Mediators of change in screen-time in a school-based intervention for adolescent boys: Findings from the ATLAS cluster randomized controlled trial

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ABSTRACT

Background. The mechanisms of behavior change in youth screen-time interventions are poorly understood.

Methods. Participants were 361 adolescent boys (12-14 years) participating in the ATLAS obesity prevention trial, evaluated in 14 schools in low-income areas of New South Wales, Australia. Recreational screen-time was assessed at baseline, 8- and 18-months, whereas potential mediators (i.e., motivation to limit screen-time and parental rules) were assessed at baseline, 4- and 18-months. Multi-level mediation analyses followed the intention-to-treat principle and were conducted using a product-of-coefficients test.

Results. The intervention had a significant impact on screen-time at both time-points, and on autonomous motivation at 18-months. Changes in autonomous motivation partially mediated the effect on screen-time at 18-months in single and multi-mediator models (AB [95% CI] = -5.49 [-12.13, -0.70]).

Conclusion. Enhancing autonomous motivation may be effective for limiting screen-time among adolescent males.

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Key words: self-determination theory; sedentary behavior; rules; physical activity; obesity prevention

INTRODUCTION

Screen-based recreation (hereafter referred to as screen-time) is one of the most popular leisure-time activities for young people (Rideout et al., 2010). Among children and adolescents, excessive screen-time has been linked to cardiovascular risk, low self-esteem, antisocial behavior and poor academic performance (Rezende et al., 2014). Of concern, the habituation of screen-based sedentary behavior during childhood and adolescence may have long-lasting adverse effects on physical (Hancox et al., 2004) and mental (Grøntved et al., 2015) health. International guidelines recommend children and adolescents limit their recreational screen-time to less than two hours per day (World Health Organization, 2010). However, a recent investigation of more than 11,000 school-aged youth (4-17 years) from eight countries found that approximately two thirds exceeded this threshold (Atkin et al., 2014). Screen-time tends to increase with age (Rideout et al., 2010), and Australian data show that 80% of adolescents exceed screen-time recommendations (Morley et al., 2012). Moreover, males and low-income youth are more likely to engage in high levels of screen-time compared with females and those from higher socioeconomic strata (Morley et al., 2012).

Considering the ubiquity of screen devices in the lives of young people, and the clear likelihood that this trend will continue in the future, there is an urgent need for interventions aimed at reducing (or at least limiting increases in) screen-time, particularly for adolescent boys living in low-income communities. Previous screen-time interventions targeting children and adolescents have utilized a variety of behavior modification strategies, ranging from basic education on consequences through to changes in the home environment (Altenburg et al., 2016; Biddle et al., 2014). Although the strategies used in previous intervention research have varied, they broadly align with two main approaches: (i) imposing restrictions on screen-time (e.g., parental screen-time rules, removal of screens from bedrooms, electronic TV monitoring devices); and (ii) promoting self-regulation of screen-time (e.g., education, teaching self-monitoring and goal setting skills). While these two approaches appear to be diametrically opposed, either may be effective for limiting screen-time (Steeves et al., 2012). For example, prior research has demonstrated parental enforcement of screen-time rules at home is associated with less screen-time among children (Carlson et al., 2010; Ramirez et al., 2011). In addition, the use of behavioral skills such as self-monitoring, stimulus control and goal setting have been the most commonly used strategies in previous screen-time interventions (Steeves et al., 2012), and have been included in successful trials with adolescents (Gortmaker et al., 1999; Lubans et al., 2012). In view of these findings, utilizing both approaches together might be a worthwhile strategy for interventions directed at youth.

According to previous systematic reviews of screen-time interventions (Buchanan et al., 2016; Steeves et al., 2012), externally imposed restrictions on screen-time (particularly through electronic TV monitoring devices) appeared to be the most effective intervention strategy. However, the majority of prior studies have targeted preadolescent children (Altenburg et al., 2016; Buchanan et al., 2016; Steeves et al., 2012), and the lack of long-term follow-up makes it difficult to determine whether these strategies have lasting effects (Biddle et al., 2014). Further research is needed to determine whether imposing restrictions results in sustained changes in screen viewing behavior (particularly once the restriction is removed), or whether this is simply a short-term ‘fix’. Importantly, introducing restrictions on screen viewing may be less effective for adolescents compared with younger children. For example, the most effective screen-time interventions have been conducted among pre-school aged children (Biddle et al., 2014), and studies reporting null or negative effects (i.e., an increase in screen-time as a result of the intervention) are more common in studies involving adolescents (Steeves et al., 2012). Most western adolescents have access to a variety of screen devices at home (Strasburger et al., 2013). Therefore, controlling access to one device (e.g., TV) may simply shift screen use to another medium (e.g., laptop, PC, tablet, smartphone). As adolescents become increasingly responsible for their health behaviors as they get older, promoting self-regulation of screen-time may be an important strategy to assist them to both implement and sustain healthy screen viewing behaviors.

