Examining real-time physical activity in adolescents using the Multi-Process Action Control Model: An ecological momentary assessment study

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ABSTRACT

The purpose of this study was to examine real-time associations between reflective (i.e., state motivation), regulatory (i.e., reactive regulation), and reflexive (i.e., habit) constructs from the Multi-Process Action Control (M-PAC) model and acute moderate-to-vigorous physical activity (MVPA) behavior among adolescents using ecological momentary assessments. One hundred and ninety adolescents (M_{age} = 15.8 ± 0.5 years; n = 101 boys) wore an accelerometer and responded to digital survey prompts up to four times daily during the after-school periods for seven consecutive days. MVPA in the 60-minute time window following each survey prompt was recorded. Multilevel mixed-effects linear and logistic models were computed with disaggregated between- and within-person effects to analyze the data. Results from both linear and logistic multilevel models revealed adolescents with higher state motivation in general and experiencing higher state motivation than one's typical levels were associated with engaging in more MVPA and higher likelihood of engaging in ⩾ 10 minutes of MVPA. Engaging in activities less consistent with usual habits were associated with more MVPA and higher likelihood of engaging in ⩾ 10 minutes of MVPA. By contrast, reactive regulation was not associated with MVPA; however exploratory gender-based

analyses suggest the effects of M-PAC constructs on acute MVPA may differ between girls and boys. Results from this study extend previous work demonstrating the importance of reflective and reflexive processes on acute MVPA using real-time intensive longitudinal methods. Collectively, this study provides some initial support for use of the M-PAC framework to explain physical activity behavior in real-time and natural contexts.

Keywords

emerging adults, accelerometry, EMA, M-PAC, youth

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Introduction

Despite the many physical, social, and mental health benefits associated with regular engagement in moderate-to-vigorous intensity physical activity (MVPA), persistently high levels of physical inactivity continues to be a major public health concern (Das & Horton, 2012; Hallal et al., 2012). Temporal trends suggest physical activity behaviors including MVPA peak during early adolescence (van Sluijs et al., 2021), and precipitous declines tend to occur as individuals transition into emerging adulthood (Gordon-Larsen et al., 2004; Kwan et al., 2012; White & Mcteer, 2012). It is therefore critical to understand the salient factors related to physical activity behaviors during adolescence for the purpose of helping to inform strategies to attenuate such declines in physical activity behaviors, and ultimately stave off adverse health outcomes. To effectively develop population-level initiatives, a strong understanding of the underlying psychological processes related to short and long-term patterns of MVPA during adolescence is essential.

To date, the extant literature among adolescents has largely focused on investigating relationships between psychosocial factors and physical activity through the application of social cognitive theories such as the Theory of Planned Behavior and Social Cognitive Theory, among others (Ajzen, 2012; Bagozzi, 1992; Bandura, 1986; Sheeran et al., 2017). These theories posit that behavior is largely a function of an evaluation of expected behavioral outcomes along with the confidence to perform it, leading to the formation of an intention to enact the behavior. It assumes, however, that the formation of intentions to engage in regular physical activity itself should be sufficient to act in accordance with these intentions; when in reality, there is consistent evidence of an intention to physical activity behavior gap (Rhodes & De Bruijn, 2013), including within the broader youth populations (Haider et al., 2022).

Consequently, there has been greater interest in application of action control process-based models integrating post-intentional psychological constructs (Hagger et al., 2002; Rhodes & Dickau, 2012; Rothman, 2000; Schwarzer, 2008; Schwarzer & Luszczynska, 2008). The Multi-Process Action Control (M-PAC) framework (Rhodes, 2017) represents one such example of a popular action control process-based model. The M-PAC framework can be described as a harmonized model based on well-established psychological antecedents of physical activity within social cognitive theories, but with integration of regulatory and reflex-

ive constructs to better explain behavior. Regulatory constructs represent behaviors or cognitions that people enact to translate their intentions into physical activity (i.e., self-regulated behavioral action). The specific addition of reflexive (i.e., less conscious) constructs such as habit and identity – which are known to impact maintenance of physical activity behaviors (Gardner et al., 2011; Rhodes et al., 2016) - adds a novel perspective to existing behavioral theories or models. However, given its recent emergence, more research applying these action control process-based models is still warranted. In particular, research published to date largely consists of cross-sectional designs, which limits our ability to establish cause and effect relationships among components of the model and physical activity behaviors.

