Computers in Human Behavior 132 (2022) 107252

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Longitudinal relations between gaming, physical activity, and athletic self-esteem☆

Beate W. Hygen[a,c,*], Jay Belsky[b], Frode Stenseng[a,d], Silje Steinsbekk[a], Lars Wichstrøm[a,e], Vera Skalicka[a]

[a] *Norwegian University of Science and Technology, Norway*
[b] *University of California, Davis, United States*
[c] *NTNU Social Research, Norway*
[d] *Queen Maud University College, Norway*
[e] *St. Olavs Hospital, Norway*

ARTICLE INFO

Keywords:
Gaming
Physical activity
Self-esteem
Reciprocal

ABSTRACT

Background: Youth are increasingly engaged in digital games; while physical activity rates are declining. This study examines whether the amount of time children spend on gaming is related to physical activity and athletic self-esteem.

Method: At ages 8, 10, 12, and 14, a community sample of children (n = 751, 379 girls) was interviewed about how often they played digital games, completed questionnaires regarding their athletic self-esteem and wore an accelerometer to measure physical activity.

Results: A random intercept cross-lagged panel model using the participants as their own controls adjusting for all time-invariant potential confounding factors, revealed that increased gaming predicted reduced athletic self-esteem ($B = -0.17$, 95% CI: 0.26 to −0.10). Among boys aged 10 years, increased moderate and vigorous physical activity (MVPA) predicted decreased gaming ($B = -0.64$, 95% CI: 1.12 to −0.16) whereas increased gaming predicted reduced MVPA at the age of 12 ($B = -0.08$, 95% CI: 0.12 to −0.03). These effects remained evident two years later via stability in gaming and MVPA.

Conclusions: Findings suggest a developmental window for boys in middle childhood during which changes in physical activity and gaming result in longer-term cascades that endure into adolescence: increased gaming predicts reduced MVPA, whereas reduced MVPA predicts increased gaming.

1. Introduction

Digital games are widely popular and central to the lives of many children and adolescents. In the United States, 91% of children and youth play digital games, devoting a substantial amount of their time to them (Rideout et al., 2020; The NPD Group TN, 2020). At the same time, physical activity (PA) rates are declining among children (Bassett et al., 2015), which raises concern, as moderate and vigorous physical activity (MVPA) in particular is beneficial for children's and adolescents' health (Carson et al., 2016), benefits that extend into adulthood (Kwon et al., 2015). These observations have led policymakers, interventionists, health workers, and parents alike to wonder whether reducing gaming would lead to increased MVPA. Although PA and any type of sedentariness are inversely related (Pearson et al., 2014), the specific relation between *gaming* and PA needs clarification, including whether these two activities are reciprocally related.

☆ Beate Wold Hygen, Department of Psychology, Norwegian University of Science and Technology, NTNU Social Research, Norway; Jay Belsky, Department of Human Ecology, University of California, Davis; Frode Stenseng, Department of Education and Lifelong Learning, Norwegian University of Science and Technology, Queen Maud University College, Trondheim, Norway ; Vera Skalicka, Department of Psychology, Norwegian University of Science and Technology; Silje Steinsbekk, Department of Psychology, Norwegian University of Science and Technology; Lars Wichstrøm, Department of Psychology, Norwegian University of Science and Technology, Department of Child and Adolescent Mental Health, St. Olavs Hospital. This research was supported by grants 240097 and ES611813 from the Research Council of Norway and by a grant from the Liaison Committee between Central Norway RHA and NTNU. The study was approved by the Regional Committee for Medical and Health Research Ethics, Mid-Norway.

* Corresponding author. NTNU Social Research, NTNU, N-7491, Trondheim, Norway.
E-mail address: beate.hygen@samforsk.no (B.W. Hygen).

https://doi.org/10.1016/j.chb.2022.107252
Received 12 August 2021; Received in revised form 21 February 2022; Accepted 24 February 2022
Available online 26 February 2022
0747-5632/

According to the displacement hypothesis (Neuman, 1988), more time spent gaming may leave less time for PA. However, it might just as well be the case that less physically active children are prone to game more. Indeed, there are likely substantial selection effects regarding who does and does not become heavily involved in gaming (Wichstrøm et al., 2019). Sports and nonorganized PA constitute an important arena for social interaction and mastery in childhood and build athletic self-esteem. In turn, high athletic self-esteem may increase involvement in sports and PA (Inchley et al., 2011). Conceivably, at the other end of the continuum, a child who perceives herself or himself to have limited athletic competence may pursue alternative activities, including gaming.