Self-Determination Theory (SDT) (Deci & Ryan, 1985) has emerged as a prominent theory for understanding human motivation, and has been applied extensively to understand and modify health behaviors such as smoking, healthy eating and physical activity (Ryan et al., 2008). However, there is currently little research investigating the utility of SDT for addressing sedentary behaviors such as screen-time. SDT posits that motivation exists along a continuum, which can be broadly subdivided into three main categories: (i) amotivation (i.e., a complete lack of desire or intention to perform the behavior); controlled motivation (i.e., performing the behavior due to external pressures, such as to avoid punishment or gain reward); and (iii) autonomous motivation (i.e., performing the behavior for reasons that are personally endorsed, such as recognizing and valuing the benefits to self) (Ryan & Deci, 2007). Using SDT as a framework, we recently developed a scale for assessing adolescents' motivation to limit their screen-time – the Motivation to Limit Screen-time Questionnaire (MLSQ) (Lubans et al., 2013). The MLSQ includes three subscales aligning with the three broad categories of motivational regulations outlined within SDT. We have previously shown that autonomous and controlled motivations are inversely associated with screen-time among adolescents, whereas amotivation is positively associated (Lubans et al., 2013). However, it remains to be seen whether adolescents' motivation to limit their screen-time is responsive to intervention, or to what extent reductions in recreational screen-time might be mediated by motivational changes.

The 'Active Teen Leaders Avoiding Screen-time' (ATLAS) trial (Lubans et al., 2016c; Smith et al., 2014a; Smith et al., 2014b) was a school-based obesity prevention intervention targeting adolescent boys attending schools in low-income communities. The 20-week intervention targeted key weight-related behaviors, and a number of strategies were used to reduce boys' recreational screen-time. We have previously reported the post-intervention (8-month) (Smith et al., 2014b) and sustained (18-month) (Lubans et al., 2016c) effects of ATLAS for the main study outcomes. The objective of the present study is to explore potential mechanisms for the effect on screen-time. Exploring mediating processes in interventions is an important goal, as these investigations can help to identify areas where the intervention could be improved or re-designed in order to be more efficient (Craig et al., 2008). Moreover, identifying the efficacy of novel intervention strategies can inform the development of future programs. Specifically, the aims of the present study are: (i) to assess the impact of the ATLAS intervention on motivation to limit screen-time and the provision of parental screen-time rules; and (ii) to test the potential mediating effects of these variables on changes in recreational screen-time.

METHODS

Study design and participants

Participants for the present study were adolescent boys taking part in the 'Active Teen Leaders Avoiding Screen-time' (ATLAS) school-based obesity prevention trial (Smith et al., 2014a; Smith et al., 2014b). The intervention was evaluated using a cluster randomized controlled trial (RCT) design in 14 secondary schools located in low-income areas of New South Wales (NSW), Australia. Participants were considered eligible for the study if they reported failing to meet national guidelines regarding physical activity participation (i.e., ≥ 60 minutes of MVPA each day) and/or recreational screen-time (< 2 hours per day) (Department of Health, 2014) and did not have a physical impairment that would prevent them from participating in physical activity. Following baseline assessments, schools were match paired based on size, geographical location and socioeconomic position and randomly allocated to the intervention group or a wait-list control group. Research approval was provided by the NSW Department of Education and Communities and ethical approval for the study was given by the Human Research Ethics Committee of the University of Newcastle. Prior to the collection of data, the trial was registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12612000978864). Study participants and their parents provided informed written consent prior to enrolment in the trial.

Power calculation

Prior to recruitment, a power calculation was conducted to determine the sample size needed to detect clinically meaningful changes in the primary outcomes (i.e., BMI and waist circumference). Assuming 80% power, an α level of .05, a school clustering effect of intra-class correlation coefficient (ICC) = 0.03, and an expected dropout rate of 20% by the primary study endpoint (i.e., 8-months), a sample of 350 participants would be required for the trial to be adequately powered. With this sample size, the study would also be powered to detect small- to medium-sized mediation effects using a product-of-coefficients test (Fritz & MacKinnon, 2007).

