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Screen time and working memory in adolescents: A longitudinal study

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ABSTRACT

Little is known about the effects of excessive screen time on Working Memory (WM) in adolescents. The aim of this study was to investigate the association between measures of screen time in adolescence and Working Memory. Data from the 1993 Pelotas (Brazil) Birth Cohort Study were analyzed (N = 3625). Self-reported screen time was collected at ages 11, 15 and 18. Working Memory performance (Digit Span backward score) was examined at age 22. Multiple linear regression was used to assess the associations between three screen time measures (television, video game and computer time) for each age and WM at age 22. We also evaluated the direct and indirect effect by mediation analysis, using the intelligence quotient (IQ) at 18 years as mediator. In men, television and video game time at 11 years and computer at ages 11 and 15 years had a positive effect on WM. Also, these effects were mediated through IQ. In women there was no significant association between screen time measures at ages 11, 15, and 18 and WM. This study provides new insights about the relationship between television, videogame, and computer time with WM in adolescents, by exploring the paths of these associations and considering the important mediating role of IQ.

1. Introduction

It is recommended that the maximum time for screen activities by children and adolescents be 2 h a day (Strasburger et al., 2013). Probably due to the drastic changes in the use of media and the fast pace of the introduction of new technologies in the last decades, in several countries an increased prevalence of excessive screen time (≥2 h/day) has been observed among children and adolescents (Bucksch et al., 2016).

Working memory (WM) is the ability to temporarily store and retain information, while a particular task is being performed, which can be accessed, manipulated and reorganized (Baddeley and Hitch, 1994). WM seems to be related to activities relevant to academic performance such as cognitive control and reading skills (Peng et al., 2018).

Working Memory develops considerably between the time of puberty and adulthood in parallel with the maturation of the prefrontal cortex (Gathercole et al., 2004). A systematic review indicated that WM performance is unstable and sensitive to many social and situational factors such as stress, sleep, and certain mental illnesses (Blasiman and Was, 2018). The results of a meta-analysis of 23 experimental and quasi-experimental studies showed that specific training on a WM task was associated with improvements in these skills at childhood and adolescence. However, the duration of the effects and the underlying mechanism are still uncertain (Melby-Lervåg and Hulme, 2013).

In two systematic reviews the body of evidence suggests that excessive screen time in childhood may impair the development of cognitive processes, including WM (Kostyrka-Allchorne et al., 2017; Lillard et al., 2015). Depending on age, individuals use electronic devices in different ways. However, the effects of the use of media in adolescence as well as the variety of media used simultaneously are not widely known (Roberts and Foehr, 2008). Available evidence on the impact of screen time on WM in adolescents is inconsistent. While some studies suggest adverse effects (Alloway and Alloway, 2012; Rosenqvist et al., 2016), others suggest that excessive screen time has a beneficial effect on WM performance (Appelbaum et al., 2013; Blacker and Curby, 2013).

The scarcity of available studies on the association between screen time and WM in adolescents, as well as the inconsistency of their results, justifies investigations of this relationship in different periods of adolescence as the type of activities and cognitive development vary over time (Valkenburg et al., 2016). The aims of this study were to investigate the association between adolescents' time spent on three types of screen activities (e.g., watching television, playing video games, and using a computer) and Working Memory. Our main hypothesis was

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that television, video game or computer time at 11, 15 and 18 years old would be associated with a poorer performance on Digit Span Task (Backwards only) at 22 years old. We also hypothesized that the effects of television, video game, or computer time at 11, 15 and 18 years old on Digit Span Task (Backwards only) at 22 years would not be mediated by intelligence quotient (IQ) at age 18 or by short-term memory at age 22.

2. Methods

2.1. Study data and cohort formation

In 1993, all hospitals in the city of Pelotas (Brazil) were monitored daily, and mothers of newborns were invited to participate in a prospective study. From the 5265 live births in the city, 5249 were enrolled in the birth cohort study. Mothers were interviewed shortly after delivery on demographic, socioeconomic, and health-related variables and newborns were weighted and measured by the study team (Victora et al., 2006). All cohort members were sought when they reached the mean age of 11, 15, 18 and 22 years (Gonçalves et al., 2018) (Fig. 1).