It is also possible that those who game more may have less time to spend on PA and therefore develop less athletic self-esteem due to lack of practice. Athletic self-esteem (perceived competence in sports and other physical activities) is one of the domain-specific self-perceptions that seems to influence global self-esteem (Marsh, 1990). Global self-esteem denotes the overall evaluation of oneself and reflects beliefs about how worthy one is as a person, which is related to positive outcomes such as improved mental health (e.g., Sowislo & Orth, 2013). It is therefore important to reveal whether gaming negatively impacts athletic self-esteem, as we do here (Harter, 2012). Important to appreciate is that some or all associations linking gaming, athletic self-esteem and PA may be artifacts of a range of confounders, which are difficult to control in observational studies (e.g., genetics (Butković et al., 2017)). We therefore extend the research in this area by adjusting for all unmeasured time-invariant confounding factors (Hamaker et al., 2015), including genetics. By using children as their own controls, we ask whether *changes* in MVPA, gaming, and athletic self-esteem predict later *changes* in the same constructs. Based on the preceding analysis and using a large community sample of Norwegian children assessed at ages 8, 10, 12 and 14 years, we hypothesized that (1) increased gaming predicts reduced MVPA and athletic self-esteem and (2) decreased MVPA and athletic self-esteem predict increased gaming. Furthermore, we expected that (3) these associations would be stronger in boys than girls due to gender disparities in time spent gaming (Lemmens et al., 2011), the alleged effects of gaming (Hygen et al., 2019), PA (Hallal et al., 2012; Trost et al., 2002), and of athletic self-esteem (Gentile et al., 2009).

2. Materials and methods

2.1. Study design

The present work is derived from the the Trondheim Early Secure Study (TESS), a longitudinal cohort study of the psychosocial development of children and adolescents (Steinsbekk and Wichstrøm, 2018). Information from children, their parents and teachers have been collected biennially since the children were 4-years of age. This report uses data obtained at ages 8 (**T3,** n = 704), 10 (**T4**, n = 703), 12 (**T5**, n = 666) and 14 (**T6**, n = 636) years, respectively Data collected when participants were 4 and 6 years of age were omitted from due to the infrequent gaming at these timepoints (Age 4: 6.5 min per day, 95% CI: 5.5 to 7.6; Age 6: 21.5 min per day, 95% CI: 19.7–23.4 min per day).

2.2. Participants, recruitment, and procedure

Parents of the 2003 and 2004 birth cohorts in Trondheim, Norway (N = 3456) were invited to participate in the TESS study. In total, 3358 families presented at the well-child clinic for the scheduled 4-year-old health check-up. A health nurse obtained written informed consent to participate. Parents ($n = 176$) with insufficient proficiency in Norwegian language were excluded, and nurses did not invite 166 parents; ultimately, 2475 parents consented (82.1% of eligible parents).

Because a primary aim of the TESS study was to study child mental health, children with emotional and behavioral problems were oversampled. Thus, the parent-completed Strength and Difficulties Questionnaire (SDQ: Goodman, 1997) and the children's total problem scores were divided into four strata. The probability of being included in the study increased with increasing behavioral problems, but in the analyses, the data were weighted back to correct for population estimates. Based on the above procedures, 1250 families were drawn to participate, and 1007 families were successfully enrolled at time 1 (T1, see Fig. 1 for a complete overview of recruitment and follow-up for the TESS study). The dropout rate from consent to enrollment did not vary by SDQ stratum ($\chi^2 = 5.70$, $df = 3$, $p = .13$) or gender ($\chi^2 = 0.23$, $df = 1$, $p = .63$). In total, 751 children had useable data from at least 1 measurement and constituted the analytical sample.

2.3. Measures

2.3.1. Time spent gaming

Interviews were administered to parents when children were 8 years and to children when children were 10, 12 and 14 years old; the questions asked about how often the child played digital games (on tablets, PCs, game consoles, and phones) in terms of days per week and average time spent per day (hours and minutes). These data were summed and are presented as hours of gaming per day.

2.3.2. Athletic self-esteem

Children completed the Self-Description Questionnaire I (SDQ I; Marsh et al., 1984) at ages 8 and 10, from which we used the Physical self-esteem subscale (e.g., "I can run fast"), which is rated on a five-point scale (1 = False, 5 = True). Research indicates that SDQ I is both reliable and valid (e.g., Arens et al., 2013), and the measure displayed good internal consistency in the present study (α = 0.83 and 0.85 at ages 8 and 10, respectively). To obtain a more developmentally appropriate measure at ages 12 and 14, the corresponding subscales of the Revised Self-Perception Profile for Adolescents (SPPA; Wichstrøm, 1995) (α = 0.74 and 0.81) was used. This questionnaire has also been shown to be reliable and valid (Wichstrøm, 1995). To examine whether the instruments SDQ-I and SPPA captured the same construct, they were both applied at age 12. The correlation between the two subscales corrected for attenuation (Muchinsky, 1996) was $r = 0.84$ ($p \le .001$). Z-scores were applied in the analyses.

2.3.3. Moderate and vigorous physical activity (MVPA)

The children wore an ActiGraph GT3X accelerometer (Manufacturing Technology, Inc., Fort Walton Beach, FL) around their waists for 7 successive days, 24 h per day (except when bathing or showering). Only daytime activity (06:00–23.59) was included in the analysis. As recommended, sequences of consecutive zero counts lasting ≥20 min were interpreted as nonwear time, and only children with ≥3 days of recordings and ≥480 min of activity each day were included (Cain et al., 2013). Because children's activity often consists of short bursts, we employed the commonly used 10-s epoch length (Cain et al., 2013). The Evenson et al. (2008) cutoff point of ≥2296 counts per minute for MVPA was used because it has shown superior classification ability in children across the ages relevant to the current study (Trost et al., 2011). MVPA was represented in hours per day. Data were processed using accelerometer analysis software (ActiGraph LLC, Pensacola, FL).