Intervention description

ATLAS was a 20-week multi-component school-based program targeting improvements in body composition, muscular fitness and weight-related behaviors (i.e., recreational screen-time, physical activity and sugar-sweetened beverage consumption) among low-income adolescent males considered at risk of obesity. The intervention was guided by SDT (Deci & Ryan, 1985) and Social Cognitive Theory (Bandura, 1986) and involved: professional learning workshops for teachers (2 x 5 hour workshops), provision of fitness equipment to schools (1 x pack per school valued at ~$1500), researcher-led information seminars for students (3 x 20 minutes), teacher delivered physical activity sessions (20 x ~90 minutes), lunch-time physical activity mentoring sessions (6 x ~20 minutes), pedometers for self-monitoring (17 weeks), screen-time newsletters for parents (4 x newsletters) and a purpose-built smartphone application (i.e., app) and website (15 weeks). ATLAS used a number of gender targeting strategies to enhance the salience of intervention content (Morgan et al., 2016). For example, the intervention was delivered by male teachers, focused on the development of muscular fitness in a male-only environment, and utilized resistance training, which is a form of physical activity that appeals to male ideals of strength and masculinity. Other examples include naming CrossFit-style workouts after video game titles, fictional superheroes, and well known male athletes; as well as the use of appropriate 'male centric' language within the messages sent through the ATLAS smartphone app (e.g., *right after school is a gr8 time 2 b active with mates. If it's raining, try an active video game*). A full description of the intervention has been published previously (Smith et al., 2014a). However, consistent with recent recommendations (Altenburg et al., 2016), a description of the intervention strategies and behavior change techniques used to target recreational screen-time is provided (Table 1).

Measures.

Assessments for the main outcomes were conducted by trained research assistants at the study schools at baseline, 8-months and 18-months. Demographic data including age, cultural background, country of birth, language spoken at home and residential postcode were collected via an online questionnaire. As true mediation implies a change in cognitions or conditions that precede a change in behavior, assessments for the hypothesized mediators (i.e., motivation to limit screen-time and parental screen-time rules) were conducted at mid-program (4-months) instead of post-intervention (8-months). The hypothesized mediators were assessed again at the 18-month time point.

Recreational screen-time. Measured using a modified version of the Adolescent Sedentary Activity Questionnaire (ASAQ)(Hardy et al., 2007). Previous research suggests media-multitasking (i.e. the use of multiple small screen devices concurrently) is common amongst youth (Foehr, 2006). Reporting the time spent on individual devices separately and adding them together, as done with the original ASAQ, may therefore inflate estimates of total screen-time. To address this, the modified ASAQ requires respondents to self-report, for each day of the week, the total time spent sitting using screens (of any kind) for the purposes of entertainment. Screen-time reported in hours and minutes for each day of the week was converted to minutes and average daily screen-time was calculated by dividing total screen-time by the number of reported days.

Motivation to limit screen-time. Assessed using the Motivation to Limit Screen-time Questionnaire (MLSQ) (Lubans et al., 2013). The MLSQ is a 9-item instrument comprising three subscales corresponding to the broad behavioral regulations outlined in SDT (i.e., amotivation, controlled motivation and autonomous motivation). Participants responded on a 7-point scale (1 = *Not at all true* to 7 = *Very true*) to items relating to each of these behavioral regulations (e.g., *I try to limit my screen-time because I know that reducing my screen time is good for me*). Separate subscales for the three behavioral regulations are calculated as the mean of corresponding items. The MLSQ demonstrated adequate factorial validity (e.g., confirmatory fit index = .96) among the current sample, and satisfactory test-retest reliability among a separate sample of adolescents (intra-class correlation = .67 to .81) (Lubans et al., 2013).

Screen-time rules in the family home. Assessed using a scale developed for use with adolescents (Ramirez et al., 2011). Participants responded "*Yes*", "*No*", or "*Sometimes*" to the presence of nine separate rules within their family home. Students with parents/caregivers living in separate homes (i.e., due to divorce or separation) were asked to base their responses on the residence in which they spent the most time. For the present study, only the three rules promoted to parents within the newsletters (i.e., *less than two hours of screen-time per day*; *no screen-time during daylight hours*; and *no electronic screen devices in the bedroom after bedtime*) were investigated. Reponses were dichotomized with "*Sometimes"* considered a "*Yes*" and a composite score was calculated as the sum of the three rules (possible range 0 to 3).

Statistical analyses

Multi-level mediation analysis was conducted using a product-of-coefficients test (Krull & MacKinnon, 2001) in MPlus, version 7.11 for Windows (Muthén & Muthén, Los Angeles, CA), with statistical significance set at $p < .05$. Consistent with the intention-to-treat principle, missing values were imputed using the expectation maximization method (Dempster et al., 1977). Expectation maximization is an acceptable method for imputing missing data, assuming the data are missing at random. Little's MCAR test (chi square = 235, DF = 207, $p = .085$) demonstrated the data were missing completely at random. A depiction of the mediation models is provided in Figure 1. Four separate single-mediator models (mediators: autonomous motivation, controlled motivation, amotivation, and screen-time rules) were tested for both the 8-month (post-intervention) and 18-month (follow-up) time points. Multi-level linear regression was used to determine: (i) the total intervention effect for screen-time (Pathway C); (ii) the effect of the intervention on the potential mediators (Pathway A); and (iii) the association between changes in potential mediators and changes in screen-time, independent of group assignment (Pathway B). This step also provides the direct effect of the intervention (Pathway C'), which is the effect of the intervention on screen-time adjusted for the mediated effect. All analyses were adjusted for participant socioeconomic position, baseline values and school-level clustering. In the final stage, the significance of the product-of-coefficients (AB pathway) was tested using Tofighi and MacKinnon's 'RMediation' package (Tofighi & MacKinnon, 2011). To satisfy the criteria for mediation, the 95% confidence intervals (95% CI's) for the product-of-coefficients must not include zero. To test the robustness of the mediation results, two multiple mediator models were tested (i.e., one for each of the study time points) using the same procedure as noted above, but with all potential mediators included in the third step (i.e., Pathway B). Finally, for any statistically significant mediators, the proportion of the intervention effect mediated was calculated using the equation: % mediated = AB/C (MacKinnon, 2008).