From the 5249 original cohort members, 3810 were followed up to the age of 22 years (representing a retention rate of 76.3%; Fig. 1). Chi-square tests were performed comparing the distribution of the variables sex, family income, maternal education, and birth weight of the perinatal period with those of the 22-year-old follow-up to determine whether losses from follow-up could affect the sample.

2.2. Measurements

Working Memory and Short-term memory: At the 22-year follow-up, we assessed Working Memory and Short-term memory using the Digit Span subtest from the WAIS-III (Wechsler, 1997). This task consists of two sections. Digits forward is administered first and requires the repetition of digits in the same order presented, while in digits backward participants must repeat digits in an inverse or backwards order. The digits forward involves attention and short-term memory, and the digits backward more closely involves working memory.

In the present study, a duly-trained psychologist recited a set of digits (at the rate of one digit per second) which the participant repeated in forward or reverse order. The first set of digits consisted of two digits. The set size increased by one digit every two trials. The test stopped when the subject made two consecutive errors at any given set size in each section. The total score was the sum of the item scores; the maximum forward digit span total score was 16 points and backwards digit span was 14 points.

The WAIS-III has been adapted and standardized for the Brazilian population (Nascimento, 2004). In the 20- to 29-year-old participants in the Brazilian standardization sample, the median was seven points in the digits forward and five points in the digits backwards (De Figueiredo and Do Nascimento, 2007).

Screen time: Information about screen time was collected when adolescents were 11, 15 and 18 years old. Screen time was self-reported through face-to-face interviews using a standardized questionnaire including questions about time spent watching television, playing video games, and using a computer on a normal weekday.

Intelligence quotient (IQ): We assessed IQ using the Wechsler Adult Intelligence Scale, third version (WAIS-III), at 18 years, with the arithmetic, digit symbol, similarities, and picture completion subtests. Crude scores for each subtest were converted into weighted scores in accordance with the Brazilian standard (Nascimento, 2004). The test was administered individually by trained psychologists using a standardized procedure in a private and quiet room.

Covariates: The covariates included were based on the literature on the use of electronic devices and cognitive development (Valkenburg et al., 2016). Birth-related covariates included sex (female and male), skin color (white, black, brown and others), household income (expressed in Brazilian minimum wages), birth weight (<2500 g and ≥2500 g), gestational age, according to the date of the last menstrual period (<37 weeks and ≥37 weeks) and maternal information —maternal education (years), alcohol consumption (no/yes) and smoking during pregnancy (no/yes). Birth weight was measured by trained interviewers using pediatric scales with a precision of 10 g, and the other information was self-reported by the mothers.

From the 11-year follow-up, the following covariates were included: maternal common mental disorders, attention difficulties and hyperactivity, reading habits, physical activity time, and sleep duration. Maternal common mental disorders were assessed using the Brazilian version of the *Self-Reporting Questionnaire* (SRQ-20) (Mari and Williams, 1986). The cutoff point of 7 points was adopted (Gonçalves et al., 2008). We assessed attention difficulties and hyperactivity using the Brazilian version of the *Strengths and Difficulties Questionnaire* (SDQ, parent-reported version) applied to the parents of the participants in the form of an interview conducted by trained personnel. The cutoff point of 8 or more points on the SDQ hyperactivity scale was adopted (Anselmi et al., 2010). We defined reading habit as the number of days per week that the adolescents read newspapers, magazines, or books (Never, 1–4 and ≥5). Physical activity time was self-reported in all interviews through a list of different activities during the past week. The time spent on physical activity was estimated from the weekly frequency and duration of each activity. Participants were considered active if they performed ≥300 min/week of moderate or vigorous physical activity.

