Predicting Accelerometer-Assessed Estimates of Adolescent's Multi-Dimensional Physical Activity: A Self-Determination Theory Approach

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Abstract

Based on the tenets within self-determination theory (SDT; Ryan & Deci, 2017; Ryan & Vansteenkiste, 2023), a dual-process model of motivational processes was tested to predict accelerometer-assessed estimates of adolescents' light (LPA), moderate-to-vigorous physical activity (MVPA), and sedentary time. Here, we hypothesized that (1) perceptions of psychological need support for exercise would be positively associated with LPA and MVPA and negatively associated with sedentary time via exercise-related psychological need satisfaction and autonomous exercise motivation; and (2) perceptions of psychological need thwarting for exercise would be negatively associated with LPA and MVPA, and positively associated with sedentary time via exercise-related psychological need frustration and controlled exercise motivation. Adolescents (N= 338; 234 females) aged 11-15 years (M=12.75, SD=.90) wore an ActiGraph™ accelerometer for eight days and completed questionnaires pertaining to the SDT variables. Results showed psychological need support to indirectly and positively predict LPA and MVPA via psychological need satisfaction and autonomous exercise motivation. Although directly predictive of need frustration and indirectly predictive of controlled motivation and amotivation, the hypothesized effects from psychological need thwarting to the behavioral outcomes were non-significant. The current findings highlight the important role that need-supportive environments play in facilitating autonomous exercise motivation and behavior by being conducive to exercise-related psychological need satisfaction.

Keywords: motivation, accelerometer, need support, need thwarting

Predicting Accelerometer-Assessed Estimates of Adolescent's Multi-Dimensional Physical Activity: A Self-Determination Theory Approach

The physical and psychological health benefits to children and adolescents of regular moderate-to-vigorous physical activity (MVPA) are well established (Janssen & LeBlanc, 2010; Poitras et al., 2016). Research also highlights the potential benefits of light physical activity (LPA) to the health and wellbeing of children and youth, albeit to a lesser extent (Poitras et al., 2016). Yet within developed nations, data show that many young people spend much of their time engaged in sedentary behavior (e.g., computer use, television viewing, social media, motorized commuting; Matthews et al., 2008). Despite children and adolescents remaining the most active age-groups, MVPA levels decline from mid-childhood, with the relative decline being greater for girls than boys (Farooq et al., 2000). Today's adolescents are also faced with ever-changing technological landscapes that include several common sedentary activities (e.g., reading, homework, television, and computer games) that can crowd out more active recreational pursuits (Hills, King, & Armstrong, 2007). As such, there is a need to understand the determinants of different intensities of adolescents' physical activity (PA) and the time that they spend sedentary (Poitras et al., 2016), especially as adolescence provides a key period to initiate adaptive exercise-related behavioral patterns that may track through to adulthood (Biddle, Gorely, & Stensel, 2004; Flodmark, Marcus, & Britton, 2006).

Although the determinants of physical activity and sedentary time are multifaceted and reside at different levels of influence (e.g., Sallis, Bauman, & Pratt, 1998), empirical work has shown that a large proportion of variance in accelerometer assessed MVPA and sedentary time is best explained by individual level factors (e.g., Katzmarzyk et al., 2018; Salway et al., 2019). An important line of enquiry therefore is to identify key individual level variables and psychological processes that predict the amount, frequency, type, and intensity of PA engagement (Standage & Ryan, 2012; Standage & Ryan, 2020). Here, the construct of *motivation* (i.e., why one is moved into action) has been shown to be a key determinant of sustained exercise engagement across numerous studies, providing insight into several individual level factors that differentiate "why" people behave, engage, think, and experience exercise settings in differing ways (cf. Standage & Ryan, 2012, 2020).

Self-Determination Theory

Self Determination Theory (SDT; Ryan & Deci, 2017; Ryan & Vansteenkiste, 2023) is a macro-theory of human motivation, distinguishing between autonomous and controlled types of regulation and their behavioral and psychological consequences. Within SDT, effortful exercise engagement is most likely to occur when individuals act for autonomous reasons (or via 'high-quality' forms of motivation) (Standage & Ryan, 2012; Standage, Sebire, & Loney, 2008). *Autonomous motivation* is comprised of *identified regulation* (i.e., behaviors that are enacted when people identify with an activity as being useful and important to their goals) and *intrinsic motivation* (i.e., behavior for the inherent interest and satisfaction derived from the behavior itself; Ryan & Deci, 2017).[1] In contrast, *controlled motivation* consists of *external regulation* (i.e., actions that are controlled by factors external to the self, such as rewards and punishments; Deci & Ryan, 1987) and *introjected regulation* (i.e., actions that are controlled by self-imposed sanctions such as shame, pride, ego, and guilt; Deci & Ryan, 2002). A further regulation within SDT is *amotivation* which represents a state where a person lacks motivation and is depleted of energy and vitality (Ryan & Deci, 2000).