2.4. Data analysis

To account for the stratification at screening, analyses were weighted with a factor corresponding to the number of children in the population divided by the number of children in the stratum. A robust maximum likelihood estimator was used, and missingness was handled with full information maximum likelihood estimation (FIML).

We fitted a random intercept cross-lagged panel model (RI-CPLM: Hamaker et al., 2015) within a structural equation framework using Mplus 7.4. (Muthén & Muthén, 1998-2012). This model extends the

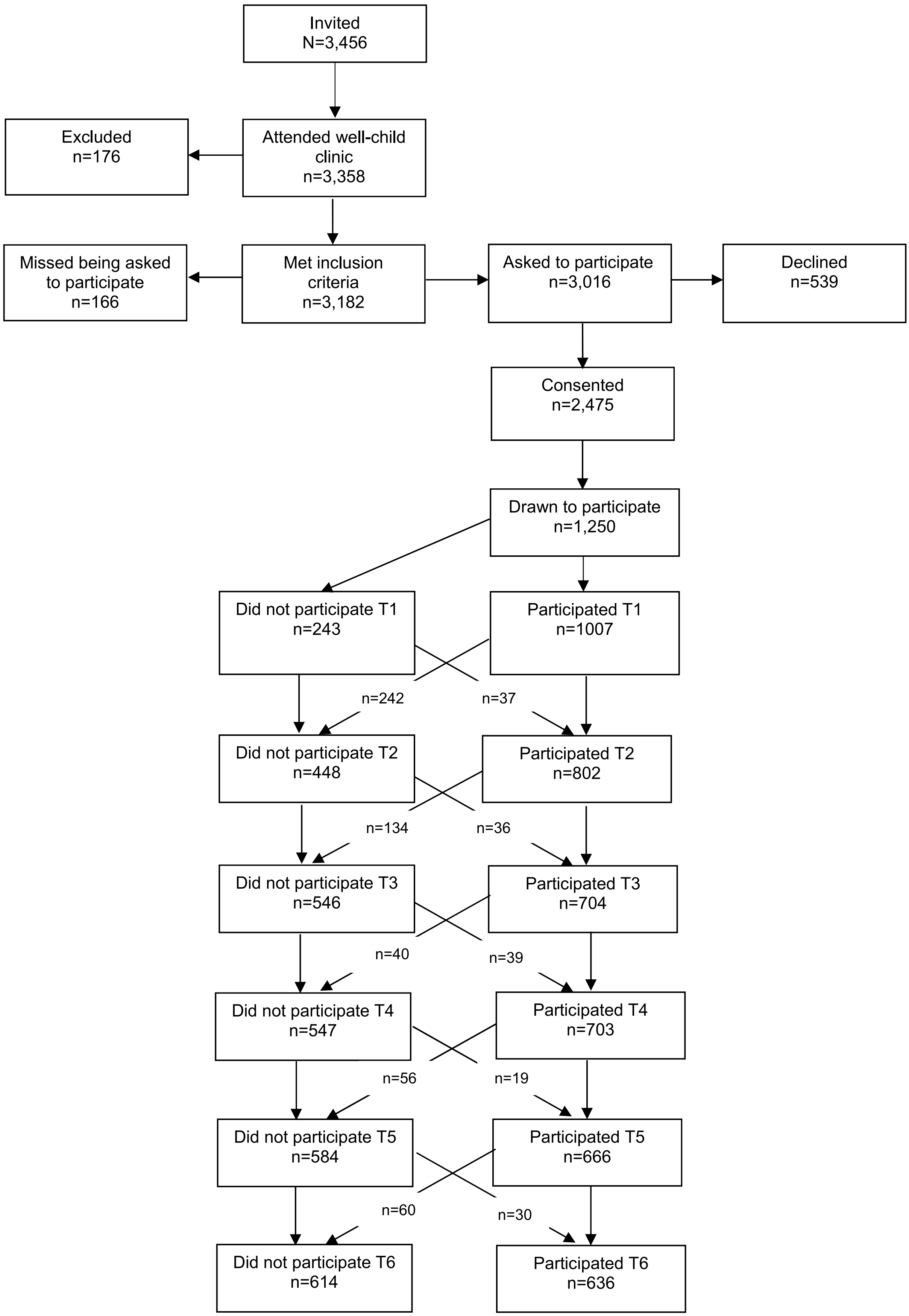

Fig. 1. Flow chart of recruitment and follow-up.

traditional autoregressive cross-lagged model consisting of reciprocal relations between gaming, athletic self-esteem and MVPA by separating variance into a stable *between-person* component (represented by three latent random intercepts loaded on the measures of gaming, athletic self-esteem, and MVPA at all time points) and a *within-person* component, which assesses changes from one's own mean level at t_i (e.g., MVPA) as a function of changes in one's own levels of the other two variables (e.g., gaming and self-esteem—cross-lagged effects) and the outcome (e.g., MVPA—autoregressive effect) at t_{i-1} (Fig. 2). In the mediation analyses, using Sobel's test, we controlled for direct cross-lagged effects across three time points (e.g., from age 10 to age 14). To test whether there were any differences in the magnitude of the cross-lagged paths between boys and girls, we applied the Satorra-Bentler scaled χ^2 test (Satorra & Bentler, 2001).