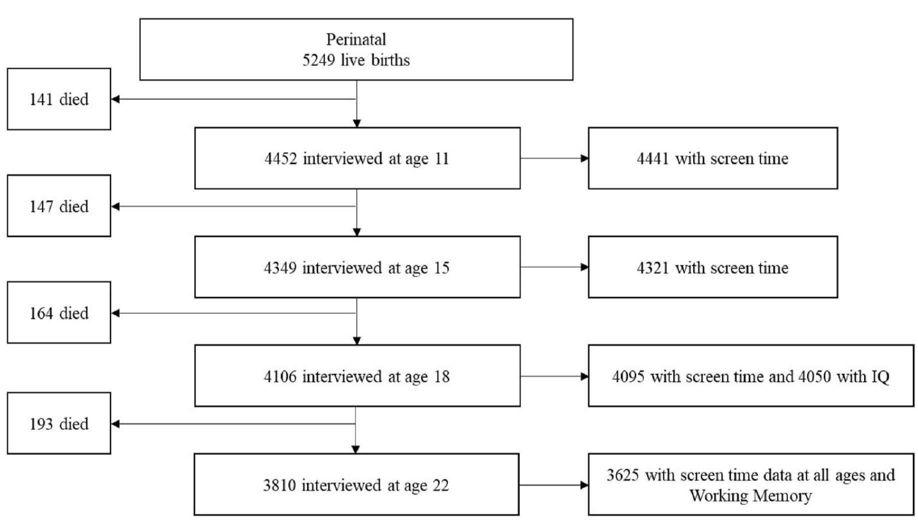

Fig. 1. Flow chart of data collected on screen time and working memory in the 1993 Pelotas Birth Cohort Study.

Sleep duration was calculated using the difference between the usual time to wake up and sleep, except on Saturday and Sunday (<9 and ≥ 9 h).

2.3. Ethics

The study was approved by the Ethics Committee of the Faculty of Medicine of the Federal University of Pelotas. Before participating in the study, the parental consent of the participants was obtained. More details of the methods have been reported previously (Gonçalves et al., 2018).

2.4. Analysis

Our outcome was Working Memory (Digit Span backward score). The Digit Span backward score followed a normal distribution. We used one-way analysis of variance to compare means and multiple linear regression to adjust the estimates for confounders. Interaction tests between Working Memory, sex, and three screen time measures (television time at 11 and computer time at 11 and 15 years old) were significant; therefore, we chose to show the results stratified by sex.

To investigate the association between screen time and WM the analysis was conducted in two steps. We first estimated the association between screen time measures and WM without considering IQ and Digits Span forward (short-term memory performance). Unadjusted and adjusted linear regressions were used to examine the relationship between screen time measures at each age (11, 15 and 18 years) and WM at 22 years. In the linear regression models we based statistical comparisons between categories of tests of heterogeneity or linear trend. There was no evidence of collinearity in the adjusted models with variance inflation factors ranging from 1.01 to 1.48.

Second, to elucidate whether the results found were specific to Working Memory, we evaluated the mediation of IQ and Digits Span forward (short-term memory performance) in the association between screen time variables and the WM. For mediation analysis we used the indirect method by Preacher and Hayes (2008) to estimate the direct effect of screen time measures on WM at 22 years and the indirect effect that was mediated through IQ at 18, Digits Span forward at 22, and screen time variables that were between exposure and WM (Supplementary Figure 1). This method estimates total, direct, and indirect unstandardized effects of exposures on the outcome through the mediator variables while controlling for covariates using 1000 bootstraps (Preacher and Hayes, 2008). We calculated the percentage of the total effect explained by the set of mediators in each exposure as follows: % mediation = 100 – (direct effect * 100/direct effect + indirect effect). We included the covariates listed previously. Resulting path coefficients are unstandardized regression coefficients that are scale dependent. Mediation analyses was only conducted for significant associations found with linear regression after adjustment for covariates.

Additional analysis was performed with the total screen time. Total screen time was calculated as the sum of time spent in these three domains (television, video game, and computer time) at 11, 15, and 18 years of age. The results of this analysis are presented in the Supplementary Table 2 and Supplementary Figure 2.

Statistical significance was set at 5% (in interaction analyses 10%) and all analyzes were performed using *Stata*, version 15.0 (Stata Corp., College Station, USA).

3. Results

Of the 3810 participants, the 3625 who presented information about the exposures and the outcome were included in this study. Female participants were slightly more likely to have available data compared to male participants (Supplementary Table 3).

The characteristics of the sample studied are shown in Table 1. Most of the adolescents had a perinatal household income up to three

Table 1
Sample characteristics. 1993 Pelotas Birth Cohort (N = 3625).