Research in multiple life domains document the adaptive role of autonomous motivation for behavior, wellbeing, and performance (cf. Ryan & Deci, 2017). Yet the quality of one's motivation and associated outcomes are not automatic, but rather shaped by social contexts that support specific energizing constructs, namely the basic psychological needs for autonomy (volition, ownership, and the self-endorsement of actions; Ryan, 1995), competence (mastery over behaviour; Ryan & Deci, 2007), and relatedness (being connected, involved, and cared for; Ryan, 1995; Ryan & Deci, 2017). Within SDT it is posited that autonomous motivation and behavioral engagement, well-being, and effective functioning are facilitated by social conditions that are supportive of the satisfaction of these three psychological needs whereas controlled motivation, ill-being, and passive engagement are posited to be associated with need frustrative environments (cf. Ryan & Deci, 2017).

Recent work from an SDT perspective has labelled social contexts to be either *psychological need supportive* (e.g., assisting in overcoming challenges, showing you value the individual) or *psychological need thwarting* (e.g., limiting choices, imposing opinions on the individual; see Standage, Curran, & Rouse, 2019; Standage & Ryan, 2020). Here, interactions with significant others (e.g., friends, family, and PE teachers) have been shown to play a key role in whether the psychological needs are satisfied or frustrated (e.g., Emm-Collison, Standage, & Gillison, 2016). Consistent with propositions within SDT, past work has shown need supportive environments to contribute to the satisfaction of psychological needs and subsequently facilitate autonomous motivation, whereas need thwarting environments contribute to the frustration of psychological needs and hinders autonomous motivation (e.g., Adie, Duda, & Ntoumanis, 2012; Curran, Hill, & Niemiec, 2013; De Meyer et al., 2016; Haerens, Aelterman, Vansteenkiste, Soenens, & Van Petegem, 2015).

SDT, Exercise/Physical Activity, and Sedentary Time

Within SDT it is proposed that individuals who are autonomously motivated selfendorse their actions and experience greater interest, enjoyment, and place increased importance and value on activities (Ryan & Deci, 2017). Being able to decide how to behave, to engage in appealing activities, and to maintain a positive attitude toward behaviors has been shown to enhance or maintain vitality (i.e., high-quality engagement; Nix, Ryan, Manly, & Deci, 1999; Ryan & Deci, 2017). Drawing from tenets within SDT, when people engage in exercise or physical activity for autonomous reasons it provides a vitalizing basis for action that provides the energy and direction required to spend more purposeful time being active and less time spent sedentary (i.e., an energy-mobilizing function; Standage & Ryan, 2012). Supporting such reasoning, empirical work within exercise settings has shown autonomous forms of exercise motivation to positively predict physical activity and exercise behaviors, lower levels of sedentary time, and greater levels of reported vitality (e.g., Fenton et al., 2014; Gunnell, Crocker, Mack, Wilson, & Zumbo, 2014; Standage et al., 2008; see also Standage & Ryan, 2020, for a review).

In contrast to the positive behavioral patterns associated with autonomous motivation, when people are motivated for controlled reasons, their autonomy is inhibited, and their energy and vitality depleted due to the self- and/or external contingencies that underpin controlled forms of motivation (Standage & Ryan, 2020). Indeed, experimental work has shown that engaging in an autonomous, or truly self-regulated, activity can help maintain or enhance subjective vitality relative to engaging in a more controlled activity (Nix et al., 1999). Extending such findings to exercise settings, it is plausible that engagement in exercise or physical activity for controlled reasons will result in more sedentary time and with depleted vitality manifesting behaviorally in less time engaged in purposeful, energized, and effortful activity. To this end, past empirical findings as they relate to associations between controlled exercise motivation and physical activity have yield either negative or null relationships (e.g., Fenton et al., 2014; Standage et al., 2008; see Teixeira, Carraca, Markland, Silva, & Ryan, 2012, for a review).

Individuals who experience amotivation towards physical activity or exercise will not engage in high levels of activity due to their lack of intent to act and/or their view that the activity is void of purpose. There are examples of required activities that children and adolescents engage when amotivated (e.g., school PE lessons), yet in such settings they passively engage (e.g., “go through the motions”; Standage & Ryan, 2020). The behavioral implications of this oppressed orientation towards exercise are that higher levels of sedentary time are likely to manifest. Supporting such reasoning, existing data has demonstrated either a negative or null association among amotivation and physical activity (see Teixeira et al., 2012, for a review).

