuso et al., 2017); thus, each one could affect the other in a convergent, isotemporal, and complex manner. Thereby, this study offers novel evidence proving that when multiple SBs are collectively analyzed using a multivariate approach, they can exhibit both positive and negative associations with the cognitive-academic variate. Specifically, only certain mentally active SBs showed a modest association with certain cognitive-academic achievements. This finding contributes to the literature by suggesting that not all SBs are necessarily negatively correlated, and in some cases, this association may even be positive, albeit to a small degree.

In order to find a plausible explanation for our main findings, it is reasonable to consider the mentally active/inactive sedentary domain paradigm (Khan et al., 2022; Wanders et al., 2021) and the crucial influence of the context in which the behavior takes place (Guellai et al., 2022). In our study, we considered several SBs active mentally, but of the five, only three showed a small cross-loading association with the cognitive/academic variate (i.e., using computers, engaging in scholarly tasks at home, and playing video games).

In this sense, adolescents use computers for games and study reasons more than children do (Mielgo-Ayuso et al., 2017; van Sluijs et al., 2021), while video games are one of the most prevalent leisure time SB in children and adolescents (Adelantado-Renau, Moliner-Urdiales, et al., 2019; Marshall et al., 2006). Traditionally, evidence has indicated that students who spend more hours on screen time tend to exhibit lower cognitive performance and academic achievements (Dubuc et al., 2020; Mundy et al., 2020; Syväoja et al., 2014; Zapata-Lamana et al., 2021); however, using computers (i.e., for engaging in scholarly tasks at home) and playing video games appear to require higher cognitive demands than using a cell phone and watching TV (Guellai et al., 2022; Hallgren et al., 2018).

These mentally active screening-based activities have also been linked to cognitive development (Loprinzi, 2019; Walsh et al., 2020). For instance, a review by Loprinzi (Loprinzi, 2019) found that computer use seemed to positively influence memory, compared to other sedentary activities such as TV viewing (Guellai et al., 2022; Hallgren et al., 2018), and has been related to better academic achievement (Simões, Oliveira, & Nunes, 2022). A computer at home is typically used for completing school-related tasks by solving specific assignments in a secure and comfortable setting and potentially equipped with the necessary tools for task completion (Simões et al., 2022). This aspect represents a clear synergy between the two paradigms outlined in this discussion, the importance of promoting mentally engaging sedentary activities (Khan et al., 2022; Wanders et al., 2021), and the pursuit of conducive contexts in which such activities can thrive (Guellai et al., 2022).

On the one hand, regarding the cognitive/academic variate, both the primary analysis and the first mode of covariation from the secondary analysis showed that mentally active SBs were associated with cognitive processing speed (the Digit Symbol Coding task), and English and History subjects. Most studies examining academic achievement and SBs have primarily focused on subjects participating in the PISA, which is an international assessment measuring the reading, mathematics, and science abilities of 15-year-old students, or their average scores (Adelantado-Renau, Moliner-Urdiales, et al., 2019; Bueno et al., 2022; Sánchez-Oliva et al., 2023). Consequently, there is a limited body of research literature exploring other subjects such as English and History. Nonetheless, there is some evidence supporting our findings, indicating a positive correlation between sedentary time and SBs (e.g., reading) with vocabulary and language skills (Harvey, 2019; Horowitz-Kraus & Hutton, 2018; Kuzik, Naylor, Spence, & Carson, 2020; Lima et al., 2022), and therefore, potentially, with school subjects like English and History. Moreover, language skills (capacity to comprehend language, access semantic memory, recognize objects through nomenclature, and execute behavioral actions in response to verbal instructions) has been linked to cognitive processing speed (Harvey, 2019). As a result, the time elapsed between the reception of information and the onset of comprehension, initiating subsequent responses, could potentially play a mediating role between SBs and language skills, which may be explored in future studies.

Indeed, these school subjects related to language skills are associated with brain regions linked to language development and semantic memory, which, in turn, are connected to the theory of cognitive processing speed (Salthouse, 1996). Childhood cognitive development is substantially mediated by processing speed, which tends to decline with age and can impact various cognitive functions (Luna, Garver, Urban, Lazar, & Sweeney, 2004; Nettelbeck & Burns, 2010). Studies suggest that processing speed is strongly associated with academic achievement and executive function, particularly in children with learning difficulties such as attention deficit/hyperactivity (ADHD) and reading disabilities (Cook, Braaten, & Surman, 2018; Gordon, Smith-Spark, Newton, & Henry, 2018). For instance, a meta-analysis showed a small effect size between processing speed and reading in children with ADHD (McDougal et al., 2022). Thus, mentally active SBs appear to be positively associated with the time taken to process information, potentially influencing literacy and reading abilities (Cook et al., 2018; Gordon et al., 2018; Leonard et al., 2007; McDougal et al., 2022).