	N	(%)	Digit Span Backward score	
			Mean (95% CI)	p-value[a]
Maternal data				<0.001
Household income (in minimum wage)				
≤1	640	(18.0)	4.2 (4.1–4.4)	
1.1–3	1489	(41.9)	4.7 (4.6–4.8)	
3.1–6	880	(24.7)	5.0 (4.9–5.1)	
6.1–10	290	(8.2)	5.5 (5.3–5.7)	
>10	258	(7.3)	6.0 (5.7–6.2)	
Maternal education (years)				<0.001
0–4	966	(26.7)	4.2 (4.1–4.3)	
5–8	1711	(47.3)	4.8 (4.7–4.9)	
9–11	655	(18.1)	5.4 (5.2–5.5)	
≥12	288	(8.0)	6.1 (5.8–6.3)	
Smoking during pregnancy				<0.001
No	2441	(67.3)	5.0 (4.9–5.1)	
Yes	1184	(32.7)	4.6 (4.5–4.7)	
Alcohol consumption during pregnancy				0.617
No	3435	(94.8)	4.8 (4.8–4.9)	
Yes	190	(5.2)	4.8 (4.5–5.0)	
Maternal Common Mental Disorder[b] (n = 3449)				<0.001
No	2079	(60.3)	4.9 (4.8–5.0)	
Yes	1370	(39.7)	4.6 (4.5–4.7)	
Adolescent data				
Sex				<0.001
Male	1690	(46.6)	4.8 (4.7–4.8)	
Female	1935	(53.4)	4.9 (4.8–5.0)	
Birth weight				<0.001
<2500	322	(8.9)	4.3 (4.1–4.5)	
2500–2999	906	(25.0)	4.7 (4.6–4.8)	
3000–3499	1426	(39.4)	4.9 (4.8–5.0)	
≥3500	967	(26.7)	5.1 (4.9–5.2)	
Skin color (n = 3435)				<0.001
White	2167	(63.1)	5.1 (5.0–5.2)	
Black	521	(15.2)	4.3 (4.1–4.4)	
Brown	614	(17.9)	4.4 (4.3–4.6)	
Others	133	(3.9)	4.8 (4.5–5.2)	
Gestational age (n = 3247)				<0.001
<37	345	(10.6)	4.5 (4.3–4.7)	
≥37	2902	(89.4)	4.9 (4.9–5.0)	
Attention difficulties and/or hyperactivity at age 11 (n = 3466)				<0.001
No	3038	(83.8)	4.9 (4.8–5.0)	
Yes	587	(16.2)	4.5 (4.3–4.6)	
Sleep duration at 11 years (n = 3472)				<0.001
<9 h	878	(25.3)	5.2 (5.1–5.3)	
≥9 h	2594	(74.7)	4.7 (4.7–4.8)	
Reading habit at 11 years (days/week)				<0.001
Never	1007	(28.9)	4.4 (4.3–4.5)	
1–4	1559	(44.8)	4.9 (4.8–5.0)	
≥5	910	(26.3)	5.1 (5.0–5.2)	
Physical activity at 11 years (min/week)				0.620
<300	2139	(62.2)	4.8 (4.8–4.9)	
≥300	1298	(37.8)	4.8 (4.7–4.9)	

CI: confidence interval.
[a] ANOVA test.
[b] ≥7 points in the *Self-Reporting Questionnaire* (SRQ-20).

minimum wages (59.9%) and were white (61.1%). About 11% were preterm (gestational age < 37 weeks) and 9.4% had low birth weight (<2500 g). Regarding the characteristics of the mothers, 47.8% had between five and eight successful complete years of schooling and 39.7% had a common mental disorder. During pregnancy, one-third of mothers reported having smoked and 5.2% had consumed alcohol. At 11 years old, 16.1% of the cohort participants had attention difficulties and hyperactivity, 13.2% read five or more days a week, 37.8% were physically active, and 26.3% slept 9 h or less daily. The distribution of data on screen time in each follow-up is shown in Fig. 2. The IQ average at 18 was 96.9 points (SD: ± 12.5). The average was 7.6 (SD: ± 2.1) points in the digits forward and 4.9 (SD: ± 1.9) points in the digits backward.