Methodologies such as ecological momentary assessment (EMA) that capture people's real-time experiences provide valuable insight to people's behaviors in their natural contexts (Reis, 2012). Furthermore, utilizing repeated observations from participants enables the examination of both between-person effects and within-person effects and their respective influence on behavior (Curran & Bauer, 2011; Hamaker, 2012). Importantly, these data provide valuable insight into the salient factors related to real-time behaviors, considering the normal variations of physical activity cognitions occurring throughout the course of a day. Previous research examining these temporal relationships have found habit strength to be a strong predictor of MVPA among university students on the days that physical activity intentions are weaker (Rebar et al., 2014). While other EMA research has established that reflective and affective momentary physical activity cognitions vary within a day (Bourke et al., 2021; Pickering et al., 2016), no study to date has investigated other action process-based psychosocial constructs such as self-regulation and habit. In light of recent findings that highlight coping planning, identity, and habit to be salient predictors of physical activity behaviors during the adolescent period (Kwan et al., 2022), it would be valuable to explore how M-PAC model-based between- and within-person factors relate to acute physical activity behaviors among youth.

Therefore, the purpose of the current study is to examine real-time associations between reflective, regulatory, and reflexive factors related to MVPA among adolescents using EMA, exploring both between- and within-person effects. It is hypothesized that higher levels of state motivation and greater perceptions of self-regulation will be positively related to more acute MVPA minutes. By contrast, given that adolescents typically spend most of their after-school time engaging in sedentary activities (Arundell et al., 2016), it was hypothesized that engaging in typical behaviors corresponding with the day and time of prompt (i.e., usual habits) will be associated with fewer acute MVPA minutes.

Methods

Participants

Of the 218 participants who provided informed consent for the study, 190 (87.15%) adolescents in their grade 11 year completed the baseline questionnaire and took part in the intensive baseline data collection phase for the *Application of integrateD Approaches to understanding Physical activity during the Transition to emerging Adulthood* (ADAPT) study.

Developed as a longitudinal cohort study to follow a group of high school students as they transition out of high school and into emerging adulthood, the ADAPT study aimed to recruit as many of the grade 11 students across one large school board (seven secondary schools in total) in Southern Ontario to complete a questionnaire-based study. As a subset of the broader cohort, students enrolled in two or three compulsory classes (i.e., English) selected within each school, were invited to participate in the more data-intensive component within the study, comprised of seven days of ambulatory physical activity assessments along with five EMA prompts being sent each day. A complete description of the participant characteristics can be found in Table 1.

Table 1
Descriptive Statistics for Study Participants (*N* = 190).

	Mean (*SD*)
Age (years)	15.8 (0.5)
Weekly moderate-to-vigorous intensity physical activity (minutes)	593.9 (394.9)
	***n* (%)**
Grade	
10	1 (0.5%)
11	186 (98.9%)
12	1 (0.5%)
Gender	
Boy	101 (53.7%)
Girl	83 (44.2%)
Prefer not to answer	4 (2.1%)
Ethnicity	
Aboriginal people of Canada	5 (3.0%)
Indigenous (outside of Canada)	1 (0.6%)
Arab	7 (4.2%)
Black	5 (3.0%)
Chinese	1 (0.6%)
Filipino	7 (4.2%)
Korean	1 (0.6%)
Latin, Central, or South American	4 (2.4%)
South Asian	4 (2.4%)
Southeast Asian	1 (0.6%)
West Asian	1 (0.6%)
White	105 (63.6%)
None of the above	23 (13.9%)
Parental education	
Some secondary	18 (11.0%)
Completed secondary	11 (6.8%)
Some college	6 (3.7%)
College	55 (33.7%)
Some university	8 (4.9%)
Completed university	65 (39.9%)
Participation in organized sport	
Yes	83 (51.9%)
No	76 (47.5%)
Prefer not to answer	1 (0.6%)

Age was missing for 4 participants. Grade was missing for 2 participants. Gender was missing for 2 participants. Ethnicity was missing from 25 participants. Ethnicity was dichotomized as White and Non-White in analyses. Parental education was missing from 27 participants. Participation in organized sport was missing from 30 participants.