RESULTS

In total, 361 boys (mean age, 12.7 ± 0.5) were assessed at baseline and screen-time data were collected again for 289 (80%) and 265 (73%) boys at 8- and 18-months, respectively. Assessments for the potential mediators were completed for 299 (83%) boys at 4-months (i.e., mid-intervention). The study sample was culturally homogenous with the majority of boys born in Australia (95%), identifying their cultural background as Australian (77%), and speaking English as their primary language at home (96%). In addition, the majority of boys were of low-to-middle socioeconomic position, with 85% residing in postal areas within the bottom half of the socioeconomic distribution. Values for the mediators and screen-time at each study time point can be seen in Table 2. At baseline, mean daily screen-time for the study sample was 127 ± 88 minutes per day, and 152 (42%) boys exceeded the 'less than 2 hours per day' guideline. The proportion of boys reporting 0, 1, 2 and 3 screen-time rules at home was 18%, 35%, 36% and 12%, respectively. The most common rule was "*less than 2 hours of recreational screen-time per* day" (57%), whereas the least common rule was "*no recreational screen-time during daylight hours*" (33%). At baseline, boys reported higher autonomous motivation to limit their screen-time (mean = 4.5 ± 1.4), compared with controlled (mean = 3.4 ± 1.5) and amotivation (mean = 2.6 ± 1.6). Results of the single mediator models can be seen in Table 3.

Effect of the intervention on screen-time (Pathway C)

Values reported in the table and in text are unstandardized regression coefficients, adjusted for school-level clustering, socioeconomic position and baseline values. A significant intervention effect was observed for recreational screen-time at 8-months (C [SE] = -33 [7] mins/d; $p < .001$), which was sustained at 18-months (C [SE] = -27 [10] mins/d; $p = .007$).

Effect of the intervention on the potential mediators (Pathway A)

At both the mid-program and 18-month follow-up time points, there were no statistically significant intervention effects for controlled motivation, amotivation or screen-time rules. The effect of the intervention on autonomous motivation was also non-significant at mid-program (A [SE] = .22 (.16), *p* = .174), but became statistically significant at 18-months (A [SE] = .39 (.17), *p* = .019).

Associations between change in mediators and change in screen-time (Pathway B)

With the exception of controlled motivation at 18-months, changes in all potential mediators were significantly associated in the expected direction with changes in recreational screen-time at both post-intervention and 18-month follow-up.

Significance of the mediated effect (Pathway AB)

Based on the results of the product-of-coefficients test, there was a statistically significant mediated effect for autonomous motivation on recreational screen time at 18-months (AB [95% CI] = -5.54 [-11.60, -0.82]). All other mediated effects were non-significant. The proportion of the intervention effect mediated by autonomous motivation was 20.5%.

Multiple mediator model

The results of the multiple mediator models were consistent with the single mediator models, except for the associations between change in mediators and change in screen-time (i.e., Pathway B) which were no longer significant for autonomous and controlled motivation at 8-months, and amotivation at 18-months (Supplementary Table 1). When including all potential mediators together, the mediated effect for autonomous motivation to limit screen-time at 18-months was virtually unchanged (AB [95% CI] = -5.49 [-12.13, -0.70]; proportion mediated = 20.3%). Again, no other significant mediated effects were found.

DISCUSSION

The lack of intervention studies examining mechanisms of sedentary behavior change has been noted in the field (Altenburg et al., 2016; Van Stralen et al., 2011). In addition, the need for further intervention research with adolescents (> 13 years) has recently been emphasized (Buchanan et al., 2016). To address these gaps, the present study aimed to: (i) assess the impact of the ATLAS intervention on motivation to limit screen-time and the provision of parental screen-time rules; and (ii) determine the potential mediating effects of these variables on changes in recreational screen-time. Consistent with the goals of the intervention and the tenets of SDT, ATLAS had a positive impact on autonomous motivation to limit screen-time, and changes in autonomous motivation partially mediated the intervention effect on screen-time at 18-months. No significant intervention effects or mediated effects were found for the other motivational regulations or for screen-time rules.