Table 2 shows the associations between screen time in each studied age and WM at 22 years old. In adjusted analysis, for every one-unit

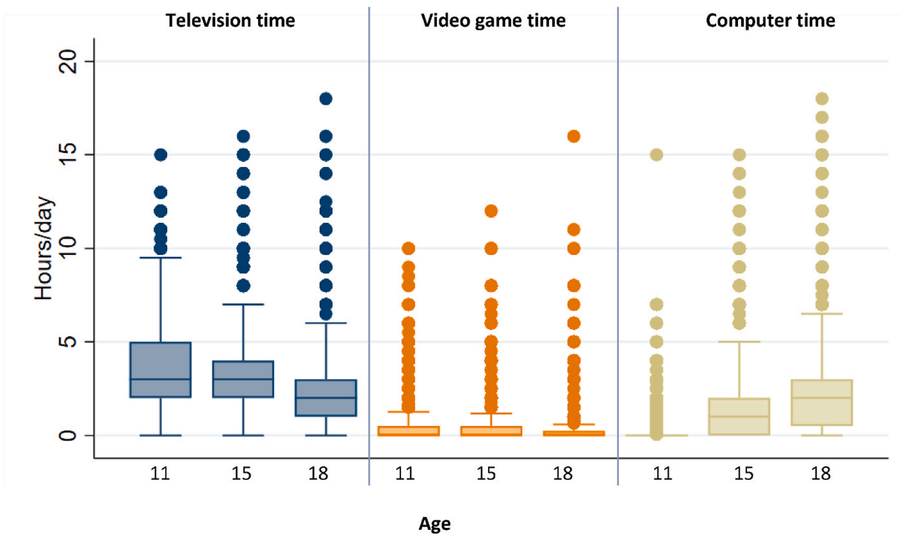

Fig. 2. Distribution of television, video game and computer time (hours/day) at 11, 15 and 18 years. 1993 Birth cohort in Pelotas (N = 3625).

Table 2
Association between screen time measures (hours/day) at the ages of 11, 15 and 18 and Working Memory at 22 according to gender. 1993 Pelotas Birth Cohort (N = 3625).

	Working Memory (Digit Span Backward score)			
	Men (N = 1690)		Women (N = 1935)	
	Crude analysis	Adjusted analysis	Crude analysis	Adjusted analysis
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
At 11 years				
Television	0.08 (0.03; 0.12)*	0.09 (0.04; 0.13)[a] **	0.02 (−0.02; 0.06)	0.03 (−0.01; 0.07)[a]
Video game	0.08 (0.01; 0.15)*	0.08 (0.00; 0.15)[a] *	−0.06 (−0.18; 0.05)	−0.08 (−0.2; 0.04)[a]
Computer	0.46 (0.34; 0.57)*	0.22 (0.10; 0.35)a**	0.27 (0.15; 0.4)**	0.07 (−0.06; 0.20)[a]
At 15 years				
Television	0.01 (−0.03; 0.06)	0.00 (−0.05; 0.05)[b]	0.02 (−0.02; 0.05)	0.02 (−0.01; 0.06)[b]
Video game	−0.01 (−0.08; 0.05)	−0.03 (−0.10; 0.03)[b]	0.12 (−0.02; 0.27)	0.14 (−0.01; 0.30)[b]
Computer	0.21 (0.16; 0.26)**	0.06 (0.01; 0.12)[b]**	0.14 (0.10; 0.18)**	0.03 (−0.02; 0.07)[b]
At 18 years				
Television	−0.10 (−0.17; −0.02)*	−0.06 (−0.14; 0.03)[c]	−0.05 (−0.10; 0.00) *	−0.03 (−0.08; 0.03)[c]
Video game	−0.10 (−0.20; 0.00)*	−0.06 (−0.17; 0.04)[c]	0.01 (−0.2; 0.23)	0.07 (−0.17; 0.32)[c]
Computer	0.03 (−0.02; 0.08)	−0.02 (−0.08; 0.04)[c]	0.05 (0.01; 0.10)*	0.03 (−0.03; 0.08)[c]