Study Procedures

Letters of information were sent ahead of time to students within selected English classes at each school, and a research assistant subsequently attended the beginning of one class to review the study purpose and requirements. All students expressing interest in participating were then provided a pre-populated study package inclusive of an accelerometer and a personalized code for an EMA app and asked to download an EMA app specifically developed for this study called Lumedi EMA (Webility Solutions Inc., 2019) along with entering the unique code provided. Participants were then instructed to put the accelerometer on their non-dominant wrist (wearing it for as much time as they can over the next week, with the exception of showering and participation in water-based activities), and to answer as many of the five prompts as they could on each day.

Participants began receiving EMA prompts on their smartphone the following day. A signal contingent sampling frame was used, whereby participants received their EMA at a random time within five pre-specified time windows. One prompt was sent during the early morning period (7:30 AM–8:30 AM) and the remaining prompts were sent during the later afternoon (i.e., 3:30 PM–4:30 PM and 5:00 PM–6:00 PM) and early evening periods (i.e., 6:30 PM–7:30 PM and 8:00 PM–9:00 PM). Each EMA prompt contained up to 13 items and took approximately 1–2 minutes to complete. All prompts remained open for a total of 30 minutes following the initial prompt and included up to two reminders sent 10 minutes apart. Only the four late afternoon and early evening prompts were used for this study, as these prompts included the same measures. Given the high participant burden, students received a $100 gift card for their participation. The protocol for the ADAPT study was approved by both the Institutional Research Ethics Board and the School Board Ethics Committee, and more detailed information on participant recruitment and the procedural elements involved in data collection are described elsewhere (Kwan et al., 2020).

Measures

Sociodemographic factors

Participants provided sociodemographic information during completion of a questionnaire. This included measures of age, gender, ethnicity, and highest level of parental/caregiver education.

Behavioral cognitions

Based on the M-PAC framework (Rhodes, 2017), with limited measures that can be included with EMA, one item was included to represent state-based reflective, regulatory, and reflexive psychological processes, respectively. State motivation was used to capture the reflective process. Specifically, the question asked participants to rate on an 11-point scale "How motivated are you to be physically active right now?", ranging from 0 (*Not at all motivated*) to 10 (*Extremely motivated*). The regulatory process was assessed using a reactive regulation measure, specifically asking participants: "If I were tempted by something right now, it would be very difficult to resist". This item was rated using a 7-point scale ranging from 1 (*Not true*) to 7 (*Very true*). Responses were reverse scored so that higher values indicated greater perceptions of regulatory-control. The reflexive process was captured by a proxy habit measure created for this study asking participants to

respond to the following statement: "Currently, I am doing something I would normally be doing on a typical day at this time", with responses rated on a 5-point Likert scale ranging from 1 (*Strongly agree*) to 5 (*Strongly disagree*).

Moderate-to-vigorous physical activity

Accelerometers are motion sensor monitors providing a more objective and less biased estimate of total activity than self-report methods, capturing both short, random bursts and prolonged leisure or organized activities (Armstrong & Welsman, 2006). Participants were given the ActiGraph GT9X Link accelerometer to wear on their non-dominant wrist for a period of seven consecutive days, programmed to only display time of day, essentially enacting as a basic watch for participants. Wear time was calculated through CentrePoint (V3, Actigraph, Penascola, FL, USA) using the Troiano et al. (2008) wear time validation parameters, with non-wear defined as ⩾ 60 minutes of consecutive zero counts. Using validated wrist cut points for the GT9X device from Rhudy et al. (2020), vector-magnitude counts per minute above 5,858 were categorized as MVPA. All accelerometer data were analyzed in 60s epochs, and only observations with valid wear time data for the 60 minutes immediately after the EMA prompt were used for analyses.