Boys who participated in the ATLAS intervention reported reductions in screen-time and greater autonomous motivation to limit their screen-time at 18-months. In the present context, autonomous motivation reflects either a personal recognition of the consequences of excessive screen-time, a desire to engage in alternate activities that are more highly valued (e.g., physical activity, socialising), or both. The ATLAS intervention incorporated strategies to enhance each of these perceptions. For example, boys were educated about the adverse effects of excessive screen-time and informed of current screen-time recommendations. This information was reinforced by teachers during the physical activity sessions, and was further promoted through the goal setting and tailored messaging functions of the ATLAS app (Lubans et al., 2014). Although not widely used by all students, the ATLAS app appeared to help some students to manage their screen viewing behaviors (see process data in Table 1). Further, boys recalled 'limiting screen-time' as one of the key intervention messages in post-intervention focus groups (Lubans et al., 2014). In addition to the strategies targeting screen-time directly, the intervention aimed to support autonomous motivation for physical activity by satisfying participants' psychological needs for autonomy, competence and relatedness during the teacher delivered physical activity sessions. This approach may have encouraged participants to enjoy and see value in physical rather than sedentary leisure activities, and may in part explain our findings. The positive effects of the ATLAS intervention on boys' motivation for school sport (Lubans et al., 2016c), and their general satisfaction with the teacher-delivered physical activity sessions (Smith et al., 2014b) support this suggestion.

Interestingly, ATLAS did not have a significant impact on autonomous motivation at 4-months, and the mediated effect at the primary study endpoint (i.e., 8-months) was not statistically significant. The lack of a mediated effect at this time point is likely explained by our measurement protocols. We originally hypothesized there would be a substantial enough change in autonomous motivation at mid-intervention (i.e., 4-months) to influence screen-time at 8-months. This would be consistent with true mediation, in which the change in the mediator precedes and causes the change in the outcome. The magnitude of change in autonomous motivation was insufficient at this time to influence behavior, but clearly continued to grow thereafter. It is likely that motivational changes did not have large ‘acute’ effects on screen viewing, but instead became influential over time as boys’ screen-use gradually increased. At 18-months, both screen-time and the mediators were assessed together. Therefore, changes in autonomous motivation occurring over the entire study period were adequately captured. Intervention effects for controlled motivation and amotivation were also non-significant, which is not surprising considering that the intervention predominantly targeted autonomous motivation. It was thought there might be a significant change in controlled motivation within the intervention group, given the strategies aimed at promoting parental screen-time rules. However, the parent materials suggested the use of autonomy supportive strategies (e.g., role modelling expected behaviour, collaborative decision making, and providing a rationale for behavior change). Further, our analyses showed no significant effects for parental rules, suggesting ATLAS boys did not have a systematically different exposure to experiences that would influence their controlled motivation.

Motivation has recently been identified as one of a number of potential cognitive mediators of screen viewing behavior, and thus a potential target for interventions (Buchanan et al., 2016). Recently, the ‘Switch-off 4 Healthy Minds’ (S4HM) intervention (Babic et al., 2016) reported a significant impact on adolescents’ autonomous and controlled motivation to limit screen-time. Although the intervention effect on screen-time was non-significant, mediation analyses demonstrated that autonomous (but not controlled) motivation was a significant mediator of changes in screen-time. These findings are in line with those of the present study, which found changes in autonomous motivation accounted for approximately 20% of the intervention effect on screen-time at 18-months. Importantly, S4HM was relatively brief (i.e., 6-months), and the study sample was predominantly female and of middle-to-high socioeconomic position. Our results therefore extend on the S4HM study by replicating the findings among a distinctly different sample of adolescents, over a longer time period, and after achieving a significant impact on both the mediator (i.e., autonomous motivation) and the outcome (i.e., screen-time). Taken together, these findings support for the utility of SDT for guiding the design and delivery of sedentary behavior interventions, and argue for the inclusion of strategies that enhance autonomous motivation to limit screen-time.

Previous intervention studies among children and youth have provided some support for mediators from the Theory of Planned Behavior (i.e., attitudes, subjective norm, perceived behavioral control) and Habit Theory (i.e., habit strength) (Chinapaw et al., 2008), as well as for self-efficacy (Salmon et al., 2010) and motivation for physical activity (Spruijt-Metz et al., 2008). However, none of these prior studies report significant mediation effects, either due to a lack of intervention effect for the mediator (Chinapaw et al., 2008) or outcome (i.e., screen-time) (Salmon et al., 2010), or due to the lack of a significant indirect effect when mediation analysis is conducted (Spruijt-Metz et al., 2008). To the authors' knowledge motivation to limit screen-time is the only hypothesized mediator shown to significantly mediate changes in screen-time in an intervention for school-aged youth (Babic et al., 2016). However, it is important to recognize that autonomous motivation only accounted for one fifth of the intervention effect on screen-time. Therefore, it is likely that other unmeasured mediators of behavior change were also operating to cause the change in screen viewing that was observed.