On the other hand, in the secondary analysis, playing video games emerged as the only SB associated with a cognitive task related to inhibitory control (independent of all other SBs). In this way, in a large sample of children from the United States ($n = 11,875$), Walsh et al. showed that video games were positively associated with general cognition (Walsh et al., 2020). Moreover, there is evidence indicating that video game training has a significant effect on inhibitory control in preschoolers and adolescents, leading to significant enhancements in this high-order cognitive process, which enables individuals to suppress prepotent reactions and resist irrelevant interference (Bediou et al., 2018; Liu, Liao, & Dou, 2019). Inhibitory control is also crucial in socio-emotional development, where video games play a significant role because of social interactions with friends, particularly those with social and collaborative aspects, which contributes to the development of prosocial behaviors in children and adolescents (Wiederhold, 2021). Developing social-emotional competence is crucial during childhood, and is associated with better academic achievement (Pahl & Barrett, 2007). Overall, intervention studies are warranted to investigate the impact of mentally active SBs on language-related academic achievements, such as English, History, and Language, with the potential mediating role of processing speed and inhibitory control.

Finally, our hypothesis postulated that mentally active SBs positively correlate with cognitive-academic achievements, whereas mentally inactive SBs negatively correlate, which could be somewhat accepted. This is because the two mentally active SBs, time sitting in the classroom at school and eating, presented almost negligible canonical loading and cross-loading (negative and positive, respectively). Thus, our study sheds light on the complex interplay between various SBs and critical aspects of adolescents' cognitive and academic outcomes. It raises intriguing questions about the complex relationships between sedentary behaviors and cognitive and academic outcomes, suggesting that not all sedentary behaviors have a negative impact. Furthermore, our findings encourage researchers to explore multiple sedentary activities in future isotemporal, compositional, and other analyses, addressing a significant gap in this area.

5. Strengths and limitations

This study involved a large sample of adolescents from a developing country and an understudied world region. It also highlights the relevance of jointly analyzing diverse SBs and providing insights supporting health and educational policies to reduce or promote certain SBs to enhance cognitive performance and academic achievement in this population. However, this study has important limitations, including its inability to assess causality because of its cross-sectional design and due to SB domains coming from two different questionaries, which can generate some biases and over/sub-estimation. Future questionaries assessing combinations of different SBs are warranted to investigate how they interact. Understanding the interactions among SBs when they occur simultaneously is valuable. For example, consider a situation in which an individual is sitting during transportation while engaging in activities, such as reading or listening to music. Moreover, it is crucial to emphasize that the strength of the relationship between SBs and various health outcomes often depends on the choice between objective (device-based) and subjective (self-report) measurement methods (Aunger & Wagnild, 2022; Colley et al., 2022). Being recommended to use a combination of both methods for a comprehensive assessment. For example, in our study, we did not use data related to sedentary time derived from accelerometry. Finally, we recognize that larger sample sizes, such as ours, can detect even minor differences as statistically significant (Andrade, 2020), which may not necessarily translate into significant clinical implications (Rutledge & Loh, 2004). Additionally, some differences emerged in the sensitivity analysis between imputed and non-imputed data. Despite employing a nonparametric imputation model for missing data, it appears that certain variables may not be missing at random. Hence, caution should be exercised when generalizing our findings to other contexts.

6. Conclusion

The present study has found a positive, albeit modest, canonical association between SBs and cognitive-academic achievements. Notably, specific mentally active SBs, such as using computers, doing school tasks at home, and playing video games, appear to be positively linked with certain cognitive-academic outcomes, including processing speed and inhibitory control, and History and English grades. These findings highlight the complex relationship between SBs and cognitive-academic achievements and emphasize the need for more in-depth research to unravel these intricate connections.

Ethical approval and consent to participate

The project was conducted between March 2017 and October 2019 and was performed according to the guidelines of the Declaration of Helsinki for human research. The Bioethics and Biosafety Committee of the Pontificia Universidad Católica de Valparaíso approved the project (BIOEPUCV-H103–2016), and school principals, parents, and participants voluntarily provided signed written informed consent before participation.

Consent for publication

Not applicable.

Availability of supporting data

As the consent forms signed by participants indicated that the data would be only accessible to the team of investigators, the data are confidential.

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Authors' contributions

CC-M contributed to the design of the project and conceptualized the design of the study. CC-M analyzed the data and along with SHJ and JPZC wrote the concept version of the manuscript. MT, FBO, NF, JM, NAF, GF, KPS, and AG critically reviewed the analysis, manuscript, and edited the article. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Carlos Cristi Montero reports financial support was provided by National Commission for Scientific and Technological Research CONICYT/FONDECYT INICIACION 2016 Grant No.: 11160703 (Chile).

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mhpa.2023.100561.

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