Confounding variables: skin color, household income, birth weight, gestational age, maternal education, alcohol consumption during pregnancy, maternal Common Mental Disorder, attention difficulties and/or hyperactivity, reading habit, physical activity time, and sleep duration at 11 years.
$^*p < 0.05$; $^{**}p < 0.001$.
[a] Linear regression model adjusted for confounding variables.
[b] Linear regression model adjusted for confounding variables, television time at 11 years, video game time at 11 years, and computer time at 11 years.
[c] Linear regression model adjusted for confounding variables, television time at 11 years, video game time at 11 years, and computer time at 11 years, television time at 15 years, video game time at 15 years, computer time at 15 years, and IQ at 18 years.

increase in television time (hours/day) at 11 years, the average Digit Span backward score at 22 years in men increased by 0.09 points. However, the direct effect was not significant and IQ at 18 was responsible for 51.6% of this association (Fig. 3). In women, the television time at 18 years was negatively associated with working memory at 22 years in crude analysis, but this association disappeared after adjustment (Table 2).

Regarding video game time, the average Digit Span backward score at 22 years in men increased by 0.08 points for every one-unit increase in video game time at 11 years (hours/day; Table 2). No direct effect was found for video game time at 11 years on WM at 22 among men (b = 0.02; 95% CI: −0.04; 0.08) and IQ at 18 mediated this association (b = 0.02; 95% CI: 0.00; 0.04, Fig. 3). In women there were no associations between the time spent playing video games and the WM.

In crude and adjusted linear models, the time dedicated to using computers at 11 and 15 years showed a positive association with Digit Span backward score at 22 among men (Table 2). However, Fig. 3 shows that these associations were mediated by IQ at 18 years. Also, the results show that computer time at 15 years have a positive indirect effect on Digit Span backward score at 22 mediated through Digit Span Forward (b = 0.03; 95% CI: 0.01; 0.06; Fig. 3). In women, no associations were found between computer time and the WM.

4. Discussion

To our knowledge, this is the first longitudinal study to investigate the association between screen time throughout adolescence and Working Memory considering the mediating role of IQ in this relationship. Our results indicate sex differences in the association between screen time and WM with men demonstrating a more potent effect than women. In addition, the effects of screen time were mediated through other variables, such as IQ.

This research provides novel findings regarding factors that mediate the relationship between television time and WM among adolescents. Observational studies that didn't include IQ in their analyses found no significant association between television time and WM performance in adolescents (O'Connor et al., 2016; Syväoja et al., 2014), including studies in which analyses were stratified by sex (Lopez-Vicente et al., 2017). We found that men who watched more television at 11 years of age showed better performance in WM at age 22. However, this effect was better explained by IQ at 18 years old.

Studies evaluating the effects of time spent watching television on IQ are scarce in the literature and the findings oppose those of the present study. In adolescents aged between 12 and 18 years, a meta-analysis of