3. Results

The sample characteristics and descriptive statistics of the study variables are presented in Table 1. At all ages, the boys reported higher athletic self-esteem and spent more time on gaming and MVPA than the girls. Greater gaming at ages 10 and 12 was significantly correlated with lower athletic self-esteem (at all ages). Greater gaming at ages 10, 12 and 14 years correlated with lower MVPA at ages 12 and 14 years (Table 2).

The tested model (i.e., the RI-CLPM) fitted the data well (χ^2 (20) = 45.593, $P < .001$, RMSEA = 0.041, SRMR = 0.030, CFI = 0.983, TLI = 0.945). At the between-person level, a higher level of gaming was associated with lower athletic self-esteem ($r = -0.08$, 95% CI: 0.15 to −0.02) and lower MVPA ($r = -0.03$, 95% CI: 0.05 to −0.01), whereas greater athletic self-esteem was associated with more MVPA ($r = 0.07$, 95% CI: 0.04–0.10). These associations indicate that youth who spend more time gaming spend less time on MVPA and have lower athletic self-esteem over time.

Results indicate that at the within-person level, increased gaming at age 10 predicted reduced MVPA and athletic self-esteem at age 12 (Fig. 3). Improved athletic self-esteem at age 10 predicted increased MVPA at age 12, and increased MVPA at age 12 in turn predicted enhanced athletic self-esteem at age 14. Notably, reduced MVPA at age 12 ($B = -0.02$, 95% CI: 0.05 to −0.003) as well as reduced athletic self-esteem at age 12 ($B = -0.07$, 95% CI: 0.11 to −0.03) mediated the effect of increased gaming at age 10 on reduced athletic self-esteem at age 14; additionally, reduced MVPA at age 12 mediated the effect of increased gaming at age 10 on reduced MVPA at age 14 ($B = -0.01$, 95% CI: 0.02 to 0.00).

Especially important was that multigroup analyses for each gender revealed that for boys–but not girls–increased gaming at age 10 predicted decreased MVPA at age 12 ($B = -0.08$, 95% CI: 0.12 to −0.03) and that increased MVPA at age 10 predicted decreased gaming at age 12 ($B = -0.64$, 95% CI: 1.12 to −0.16). These paths were stronger for boys than for girls (girls: $B = -0.02$, 95% CI: 0.06–0.02; gender difference: $\Delta\chi^2 = 26.66$ [1], $P < .001$; girls: $B = 0.22$, 95% CI: 0.28–0.73; gender difference: $\Delta\chi^2 = 11.71$ [1], $P = .001$; see Figs. 4 and 5 for details). For boys but not girls ($Z = -0.55$; $P = .015$), the effect of MVPA at age 10 on gaming at age 14 was mediated by gaming at age 12 ($B = -0.46$, 95% CI: 0.81 to −0.11).

4. Discussion

Given the recent increase in gaming and decrease in PA among children, we examined—for the first time—prospective reciprocal relations between time spent gaming, MVPA and athletic self-esteem, drawing on longitudinal data from age 8–14 years in a sizable community sample. As hypothesized, increased gaming predicted decreased athletic self-esteem. Moreover, increased gaming predicted reduced MVPA, and increased MVPA predicted decreased time spent gaming. The reciprocal effects between gaming and MVPA held only for boys, however. Notably, all predictions mentioned above emerged in early adolescence (from age 10–12 years). Finally, mediation effects were detected. Just as important was that these findings emerged when individuals served as their own controls, with individual change predicting subsequent individual change.

4.1. Increased gaming predicts decreased athletic self-esteem

Perceiving oneself as skillful and successful in physical activities (i.e., positive athletic self-esteem) to some extent reflects actual performance