Data Analysis

Descriptive data for age and MVPA levels during the 7-day study period were summarized as means and standard deviations and frequencies were summarized for grade, gender, ethnicity, parental education, and participation in organized sport. Only the answered EMA prompts responded to after school were included in the analyses and data were analyzed for MVPA observations with full 60-minute wear time following the EMA survey prompt. Summary statistics were computed for EMA data using multilevel modelling to account for the clustering of data nested within participants. Descriptive analyses were computed using STATA version 18.0.

Analyses of missing data were conducted using logistic regression models computed in STATA (coded 0 for not missing and 1 for missing) to examine whether EMA responses for M-PAC variables differed by age, gender, ethnicity, and parental education.

The data collected form a two-level hierarchy with observations (Level 1) nested within people (Level 2). Two random-intercept multilevel models were computed in STATA (Version 18.0) to assess the hypothesized relationships between state motivation (i.e., reflective processes), reactive regulation (i.e., regulatory processes), and proxy habit (i.e., reflexive processes) with MVPA. A multilevel linear regression model was used to predict the minutes of MVPA engaged in within the 60-minute epoch following the prompt and a multilevel logistic regression model was used to predict the probability of engaging in 10+ minutes of MVPA within the 60-minute epoch following the prompt. In these analyses, between-person (i.e., how participants were different from other participants; BP) and within-person (i.e., how people fluctuated within themselves across prompts; WP) effects were disaggregated (Curran & Bauer, 2011). First, the BP effect for each variable was calculated by computing the mean of the prompt-specific scores for each variable within each individual. Next, the subject-specific mean was subtracted from each person's prompt-specific score to obtain the WP effect. Both BP and WP variables were included as predictors in the model. The alpha criterion was set at 0.05.

Results

Descriptive Statistics

Among our sample of 190 youth with valid accelerometry data that responded to more than one EMA prompt, the majority identified as White (63.6%), coming from a highly educated household (73.5% reporting a parent having completed university or college), and slightly more boys (53.7%) than girls (44.2%). Participants were overall active based on the cut-points used (MVPA = 593.9, *SD* = 394.9 minutes within the

week), with approximately half of the sample reporting participation in organized sport (51.9%). See Table 1 for a full demographic breakdown. Among our sample, 17% of participants responded to at least 75% of EMA prompts, while 54% responded to at least 50% of EMA prompts.

Scores for state motivation were low-to-moderate (M = 4.4, SE = 0.16) based on a possible range from 0-10; reactive regulation scores were moderate (M = 4.7, SE = 0.08) based on a possible range from 1-7; and moderate for proxy habit (M = 2.1, SE = 0.05) based on a possible range from 1-5, with 1 representing strong agreement to currently engaging in an activity they would normally be doing. On average, participants spent 9.87 (SE = 0.43) minutes engaging in MVPA during the 60-minute period following each EMA prompt and 38% (n = 717) of the observations with valid wear time involved bouts of MVPA lasting ⩾ 10 minutes.

Missing Data

State motivation ratings were missing from 508 observations (26.92%). The likelihood of answered vs. unanswered state motivation ratings did not vary as a function of age (p = .50) or parental education (p = .12); however, state motivation scores were more likely to be missing for boys (OR = 0.63, SE = 0.07, p < .001, 95% CI [0.51, 0.79]) and non-White participants (OR = 1.36, SE = 0.16, p = .01, 95% CI [1.08, 1.72]). State reactive regulation ratings were missing from 531 (28.14%) of observations. The likelihood of answered vs. unanswered reactive regulation ratings did not vary as a function of ethnicity (p = .19); however, reactive regulation scores were more likely to be missing for younger participants (OR = 0.67, SE = 0.08, p = .001, 95% CI [0.53, 0.84]), boys (OR = 0.37, SE = 0.04, p < .001, 95% CI [0.29, 0.46]), and participants with lower parental education (OR = 0.88, SE = 0.03, p < .001, 95% CI [0.83, 0.94]). Habit ratings were missing from 23 (1.22%) of observations. The likelihood of answered vs. unanswered habit ratings did not vary as a function of age (p = .75), ethnicity (p = .09) or parental education (p = .80); however, habit scores were more likely to be missing for boys (OR = 0.30, SE = 0.15, p = .02, 95% CI [0.11, 0.83]).