In contrast to the findings for motivation, there was no impact on parental screen-time rules, and screen-time rules did not mediate the effect of the intervention on screen-time. Of interest, our analyses showed that changes in screen-time rules during the study period were significantly associated with changes in boys' screen-time. These results mirror those of the Norwegian Health in Adolescents (HEIA) trial (Bergh et al., 2014), which also found associations between changes in parental regulation of screen viewing and changes in adolescents' screen-time despite a lack of intervention effect for either. These results suggest parental rules are important for limiting young people's screen viewing, but also highlight the challenges of prompting parents to change their parenting practices. Previous research has suggested educating parents about screen-time recommendations, and encouraging them to set limits on screen-time at home may be viable strategies for reducing young people's screen-time (Carlson et al., 2010). Although ATLAS aimed to achieve just this, the low-dose of the parent-based component was insufficient to prompt meaningful changes. To have a significant impact on health-related parenting practices, more intensive intervention strategies involving contact via face-to-face, telephone, or engaging e-mediums may be required (O'Connor et al., 2009). However, screen-time rules may also be more difficult to implement in households with adolescents. The potential for family conflict is a clear barrier to the uptake of screen-time reduction strategies by parents (Evans et al., 2011), who may prioritize family harmony over their child's screen viewing, and may also not recognize excessive screen-time as a problematic behavior (Jordan et al., 2006; Rhodes, 2015).

ATLAS had both an immediate and sustained impact on boys' recreational screen-time, equating to an adjusted difference between groups of approximately 30 minutes per day (or 3 ½ hours per week). Notably, the control group increased their screen-time by close to an hour per day over 18-months, representing a 38% increase from baseline levels. These data highlight the significant changes in sedentary behavior that occur during adolescence, and underscore the importance of addressing screen viewing during the early teenage years. Recent European data have shown excessive screen-time during the transition to adolescence is a strong predictor of screen-time in early adulthood for boys (Busschaert et al., 2015). Compared to low screen users, boys exceeding screen-time recommendations at age 10 were found to be five times more likely to maintain unhealthy screen viewing practices 10 years later (Busschaert et al., 2015). The same association was not observed for girls. Intervening during the early teenage years may therefore have a substantial impact on the future health trajectory of young males, particularly for those already considered 'at-risk' of adverse outcomes (e.g., low-income, overweight, and high screen users). Indeed, we have previously shown that reductions in screen-time mediated improvements in wellbeing in the current study sample (Lubans et al., 2016b). This could be the result of boys exchanging screen-time for physical activity, which aligns with the mechanisms of change in mental health identified in a recently published conceptual model (Lubans et al., 2016a). However, there are multiple potential explanations for how reducing screen-time could influence mental health (e.g., by increasing sleep time or quality), which is an interesting area for future research.

While our findings for autonomous motivation are encouraging, there are a number of questions for future research. For example, ATLAS did not actually improve autonomous motivation, but instead attenuated a decline in motivation, which was larger in the control group. Future studies should examine whether intervention strategies can 'increase' motivation to limit screen-time, and should elucidate the most effective strategies for enhancing autonomous motives. In the present study, it was hypothesized that providing students with the skills and motivation to be active in their leisure-time would contribute to changes in motivation to limit screen-time and screen viewing. Recent research suggests interventions targeting screen-time alone, rather than multiple health behaviors, have been more effective (Buchanan et al., 2016). Yet, the S4HM intervention, which focused solely on screen-time, did not have a significant impact on students' screen-time, despite the positive impact on autonomous motivation. The lack of an effect in S4HM may be due to the overrepresentation of girls (i.e., 66% of sample). Previous interventions have significantly influenced girls' screen viewing behaviors (Lubans et al., 2012), but others have only shown effects for boys (Singh et al., 2009). As previously noted, screen-time is typically higher among adolescent boys, compared to girls (Morley et al., 2012). Due to their higher baseline levels, boys may have a greater propensity for change when exposed to interventions. However, it could also be that the most important mediators of screen behavior change differ by sex, which would further support the use of gender targeting strategies in future screen-time interventions. Finally, future research could examine the relationship between changes in motivation to limit screen-time and changes in other health-related outcomes, such as psychological wellbeing. SDT posits that the presence of autonomous motivation is reflective of enhanced wellbeing (Ryan & Deci, 2000). Reducing screen-time via the mechanism of motivation could have ripple effects on important psychological outcomes, which may be missed if interventions instead achieve behavioural changes through strategies that increase controlled motivation.

Strengths of the present study include the cluster RCT design and the use of robust multi-level statistical mediation analyses. However, there are limitations that should be noted. First, as screen-time was self-reported, there remains the possibility of socially desirable responses and recall bias. Second, the home-based component of the ATLAS intervention was low-dose (i.e., only 4 x newsletters over 20-weeks). Therefore, the lack of significant mediation effects for the parent-based strategies should not be misinterpreted as a lack of efficacy for targeting the home environment. More intensive intervention approaches may reduce adolescents' screen-time via this mechanism. However, parental adoption of screen-time rules may require a separate, more intensive intervention that may be challenging to integrate within a multi-component school-based program. Finally, our study sample was selected on the basis of a number of specific characteristics (i.e., low-income, males, inactive and/or high screen users). Therefore, replication of our findings in more heterogeneous populations is required.