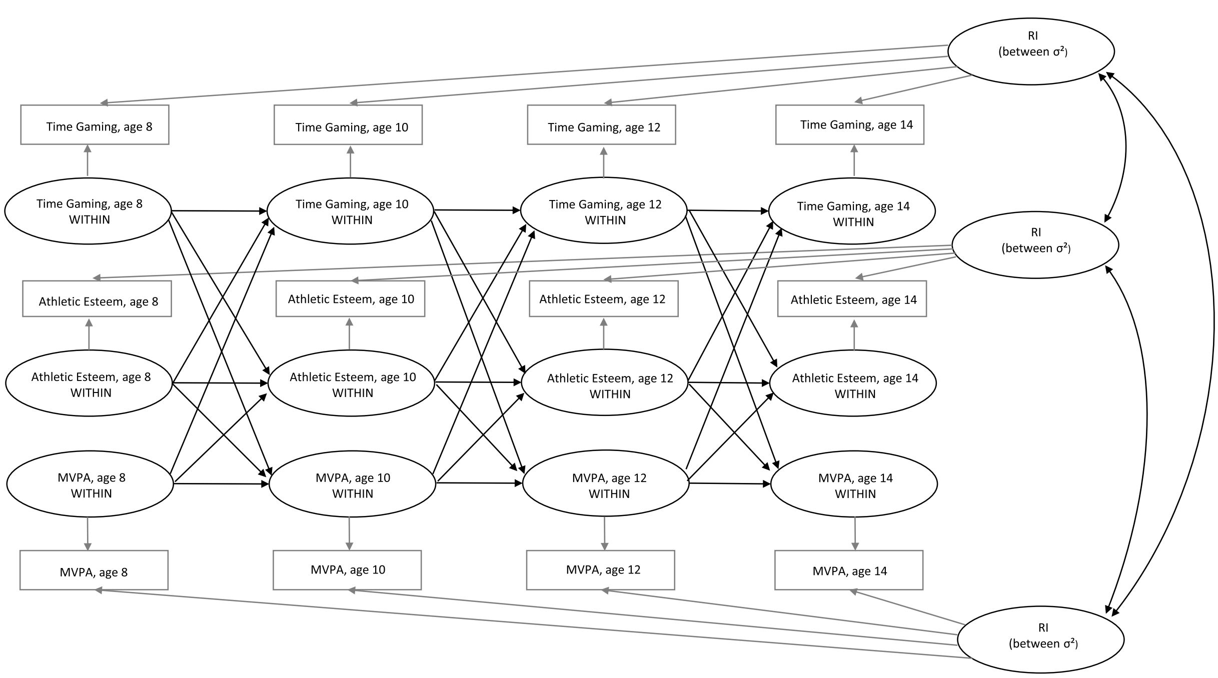

Fig. 2. Theoretical random intercept model of gaming, athletic self-esteem and MVPA.
Note. σ^2 = variance.

Table 1
Sample characteristics and descriptive characteristics of the study variables.

Sample Descriptive Statistics	%	Study Variables	Min-max	Total Sample M	Total Sample SD	Boys M	Boys SD	Girls M	Girls SD
Gender of child		Gaming, age 8	0–4.53	0.67	0.66	0.85	0.72	0.52	0.54
Male	49.6	Gaming, age 10	0–6.57	0.98	1.02	1.23	1.11	0.76	0.87
Female	50.4	Gaming, age 12	0–9.39	1.46	1.48	2.11	1.53	0.83	1.11
Parental highest socioeconomic position		Gaming, age 14	0–9.81	2.01	2.12	3.19	2.12	0.86	1.33
Skilled or unskilled worker	17.4	Athletic self-esteem, age 8	1.50–5.00	4.37	0.63	4.45	0.59	4.23	0.64
Lower professional	33.5	Athletic self-esteem, age 10	1.00–5.00	4.25	0.65	4.42	0.57	4.10	0.67
Higher professional	34.0	Athletic self-esteem, age 12	1.00–4.00	2.79	0.54	2.87	0.53	2.72	0.55
Leader	15.1	Athletic self-esteem, age 14	1.00–4.00	2.68	0.62	2.84	0.57	2.54	0.63
Ethnic origin of biological mother		MVPA, age 8	0.22–4.20	1.18	0.43	1.33	0.46	1.04	0.35
Norwegian	93.1	MVPA, age 10	0.18–2.93	1.09	0.39	1.22	0.41	0.98	0.35
Western country	3.5	MVPA, age 12	0.21–2.42	1.00	0.38	1.07	0.41	0.94	0.34
Other country	3.4	MVPA, age 14	0.06–2.19	0.90	0.37	0.96	0.39	0.85	0.34

Table 2
Correlations between the study variables.

Study Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Gaming, age 8	–												
2. Gaming, age 10	.35***	–											
3. Gaming, age 12	.31***	.43***	–										
4. Gaming, age 14	.32***	.33***	.65***	–									
5. Athletic self-esteem, age 8	.09*	-.11*	-.15*	-.06	–								
6. Athletic self-esteem, age 10	-.05	-.11**	-.11*	.05*	.54***	–							
7. Athletic self-esteem, age 12	-.06	-.21**	-.20**	-.11	.42***	.51***	–						
8. Athletic self-esteem, age 14	-.06	-.10**	-.12*	-.05	.34***	.46***	.64***	–					
9. MVPA, age 8	.03	.02	.03	.08	.23***	.24***	.22***	.30***	–				
10. MVPA, age 10	.01	-.05	-.09	.06	.20**	.26***	.25***	.29***	.46***	–			
11. MVPA, age 12	-.07	-.18**	-.21***	-.09*	.25***	.30***	.33***	.38***	.35***	.49***	–		
12. MVPA, age 14	-.05	-.17**	-.15**	-.18**	.14**	.13**	.24***	.32***	.27***	.36***	.49***	–	
13. Gender	-.25**	-.21**	-.43***	-.56***	-.17**	-.25***	-.15**	-.24***	-.34***	-.31**	-.19**	-.16**	–

* ≤ 0.05, **≤ 0.01, ***≤ 0.001 Boys = 1, Girls = 2: MVPA* and gaming are measured in hours per day.
*Moderate and vigorous physical activity.