Since the likelihood of missingness for the M-PAC variables was associated with age, gender, ethnicity, and parental education, data were considered missing at random (i.e., missing conditionally at random; Woods et al., 2023), and all variables were included in the primary analyses as covariates. Results from analyses with all covariates were compared to results from analyses including only gender as a covariate given missingness was lowest for gender and multilevel regression models remove cases with missing covariate values via listwise deletion. In both cases, the models produced similar results with identical interpretations; and thus, to preserve the study sample and keep the most parsimonious model, results of the analyses with only gender included as a covariate are reported.

Primary Analyses

Model coefficients are presented in Table 2. The multilevel linear regression model evaluating the association between M-PAC variables and MVPA minutes was statistically significant ($\chi^2(7) = 70.96$, p < .001). Results revealed significant BP (coef = 0.75, SE = 0.30, p = .01, 95% CI [0.17, 1.33]) and WP (coef = 1.01, SE = 0.15, p < .001, 95% CI [0.71, 1.3]1) effects of state motivation on acute MVPA. A significant WP effect for proxy habit (coef = 1.03, SE = 0.34, p = .002, 95% CI [0.37; 1.70]) was also observed. There were no significant BP or WP effects of reactive regulation (p's ⩾ .10) or BP effects of proxy habit (p = .81) on acute MVPA. Similar trends emerged using multilevel logistic regression in the prediction of participants engaging in ⩾ 10 minutes of MVPA. The overall model was statistically significant ($\chi^2(7) = 43.83$, p < .001), with BP state motivation (OR = 1.18, SE = 0.07, p = .01, 95% CI [1.04, 1.33]), WP state motivation (OR = 1.19, SE = 0.05, p < .001, 95% CI [1.11, 1.29]), and WP proxy habit (OR = 1.22, SE = 0.10, p = .02, 95% CI [1.03, 1.43]) being significant predictors of acute MVPA. No other predictors were found to be significant.

Table 2
Associations Between M-PAC Variables and Acute Moderate-to-Vigorous Physical Activity (MVPA).

		Coefficient estimate[1] (*SE*)	Odds ratio estimate[2] (*SE*)
Reflective	BP effect	**0.75 (0.30)***	**1.18 (0.07)***
	WP effect	**1.01 (0.15)****	**1.19 (0.05)****
Regulatory	BP effect	0.23 (0.52)	0.94 (0.10)
	WP effect	0.43 (0.26)	1.11 (0.07)
Reflexive	BP effect	-0.21 (0.86)	0.94 (0.17)
	WP effect	**1.03 (0.34)****	**1.22 (0.10)***
Gender		**2.16 (1.02)***	**1.78 (0.38)****
Constant		5.81 (3.50)	0.34 (0.24)

BP = between-person, WP = within-person. Boldface indicates statistical significance (***p* < 0.05, ****p* < 0.01**).
[1] Multilevel linear regression model predicting MVPA minutes. Level 2 *N* = 159, Level 1 *N* = 1,011.
[2] Multilevel logistic regression model predicting the likelihood of engaging in ⩾ 10 minutes of MVPA. Level 2 *N* = 159, Level 1 *N* = 1,011.