CONCLUSIONS

The current study demonstrates a gender-targeted intervention conducted in the school setting can stem the increase in screen-time occurring during the early teenage years. Additionally, our findings suggest that enhancing autonomous motivation for limiting screen-time may be a useful strategy for addressing this widespread behavior, in particular, for adolescent males. Although substantial population-level change in young peoples' screen-viewing behaviors will likely require intervention at multiple levels (i.e., environmental, social and individual), our findings suggest an educational element promoting autonomous motivation to limit screen-time could form a valuable part of this multi-level approach.

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Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Table 1. Description of intervention components targeting recreational screen-time

Component	Description	Behavior change strategies	Mediators targeted
Teacher professional learning	During the pre-program professional learning workshop, teachers were informed of the ATLAS behavioral messages, one of which related directly to recreational screen-time (i.e., *limit your recreational screen-time*). Teachers were shown evidence of the consequences of excessive screen-time and were asked to reinforce this behavioral message during the physical activity sessions. Teachers were asked to focus on valued outcomes of behavior change, such as improved fitness, sports performance and social connectedness. Teachers reported very high satisfaction with this professional learning workshop (i.e., 5.0 ± 0.0, /5) (Smith et al., 2014b).	• Plan social support or change • General encouragement • Provide information about behavior health link • Information on consequences	• Autonomous motivation to limit screen-time
Researcher-led seminar	At the start of the intervention, boys attended an information seminar delivered at the study school by a member of the research team. The seminar outlined the behavioral messages, described the consequences of excessive screen-time, and highlighted current screen-time guidelines for school-aged youth. After 5-weeks, participants attended a second seminar which outlined the self-monitoring and goal setting functions of the ATLAS smartphone app. Participants were prompted to monitor their screen viewing and to set weekly incremental goals, aiming to limit daily screen-time to less than 2 hours by the end of the study period. All seminars were delivered as intended.	• Prompt self-monitoring • Prompt specific goal setting • Plan social support or social change • General encouragement • Provide information about behavior health link • Information on consequences	• Autonomous motivation to limit screen-time
Smartphone application and website	Participants were given free access to a purpose-built smartphone app (Lubans et al., 2014). The app included functions for self-monitoring of screen-time and goal-setting. When first downloading the app, boys were prompted to select the two most salient reasons (from four options) for changing their health behaviors. Tailored informational and motivational messages designed to provide a rationale for behavior change and encourage boys to limit their screen-time were sent twice per week for 15 weeks. Approximately two thirds of boys reported using the app (although use tended to be short-term), and goal setting for screen-time and physical	• Prompt self-monitoring • Prompt specific goal setting • General encouragement • Provide information about behavior health link • Information on consequences	• Autonomous motivation to limit screen-time

	activity were the most commonly used functions (i.e., 70% of users). Close to half of the boys agreed or strongly agreed the push prompt messages reminded them about the behavioral messages, including limiting screen-time.		
Parental newsletters	Parents of study participants were mailed four newsletters over the 20-week intervention period. The newsletter series provided information on the consequences of excessive screen-time for youth, practical strategies for managing screen-time in the family home, and advice for dealing with conflict when implementing restrictions on screen-time. The first newsletter included a screen-time behavior contract and instructions for parents to use with their child. All four newsletters were successfully sent to 86% of parents (Smith et al., 2014b).	• Plan social support or social change • General encouragement • Provide information about behavior health link • Behavior contract	• Autonomous motivation to limit screen-time • Controlled motivation to limit screen-time • Screen-time rules

Table 2. Mean (SD) values of potential mediators and screen-time for intervention and control groups

Variable	Baseline, Mean (SD)	4-months[c] Mean (SD)	18-months Mean (SD)
Autonomous motivation[a]			
Intervention	4.6 (1.4)	4.2 (1.4)	4.2 (1.3)
Control	4.4 (1.4)	3.8 (1.5)	3.7 (1.6)
Controlled motivation[a]			
Intervention	3.4 (1.5)	2.9 (1.4)	3.1 (1.3)
Control	3.4 (1.4)	2.8 (1.4)	2.8 (1.4)
Amotivation[a]			
Intervention	2.4 (1.4)	2.7 (1.5)	2.4 (1.3)
Control	2.9 (1.7)	3.1 (1.8)	2.6 (1.5)
Screen-time rules[b]			
Intervention	1.4 (0.9)	1.2 (0.8)	1.1 (0.9)
Control	1.4 (0.9)	1.2 (1.0)	1.0 (1.0)
Recreational screen-time (mins/d)			
Intervention	118 (78)	124 (67)	145 (82)*
Control	136 (97)	167 (103)*	188 (128)*