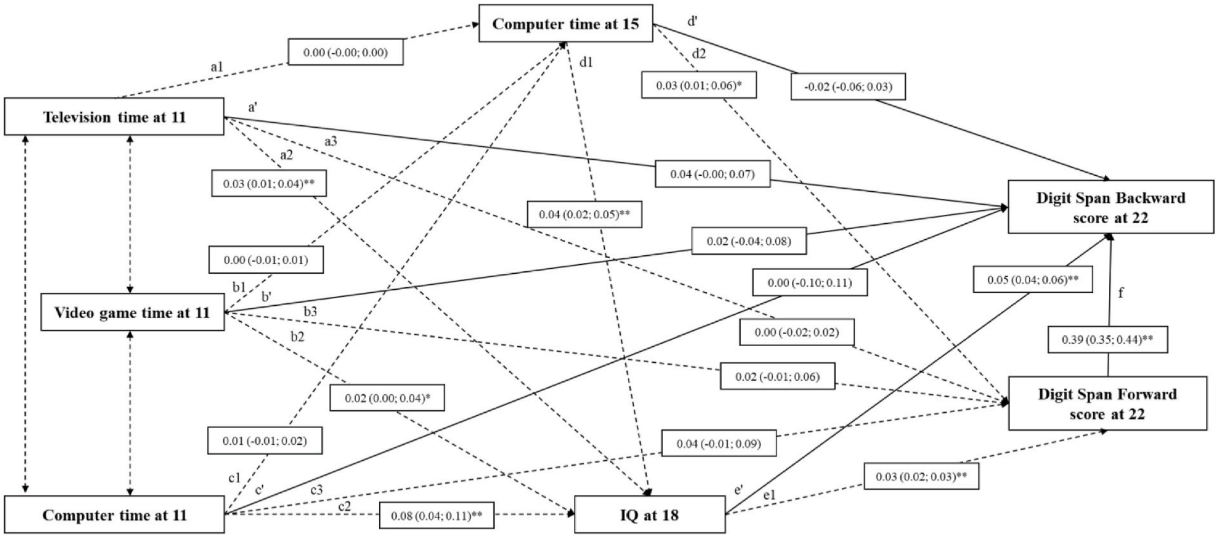

Fig. 3. Path analyses of the relation between television, video game and computer time (hours/day) in adolescence and Digit Span Backward at 22 years in men. 1993 Pelotas Birth Cohort (N = 3625).
Solid lines: direct effect of television, video game and computer time at 11 years, computer time at 15 years, IQ at 18 years, and Digit Span Forward at 22 years on Digit Span Backward at 22 years.
Dashed lines: indirect effect of television, video game and computer time at 11 years of age on Digit Span Backward at 22 years, after mediation by computer time at 15 years old, IQ at 18 years, and Digit Span Forward at 22 years. Indirect effect of computer time at 15 on Digit Span Backward at 22 years, after mediation by IQ at 18 years and Digit Span Forward at 22 years. Indirect effect of IQ at 18 on Digit Span Backward at 22 years, after mediation by Digit Span Forward at 22 years.
-Confounding variables: skin color, household income, birth weight, gestational age, maternal education, alcohol consumption during pregnancy, maternal Common Mental Disorder, attention difficulties and/or hyperactivity, reading habit, and sleep duration at 11 years.
-Path a1: Adjustment for confounding variables and video game and computer time at age 11.
-Path a2: a1 + computer time at age 15.
-Path a3: a2 + IQ at age 18.
-Path a': Direct effect of television time at 11 on Digit Span Backward at 22 years.
-Path b1: Adjustment for confounding variables and television and computer time at age 11.
-Path b2: b1 + computer time at age 15.
-Path b3: b2 + IQ at age 18.
-Path b': Direct effect of video game at 11 on Digit Span Backward at 22 years.
-Path c1: Adjustment for confounding variables and television and video game at age 11.
-Path c2: c1 + IQ at age 18.
-Path c': Direct effect of computer time at 11 on Digit Span Backward at 22 years.
-Path d1: Adjustment for confounding variables and television, video game and computer time at age 11.
-Path d2: d1 + IQ at age 18. -Path d': Direct effect of computer time at 15 on Digit Span Backward at 22 years.
-Path e1: Adjustment for confounding variables and television, video game and computer time at age 11, computer time at 15 years and IQ at age 18.
-Path e': Direct effect of IQ at 18 on Digit Span Backward at 22 years.
-Path f: Total effect of Digit Span Forward on Digit Span Backward.
$*p<0,05$; $**p<0,001$.

24 cross-sectional studies showed that television viewing was inversely associated with composite academic performance scores, language, and mathematics (Adelantado-Renau et al., 2019). However, the cross-sectional design of the included studies prevents causal inferences.

In our adjusted analysis, video game time when men were 11 years old was positively associated with WM at 22 years old. Findings in the same direction were found by Blacker, Curby and Appelbaum et al. In the study by Blacker and Curby, men (±21 years old) who played 5 h or more of action games per week showed a better performance of WM in comparison to the reference group (<5 h/week for other game categories) (Blacker and Curby, 2013). Appelbaum et al., studying individuals in the same age group (male: n = 52; female: n = 73), found similar results. The participants of both sexes with experience in action games had better performance in visual WM when compared to those without experience in action or shooting games (Appelbaum et al., 2013).

As opposed to our results, in the study by Syväoja et al. conducted with adolescents (±12 years old), after adjusting for sex (female), the highest level of parental education, and the child's need for remedial education, the regression coefficient for the relationship between video game time (h/day) was negatively associated with visuospatial working memory span (Syväoja et al., 2014).