Exploratory Analyses

As gender was a significant covariate in both analyses, we conducted exploratory analyses examining both linear and logistic regression models predicting acute MVPA separately for boys and girls. Model coefficients are presented in Table 3. Results from the linear regression models showed significant BP (coef = 1.16, *SE* = 0.42, *p* = .005, 95% CI [0.34, 1.98]) and WP (coef = 1.25, *SE* = 0.21, *p* < .001, 95% CI [0.83, 1.67]) effects of state motivation as well as a significant WP effect for proxy habit (coef = 1.22, *SE* = 0.49, *p* = .01, 95% CI [0.26, 2.19]) for boys. For girls, results showed a significant WP effects of state motivation (coef = 0.67, *SE* = 0.22, *p* = .002, 95% CI [0.24, 1.10]) as well as a significant WP effect of reactive regulation (coef = 0.82, *SE* = 0.34, *p* = .02, 95% CI [0.15, 1.49]). Logistic regression model results showed significant BP (*OR* = 1.23, *SE* = 0.11, *p* = .02, 95% CI [1.03, 1.47]) and WP (*OR* = 1.32, *SE* = 0.08, *p* < .001, 95% CI [1.17, 1.48]) effects of state motivation for boys. For girls, results showed a significant WP effect of reactive regulation (*OR* = 1.18, *SE* = 0.10, *p* = .04, 95% CI [1.01, 1.38]) and a significant WP effect of proxy habit (*OR* = 1.29, *SE* = 0.14, *p* = .02, 95% CI [1.04, 1.60]). No other predictors were found to be significant.

Table 3
Associations Between M-PAC Variables and Acute Moderate-to-Vigorous Physical Activity (MVPA) by Gender.

		Boys		Girls	
		Coefficient estimate[1] (*SE*)	Odds ratio estimate[2] (*SE*)	Coefficient estimate[3] (*SE*)	Odds ratio estimate[4] (*SE*)
Reflective	BP effect	**1.16 (0.42)****	**1.23 (0.11)***	0.26 (0.44)	1.18 (0.12)
	WP effect	**1.25 (0.21)****	**1.32 (0.08)****	**0.67 (0.22)****	1.10 (0.06)
Regulatory	BP effect	1.07 (0.78)	1.15 (0.19)	-0.72 (0.71)	0.84 (0.13)
	WP effect	-0.07 (0.39)	1.01 (0.11)	**0.82 (0.34)***	**1.18 (0.10)**
Reflexive	BP effect	0.33 (1.27)	1.09 (0.28)	-0.50 (1.23)	0.76 (0.20)
	WP effect	**1.22 (0.49)***	1.08 (0.14)	0.76 (0.46)	**1.29 (0.14)**
Constant		-1.25 (5.46)	**0.07 (0.08)***	14.77 (4.05)	1.70 (1.51)

BP = between-person, WP = within-person. Boldface indicates statistical significance (***$p < 0.05$, **$p < 0.01$**).
[1] Multilevel linear regression model predicting MVPA minutes for boys. Level 2 $N = 84$, Level 1 $N = 438$.
[2] Multilevel logistic regression model predicting the likelihood of engaging in ⩾ 10 minutes of MVPA for boys. Level 2 $N = 84$, Level 1 $N = 438$.
[3] Multilevel linear regression model predicting MVPA minutes for girls. Level 2 $N = 72$, Level 1 $N = 564$.
[4] Multilevel logistic regression model predicting the likelihood of engaging in ⩾ 10 minutes of MVPA for girls. Level 2 $N = 72$, Level 1 $N = 564$.

Discussion

This study represents one of the first studies to investigate the influences of regulatory and reflexive processes on acute physical activity using real-time data capture methodologies to better understand behavior in naturalistic environments. Study results provide partial empirical support for the M-PAC framework and highlight the importance of testing real-time associations with device-measured MVPA. Specifically, findings demonstrated significant effects of reflective processes such that higher state motivation, both when compared to others as well as compared to one's typical motivational levels was associated with greater MVPA over the next hour. In addition, higher WP proxy habit was inversely associated with acute MVPA. That is, participants engaged in less MVPA when they reported engaging in typical behaviors at the time of the EMA prompt. Neither reactive regulation nor BP proxy habit were found to be significant predictors in the primary analyses. Overall, the present study builds on previous research that has generally examined the predictive utility of the M-PAC framework in the prediction of real-time physical activity behaviors.