[a] Possible values range from 1 to 7
[b] Possible values range from 0 to 3
[c] Recreational screen-time was assessed at 8-months
*Statistically significant within-group change from baseline at $p < .05$

Table 3: Results of the single mediator models for motivation to limit screen-time and screen-time rules

Mediators	**Treatment on mediator**		**Mediator on screen-time**		**Treatment on screen-time**		**Mediated effect**	
	A (SE)	***p*-value**	**B (SE)**	***p*-value**	**C' (SE)**	***p*-value**	**AB**	**95% CI**
Autonomous motivation								
8-months	.22 (.16)	.174	**-11.5 (4.0)**	**.004**	**-23.0 (6.5)**	**< .001**	-2.55	-7.45 to 1.08
18-months	**.39 (.17)**	**.019**	**-14.1 (3.4)**	**< .001**	-21.7 (11.1)	.050	**-5.54**	**-11.60 to -0.82**
Controlled motivation								
8-months	.16 (.14)	.257	**-5.4 (2.1)**	**.013**	**-31.8 (7.4)**	**< .001**	-0.86	-2.87 to 0.617
18-months	.27 (.16)	.080	-4.5 (4.6)	.328	**-25.8 (10.5)**	**.014**	-1.22	-5.09 to 1.36
Amotivation								
8-months	-.22 (.21)	.314	**10.9 (2.0)**	**< .001**	**-24.5 (6.8)**	**< .001**	-2.40	-7.30 to 2.09
18-months	-.19 (.16)	.226	**10.4 (3.9)**	**.007**	**-24.0 (10.4)**	**.021**	-1.98	-6.36 to 1.28
Screen-time rules								
8-months	-.03 (.09)	.746	**-11.1 (3.3)**	**.001**	**-32.7 (7.3)**	**< .001**	0.33	-1.72 to 2.53
18-months	.03 (.11)	.815	**-17.1 (4.9)**	**< .001**	**-27.4 (10.5)**	**.009**	-0.51	-4.59 to 3.36

Note. Statistically significant pathways appear in bold text. Control and intervention groups were coded '1' and '2' respectively; A = estimate of unstandardized regression coefficient of treatment condition predicting change in mediators; B = estimate of unstandardized regression coefficient of the relationship between changes in mediators and changes in recreational screen-time; AB = product-of-coefficients estimate; C' = estimate of unstandardized regression coefficient of treatment condition predicting recreational screen-time with adjustment for mediator; SE = standard error, 95% CI = 95% confidence interval of the mediated effect.

Supplementary Table 1. Results of the multiple mediator models for motivation to limit screen-time and screen-time rules

Mediators	Treatment on mediator		Mediator on screen-time		Treatment on screen-time		Mediated effect	
	A (SE)	*p*-value	B (SE)	*p*-value	C' (SE)	*p*-value	AB	95% CI
Autonomous motivation								
8-months	.22 (.16)	.174	-7.2 (4.5)	.111	**-27.1 (6.9)**	**< .001**	-1.58	-5.65 to 0.88
18-months	**.39 (.17)**	**.019**	**-14.1 (4.2)**	**.001**	-21.6 (11.4)	.058	**-5.49**	**-12.13 to -0.70**
Controlled motivation								
8-months	.16 (.14)	.257	1.7 (2.4)	.469	**-27.1 (6.9)**	**< .001**	0.27	-0.67 to 1.66
18-months	.27 (.16)	.080	6.2 (5.0)	.216	-21.6 (11.4)	.058	1.67	-1.12 to 6.15
Amotivation								
8-months	-.22 (.21)	.314	**8.4 (1.9)**	**< .001**	**-27.1 (6.9)**	**< .001**	-1.85	-5.78 to 1.61
18-months	-.19 (.16)	.226	4.6 (3.6)	.202	-21.6 (11.4)	.058	-0.87	-3.72 to 0.86
Screen-time rules								
8-months	-.03 (.09)	.746	**-5.1 (2.6)**	**.048**	**-27.1 (6.9)**	**< .001**	0.15	-0.87 to 1.32
18-months	.03 (.11)	.815	**-16.1 (5.8)**	**.006**	-21.6 (11.4)	.058	-0.48	-4.50 to 3.26

Note. Statistically significant pathways appear in bold text. Control and intervention groups were coded '1' and '2' respectively; A = estimate of unstandardized regression coefficient of treatment condition predicting change in mediators; B = estimate of unstandardized regression coefficient of the relationship between changes in mediators and changes in recreational screen-time; AB = product-of-coefficients estimate; C' = estimate of unstandardized regression coefficient of treatment condition predicting recreational screen-time with adjustment for mediator; SE = standard error, 95% CI = 95% confidence interval of the mediated effect.

Figure captions:

Figure 1. Proposed mediation pathways and coefficients