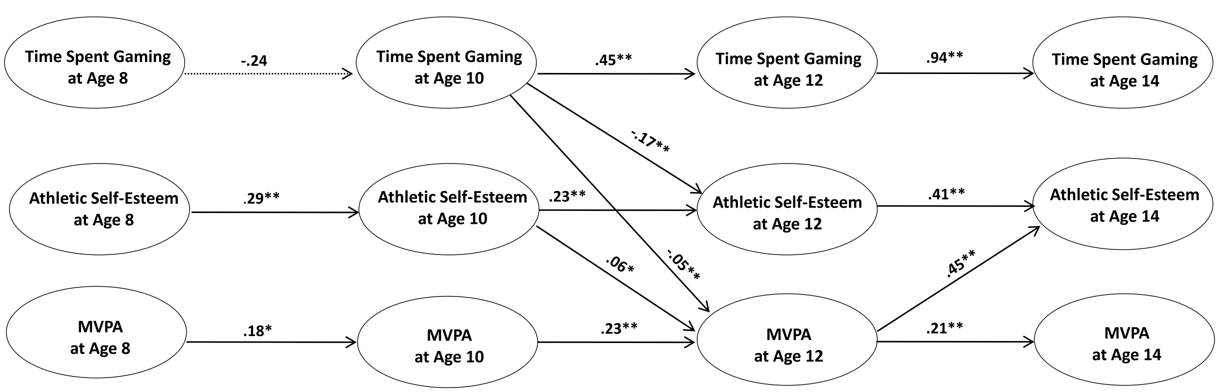

Fig. 3. Within-Person Unstandardized Estimates from the Random Intercept Model of All Children. Nonsignificant Paths and Cross-Sectional Correlations are Omitted.
Note. *p < .05, **p < .01.

(Babic et al., 2014). It is conceivable that increased gaming will displace previous time spent engaged in sports, learning and practicing new athletic skills, resulting in reduced athletic performance and therefore less positive feedback on one's skills from others and a less positive view of one's own athletic abilities. Given these processes, the result will likely be impaired athletic self-esteem. Furthermore, an adolescent who games more than others may hold an identity as a "gamer" (Shaw, 2012) (e.g., as opposed to a "sportsman"), and being successful in gaming may become central to one's overall self-worth. Other domains of the self may therefore become less important, including athletics.

4.2. Increased gaming predicts decreased MVPA in boys

As suggested by the displacement hypothesis (Neuman, 1988), the reason for increased gaming predicting decreased MVPA in boys might be that time is limited. When one spends a large amount of time gaming, he or she will inevitably have less time for other activities, including those associated with MVPA, such as sports and outdoor activities. Our results, like those of others (e.g., Lemmens et al., 2011), revealed that boys spend much more time gaming than girls. If a girl increases her gaming, the time usage might still be inconsequential with respect to maintaining participation in competitive sports. However, if a boy increases his gaming—starting from an already high level—he might

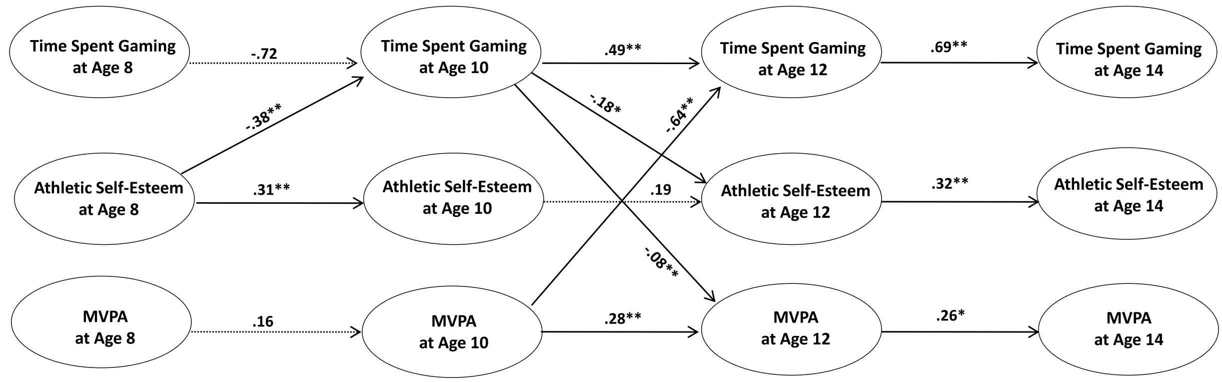

Fig. 4. Within-Person Unstandardized Estimates from the Random Intercept Model of Boys. Nonsignificant Paths and Cross-Sectional Correlations are Omitted. *Note.* *p < .05, **p < .01.