We found a positive association of computer time (at ages 11 and 15 years) and WM in men. The only study to our knowledge that evaluated the association between computer use and WM was done with 224 adolescents (male: n = 97) of 12 years old (Syväoja et al., 2014). This study found no association between self-reported computer use time (hour/day) and *Spatial Span test* score. However, the authors warn that the results may be subject to a non-differential classification error. The participants, on average, achieved high WM performance suggesting low complexity of test in healthy adolescents.

Identifying the mediators of the relationship of video game and computer time with WM can help explain these discrepant findings. Our findings of path analysis suggest that IQ is responsible for the effect of video game and computer time on WM. Evidence has indicated that playing video games and using computers require users to successfully understand language (Van Schie and Wiegman, 1997) and might increase their engagement with text online (Bowers and Berland, 2013). The cognitive processes that occur during and shortly after exposure act as mediators (Valkenburg and Peter, 2013). Given that IQ reflects cognitive processing, IQ can provide the route to media effects.

Previous research has suggested that television viewing replaces other activities such as physical activity, studying (Kostyrka-Allchorne et al., 2017; Lillard et al., 2015), or sleeping (Dworak et al., 2007), and reduces mental effort which might affect an adolescent's cognitive development (Kostyrka-Allchorne et al., 2017; Lillard et al., 2015). On the other hand, it can be assumed that several activities performed on the computer or a video game require efforts of WM (for example, playing or reading content online) (Peng et al., 2018; Spence and Feng, 2010). The constant request for WM would improve the adolescent's scores in tests that require this ability (Melby-Lervåg and Hulme, 2013). To discard these hypotheses, we adjusted the analysis for physical activity, sleep duration, and reading habits at age 11.

Our findings suggest that men are more susceptible to the effects of screen time on WM compared to women. There is a gap in the literature about the differences in the effects of screen time on WM. Studies found that activation of brain regions associated with cognitive status (e.g., mesocorticolimbic system) and decision making (e.g., dorsolateral prefrontal cortex) immediately after playing video games was significantly greater in men than in women (Dong et al., 2018; Hoeft et al., 2008).

Our study suggests that the effects of screen time on WM in men occur due to the influence of IQ. Although there are theoretical arguments for expecting that IQ can influence an individual's selective use of and responsiveness to high screen time, there is as yet not enough empirical evidence to support this claim (Valkenburg and Peter, 2013). Also, only the effect of computer time at 15 years on WM in men was better explained by short-term memory performance at 22 years old. More studies are required to clarify this observation.

Our study had several strengths. It is based on prospective data, collected with methodological rigor, from a birth cohort with an expressive sample up to 22 years of age which allows us a certain degree of generalization of the results to the population of this age group. Regarding the complexity of the phenomenon studied, our analyzes were controlled for a wide variety of sociodemographic factors at 11 years of age and psychosocial factors, such as maternal schooling, which can influence the time dedicated to screen activities and be associated with neural development affecting WM performance. In addition, demographic factors such as gender may affect the selection of content by the individual and their ability to respond to its effects.

It is also important to consider that the data collected impose some limitations on the analyzes. The biggest limitation is the non-availability of data on the screen time content on television, video games, and computers. It is also pointed out that screen time exposures may be subject to some recall bias as they were self-reported. The absence of screen time data before age 11 made it impossible to assess whether television, video game, and computer time at younger ages may be related to the outcome. The same occurred with the use of cell phones, game consoles etc., since these devices were not popular yet.

5. Conclusions

This longitudinal study provides new insights about the relationship between television, video game, and computer time with WM in adolescents by exploring the paths of these associations and considering the important mediating role of IQ. The results showed positive associations between television, video game and computer time and WM performance only in men, suggesting that the effects of screen time are not the same between genders. Our findings may contribute to future investigations of possible explanatory avenues for these associations as well as the development of interventions aimed at improving the performance of WM.

Author statement

Pedro San Martin Soares, Paula Duarte de Oliveira, Fernando César Wehrmeister, Ana Maria Baptista Menezes, and Helen Gonçalves - Contributed in the conception and design of the study, and in drafting and revising the paper. Pedro San Martin Soares and Paula Duarte de Oliveira – Contributed in data analysis and interpretation. All authors approved the final version.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpsychires.2021.02.066.

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