The findings that higher state motivation is positively associated with MVPA is consistent with previous cross-sectional work examining motivation in adolescents (Nogg et al., 2021). However, previous work in this area has relied heavily on aggregate measures assessing motivation which assumes motivation is stable across time. This study contributes to the emerging body of literature examining real-time associations

between behavioral cognitions and physical activity (Maher et al., 2016), specifically by examining the dynamic fluctuations in motivation throughout the day in a sample of adolescents. The observed BP effects highlight that people reporting, on average, more motivation to engage in MVPA are more active in the 60-minutes following the prompt than those reporting lower motivation on average. Results of the WP effects highlight the dynamic nature of motivation, indicating that higher motivations at a moment in time compared to one's typical levels of motivation are also associated with engaging in more MVPA over the subsequent hour. Taken together, these results suggest strategies or interventions aimed to improve people's overall and momentary motivations can help adolescents accumulate greater daily MVPA.

Contrary to our hypotheses, there was no effect of regulatory processes on MVPA in the primary analyses. This, however, may be attributable to how regulatory processes were operationalized in this study. Notably, the current study represents one of the first attempts to understand real-time regulatory cognitions, specifically asking participants about their ability to resist temptation. This may be better described as a measure capturing reactive regulations or self-control (Tangney et al., 2004), rather than tactics used to manage action control. Further, the measure selected was not specifically anchored to MVPA (i.e., simply referred to how much self-control one had rather than how they would monitor/plan/goal set for MVPA), which may also explain why significant associations were not observed. The role of the regulatory processes (reactive regulation or self-regulation) within the presence of reflective and reflexive processes has also been understudied. There has been some belief within dual-process frameworks that reciprocal interactions exist between impulsive to reflective systems, whereby impulses are considered to enter and be processed (i.e., superseded) by the reflective system (Brand & Ekkekakis, 2018), while others have suggested that self-regulation acts as a bridge between conscious decision making processes and more automatic habits and self-identity, influencing individuals' responses to conflicting stimuli and shaping behavioral outcomes (Rhodes, 2021). More work is needed to understand these interactions, and to explore how different operationalizations of the regulatory processes being assessed on a real-time momentary basis might impact acute physical activity.

The significant association between habit and MVPA observed in this study is consistent with emerging research demonstrating physical activity is partially regulated by non-conscious processes (Rebar et al., 2016). Specifically, study results indicate that engagement in more typical activities is associated with lower acute MVPA. This supports previous research showing adolescents spend the majority of their after-school time period in sedentary pursuits (Arundell et al., 2016), and that the break from that habitual behavioral pattern results in a greater likelihood of engaging in more physical activity. It should be noted that in this study, participants indicated agreement or strong agreement to engaging in an activity they would normally be doing in 67% of observations, which may not be surprising during the latter evening prompt periods where stability in routines may be more evident. Future research with additional indicators or passive sensing of habitual behaviors warrants further investigations.

Findings from exploratory gender-based analyses reveal similar results as the primary analyses, but with some nuanced differences. For example, results examining the BP and WP effects of state motivation on MVPA in boys mirrored results from primary analyses, suggesting boys with higher motivation on average, and moments in the day when boys report experiencing higher motivation than their average levels were associated with higher MVPA in the following hour. For girls, it was found that higher state motivation than their average levels were associated with engaging in more MVPA minutes, although this effect was not as strong for girls (coef = .67, *SE* = .22) as it was for boys (coef = 1.25, *SE* = .21). Results suggest state motivation may be a stronger predictor of MVPA in boys than girls. Interestingly, while reactive regulatory processes were not significant in the primary analysis, WP reactive

regulatory processes were significant in analyses for girls, such that girls engaged in more MVPA when they reported higher self-control than their typical levels; however, this effect was not observed in boys. Finally, WP reflexive processes were significant predictors of MVPA minutes in boys and the likelihood of engaging in 10 or more minutes of MVPA in girls. Taken together, results from exploratory analyses highlight that the effects of reflective, reactive regulatory, and reflexive processes on MVPA may have some slight gendered differences and may warrant further investigation.