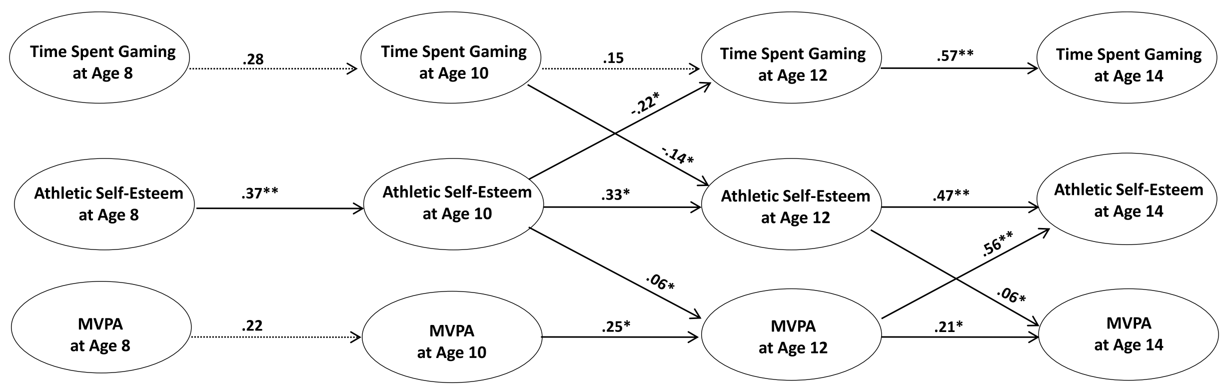

Fig. 5. Within-Person Unstandardized Estimates from the Random Intercept Model of Girls. Nonsignificant Paths and Cross-Sectional Correlations are Omitted. *Note.* *p < .05, **p < .01.

reach a tipping point at which he starts skipping training sessions; it becomes difficult to keep up with his teammates, practicewise and thus performancewise; and the commitment and sense of belongingness to his team might be impaired. In sum, this may increase the risk of dropping out of sports, which is related to reduced MVPA (Nelson et al., 2011). Notably, participation in extracurricular sports is protective against decreases in PA over time among boys but not girls (Telford et al., 2016). Relatedly, increased gaming may displace other activities in not only time but also interest. Losing interest in other leisure time activities is a symptom of Internet gaming disorder (American Psychiatric Association, 2013). Indeed, loss of interest is known to occur in a proportion of those most heavily involved in gaming (Kim et al., 2016; Wichstrøm et al., 2019). However, changing interests is also a normal part of adolescence (Jarus et al., 2010) that occurs in a much larger share of youth than those with pathological gaming behavior. Therefore, increased gaming may solidify a gamer identity at the expense of a sports or "jock" identity, facilitating the transition away from MVPA.

Another explanation for the reduced MVPA among boys may be that gaming is a social arena for boys more so than for girls. Hence, boy gamers may meet friends through gaming and depend less on other involvements to maintain relationships, potentially reinforcing their interest in gaming. Indeed, gamers report that online gaming fosters offline contact (Trepte et al., 2012). The opposite direction of influence is also possible: gaming may lead to a decrease in the quality of interpersonal relationships (Lo et al., 2005). This decreased quality of relationships may lead to reduced motivation to participate in (team-based) MVPA because of the lack of good friends to engage with.

4.3. Increased MVPA predicts decreased gaming in boys

Notably, displacement is related not only to gaming but also to MVPA. Those continuing in organized sports in adolescence may have less time to game. As a complimentary process, boys who succeed in sports may maintain an identity as an "athlete" or "soccer player" and therefore be less inclined to spend much time gaming. Reinforcing cycles may certainly be at play. However, why was this relation discerned only among boys? The most obvious reason might be that boys participate in sports more than girls (Slater & Tiggemann, 2011), which may be reflected in the boys' higher MVPA demonstrated in this study. With increasing age, high levels of MVPA may place more demands on boys timewise, leaving less time for them to game. Furthermore, because girls generally game less than boys (Hygen et al., 2019) increased levels of MVPA among girls may affect activities other than gaming (e.g., spending less time with friends). Engaging in sports may also satisfy the need for competitive and fun activities (Kuss, 2013). For these reasons, gaming may be of less interest for those with high levels of MVPA.

4.4. Mediation effects

In addition to the direct path, by which increased gaming at age 10 led to decreased athletic self-esteem at age 12, gaming at age 10 also predicted a longer-term reduction in athletic self-esteem at age 14 via reduced MVPA at age 12. This finding underscores the aforementioned notion that the effect of gaming on diminished athletic self-esteem can be explained by reduced MVPA, which in turn erodes confidence in one's physical abilities.

Notably, we also found that reduced athletic self-esteem at age 12 mediated the relation between increased gaming at age 10 and later reduced athletic self-esteem at age 14. Thus, more time spent gaming predicted a reduction in athletic self-esteem two years later, and once established, reduced athletic self-esteem appears to undermine later self-esteem. The same effect applied for MVPA in that greater gaming predicted decreased MVPA at age 12, which in turn predicted even lower MVPA two years later. Results thus suggest that increased gaming in middle childhood may initiate a negative cycle undermining athletic self-esteem while reducing MVPA.

Just as interesting was the reciprocal effect for boys, with lower MVPA at age 10 predicting increased gaming age 12, which itself predicted further increases in gaming by age 14. Perhaps less active young boys seek out or prefer gaming, which again may increase later gaming.

The findings of the mediation analyses support the view that increases in gaming activities at age 10 would seem to have long-term consequences for both MVPA and athletic self-esteem, whereas increases in MVPA at age 10 would seem to exert long-term effects by reducing gaming. Therefore, children's choices and preferences regarding leisure activities in middle childhood would seem to place children on different developmental trajectories that extend at least into adolescence.

The present results add to previous research chronicling gaming in youth to be cross-sectionally correlated with sedentary behavior (Rudolf et al., 2020). Sedentary activity such as gaming will inevitably make less time for physical activity at that very day, a finding echoed in a meta-analytic study showing gaming in youth to be correlated with reduced MVPA in boys (Melkevik et al., 2010). However, cross-sectional findings cannot shed light on whether gaming specifically forecasts prospective MVPA or *vice versa*–knowledge needed for implementing interventions and informing on theory development. As far as we know, this is the first study to examine how gaming, MVPA and athletic self-esteem may predict each other over time during the important developmental phase of middle childhood. In this period peers play an increasingly important role and autonomy (and thus the freedom to choose your own activities) typically increases, and both peers and increased autonomy may affect the level of PA and sedentariness youth engage in.

In view of the finding that PA rates are declining among children (Bassett et al., 2015), while appreciating the beneficial effects of MVPA on children and adolescents' health (Carson et al., 2016), our results not only highlight possible factors (i.e., gaming) that might influence PA, but also when such influence may occur (i.e., middle childhood). Such knowledge is valuable for parents, interventionists, and policy makers alike. PA and sedentariness track from childhood to adolescence and adulthood (Biddle et al., 2010).

Hence, despite potential benefits of gaming (Granic, Lobels & Engels, 2014), one should be aware of the risk of long-term reduced MVPA in boys who game extensively during middle childhood.

To the extent that the potential negative impact of gaming on MVPA is due to displacement, engaging in games that require players to be physically active (e.g., exergames) may to some extent counteract this detrimental effect. A 12-week randomized intervention study (RCT) of children (10–14-year-olds) found that playing such active videogames on a regular basis could have positive effects on children's overall PA levels (Mhurchu et al., 2008).

Future studies should examine whether the relation between gaming, PA and athletic self-esteem revealed in the present study is moderated by the types of games played (e.g., exergames vs non-exergames), and whether efforts to uphold PA levels in the face of gaming, or the opposite, affect the relation between the two.

4.5. Strengths and limitations

Although we applied a multiwave, longitudinal design using a novel statistical approach that enabled us to examine the prospective relations between within-person changes in gaming, athletic self-esteem and objectively measured MVPA with adjustment for all unmeasured time-invariant confounders, the findings just discussed should be interpreted in light of some study limitations. First, players often lose track of time while gaming (Wood et al., 2007), possibly because of its absorbing nature. Moreover, many parents may not have a complete overview of their child's spare time use, including their gaming. Thus, our self- and parent-reported measure of gaming may be error prone. Second, parents of children who display less physical activity may report them to game more because they believe gaming to be the reason for the child's diminished PA, thereby inflating the negative relationship between gaming MVPA. Third, although we adjusted for all time-invariant confounding factors, time-*varying* factors could still have confounded our results. To illustrate, injury could leave more time for gaming because of decreased or no MVPA, resulting in reduced athletic self-esteem as one is hindered from participating in physical activities. Additionally, likely because of the strong seasonality in Norway and because outdoor time is one of the strongest predictors of PA in children (Zahl-Thanem et al., 2018), children are less physically active during winter (Atkin et al., 2016). It is possible that the resulting increased indoor time is spent gaming. Thus, seasonal changes may have inflated the associations. However, because participants were tested at 2-year intervals (hence in roughly the same season), *changes* in gaming and MVPA—which we addressed—might not be affected by seasonality. Moreover, it is important to acknowledge that cultural differences may influence associations between PA and sedentary screen-based behavior. Time youth spend on MVPA vary according to country (Borraccino et al., 2009), and a large cross-cultural study (N = 22,615; 39 countries) demonstrated stronger negative associations between screen-based behavior and PA in countries where the level of PA was relatively high (Melkevit et al., 2010). Thus, similar studies to ours should be conducted in a variety of countries before firm conclusions can be drawn. Also, the data was collected between 2011 and 2017. In the last couple of years there has been increased focus on the benefits of PA to perform optimal when gaming and conducting esports. Esport may be defined as "the casual or organized competitive activity of playing specific video games that provide professional and/or personal development to the player" (Pedraza-Ramirez et al., 2020, p. 322). Benefits of PA on gaming performance is reflected in empirical studies (e.g., de Las Heras et al., 2020). Such results may encourage esport players to be more physically active, which again may motivate non-professional gamers that have these professional players as their idols. Hence, we might have obtained different results had the research been conducted today.

5. Conclusion

Our findings are suggestive of a developmental window for boys in middle childhood during which changes in PA and gaming result in longer-term cascades that endure into adolescence: increased gaming predicts reduced MVPA, whereas reduced MVPA predicts increased gaming. Additionally, those who game more in late middle childhood are more likely to develop poorer athletic self-esteem. These developmental processes seem interrelated in that increased gaming instigates reduced athletic self-esteem via reduced MVPA. Although controlled trials are needed to determine any causality, our findings are consistent with the view that curbing boys' typical increase in gaming during middle childhood may have longer-term effects on increasing their MVPA.

Credit author statement

Beate W. Hygen: Conceptualization, Methodology, Writing – original draft, Project administration **Frode Stenseng**: Writing- Reviewing and Editing **Jay Belsky**: Writing- Reviewing and Editing **Silje Steinsbekk**: Writing- Reviewing and Editing **Lars Wichstrøm**: Writing-Reviewing and Editing, Supervision, Funding acquisition **Vera Skalicka**: Formal analysis, Methodology, Writing- Reviewing and Editing, Supervision.

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