Together, the results from the present study hold important theoretical implications to advance our understanding of how the M-PAC framework may explain acute physical activity behaviors in adolescents. In contrast to cross-sectional work that found regulatory and reflexive processes being the salient factors explaining variance in self-reported weekly MVPA (Kwan et al., 2022), findings from the present study found reflective processes as a consistent predictor of acute MVPA. It is noteworthy to mention that the reflective processes examined by Kwan et al. (2022) included attitudes, perceived opportunity, and perceived capability which differed from the motivation-focused reflective process assessed in the present study. Nonetheless, despite reflective constructs having the smallest effect sizes in cross sectional data (Rhodes, 2021), our findings indicate reflective processes (i.e., motivation) may have stronger associations with real-time MVPA. Furthermore, consistent with previous work (Kwan et al., 2022), results show reflexive processes significantly predicted MVPA at the within-person level. This finding extends previous work and highlights the importance of accounting for automatic processes when investigating MVPA behavior in real-time as adolescents go about their day.

Strengths and Limitations

There are several strengths and limitations of the present research that should be noted. First, recruitment of a sample of adolescents during their final years at high school will enable future work to see how these real-time factors related to acute physical activity will change as they transition into emerging adulthood, a period for which steep declines in physical activity tend to occur (Kwan et al., 2012). Second, examining the disaggregated effects allows for a more holistic understanding of the unique contributions of WP and BP effects of M-PAC variables on real-time physical activity in naturalistic contexts. Despite these noted strengths, there are several limitations that should also be acknowledged. First, while the aim was to obtain a more representative sample by recruitment within compulsory classes, there may be a response bias in that more active students may be more keen to participate in the intensive component of the study, thus limiting our results' generalizability. Second, given the participant-heavy burdens of EMA, there were missing data due to issues with compliance related to answering the EMA prompts. It may be possible that participants were unable to respond to prompts due to engagement in sport or other physical activities, impacting their abilities to answer prompts within the random time-windows. Third, as noted earlier, this study represents the first EMA study to apply the M-PAC framework, thus reliability and validity of the M-PAC-based measures have not been examined and results need to be interpreted with caution. In particular, the EMA measures used in this study are not in perfect alignment with the behavioral skills or automatic nature with regulatory and reflexive M-PAC measures identified by Rhodes (2017). Future work could explore alternative measures to assess the real-time regulatory and reflexive processes, as well as the convergent validity of single-item measures with validated questionnaires measuring action and coping planning (Sniehotta et al., 2005). For example, Bierbauer et al. (2023) examined self-regulatory processes including measures of previous day planning and action control using an intensive longitudinal design. Regarding reflexive processes, while no gold standard measure currently exists, Rebar et al. (2018) provide recommendations regarding indicators of validity that can inform the development of habit measures. Overall, more research aimed at exploring these real-time psychosocial factors predicting physical activity are clearly warranted.

Conclusions

This study examined real-time associations between reflective, regulatory, and reflexive factors and MVPA among adolescents using EMA. Results showed participants with higher motivation than others on average as well as those experiencing higher motivation than their typical levels were associated with engaging in more acute MVPA. Comparatively, engaging in activities that were consistent with one's typical behavior at the time of the prompt was also associated with engaging in less MVPA following each prompt. Overall, findings from this study suggest both reflective (i.e., motivation) and reflexive (i.e., usual habits) processes are associated with real time MVPA behavior in adolescents in naturalistic settings, providing partial support for the M-PAC framework.

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Data availability statement

Data are available upon reasonable request.

Author's contribution statement

Sheereen Harris: Methodology, data curation, formal analysis, writing – original draft preparation.

Denver M.Y. Brown: Methodology, writing – original draft preparation.

Sara King-Dowling: Methodology, writing – review.

John Cairney: Conceptualization, methodology, writing – review.

Matthew Y. W. Kwan: Conceptualization, methodology, supervision, funding acquisition, writing – original draft preparation.

A Appendix

Table 4
Model Coefficients Analyzing the Random Effects of M-PAC Variables and MVPA Minutes.

Random-effects parameters	Estimate	*SE*	95% CI
Between-subject variance	23.23	5.02	15.21 to 35.47
Within-subject variance	83.52	4.06	75.93 to 91.86

Table 5
Model Coefficients Analyzing the Random Effects of M-PAC Variables and the Probability of Engaging in ⩾ 10 Minutes of MVPA.

Random-effects parameters	*OR*	*SE*	95% CI
Between-subject variance	0.70	0.23	0.37 to 1.32