Motivation and Accelerometer-Assessed Behavior

Although there is a growing body of evidence for the associations among different motivation types and exercise or physical activity behavior, further work is needed to ascertain whether these associations are applicable in the context of adolescent exercise behaviours.[2] To this end, past work with adolescents has shown autonomous motivation towards exercise to be positively associated with exercise behavior (see Owen, Smith, Lubans, Ng, & Lonsdale, 2014) and negatively associated with sedentary time (see Fenton, Duda, Quested, & Barrett, 2014; Lonsdale et al., 2013). These studies have also reported little to no association between controlled motivation and either physical activity or sedentary time (e.g., Fenton et al., 2014; Gillison et al., 2017; Standage et al., 2008). Yet, most of this research has relied on self-report assessments of exercise behavior which are prone to overestimation (Sallis & Saelens, 2000), particularly in children and adolescents who have poorer behavioral recall (Slootmaker, Schuit, Chinapaw, Seidell, & van Mechelen, 2009). Estimates of behavior derived from accelerometer devices are advantageous due to the capacity for real time data storage, therefore providing more reliable estimates of physical activity and exercise patterns over a set time-period and in large samples (Trost, Pate, Freedson, Sallis, & Taylor, 2000).

In the few studies to have explored the application of SDT to accelerometer-assessed physical activity behaviors, researchers have focused on specific settings and populations such as physical education (e.g., within a PE lesson; Owen et al., 2013), youth sport (Fenton et al., 2016), university students (Standage et al., 2008), and children (Sebire, Jago, Fox, Edwards, & Thompson, 2013). These studies show small to moderate associations (β=.21-.39) between autonomous exercise motivation and MVPA, with autonomous motivation explaining small-to-moderate-amounts of variance in MVPA (R^2=.05-.31; Fenton et al., 2016; Fenton et al., 2014; Owen et al., 2013; Standage et al., 2008). These studies also show small negative, or null, associations (β= -.06-.15) between controlled exercise motivation and MVPA (Fenton et al., 2014; Standage et al., 2008). To date, studies have not explored associations between amotivation and accelerometer-estimated physical activity in the context of adolescent exercise behavior. Although the relationships reported in the extant literature are relatively small, motivation is a key driver of human behavior, and the evidence for motivation as a significant predictor of physical activity in PE, leisure time, and sport suggests that motivation plays a central role in determining behavioral engagement. Currently little is known about how motivation relates to adolescent physical activity behavior more generally. Additionally, there is some evidence showing a small negative relationship between autonomous exercise motivation and accelerometer-assessed sedentary time (β= -.15) and little association between controlled exercise motivation and accelerometer assessed sedentary time (β= -.06), with motivation explaining a small amount of variance in sedentary time (Fenton et al., 2014). Whilst sedentary behavior is distinct from physical activity behavior, there is an increased interest in how different movement-related behaviors (e.g., sedentary time through to high intensity exercise behavior) combine and interact (e.g., Jago et al., 2018a; Tremblay et al., 2016). Therefore, it is surprising that research has not examined how different types of motivation towards a given context (e.g., controlled exercise motivation) correspond to the full spectrum of available movement-related behaviors. With a view to informing future application and intervention, and given the public health interest in understanding and reducing sedentariness among young people (e.g., National Health Service, 2019), it is important to understand the motivational process that underpin both physical activity engagement and a lack of behavior (i.e., indexed in the current work as sedentary time).

Empirical work in related contexts (e.g., PE, youth sport) has shown psychological need support to positively predict need satisfaction, autonomous exercise motivation, physical activity behavior, and well-being (e.g., Chatzisarantis, Hagger, Kamarova, & Kawabata, 2012; Ntoumanis, 2005; Standage et al., 2005). There is also some evidence to support positive relationships between autonomy-thwarting, need frustration, controlled motivation, and amotivation in the PE-context (e.g., Haerens et al., 2015). Need frustration has also been shown to be associated with greater exercise-related ill-being (e.g., disordered eating, burnout, depression, negative affect; Curran, Hill, Hall, & Jowett, 2014; Haerens et al., 2015). However, overall, there has been limited empirical enquiry in the context of adolescent exercise behavior into the social contexts that facilitate, or undermine, autonomous exercise motivation.

The Role of Significant Others in Supporting Physical Activity Behavior

In addition to the general social context surrounding adolescent PA, it is important to understand the influence of specific social agents on behavioral engagement. Adolescents engage in physical activity in a variety of contexts (including at school, at home, in sport settings, and outdoors; Dunton, Whalen, Jamner, & Floro, 2007) and with a variety of different people (e.g., family, friends, teachers). As such, adolescent exercise and physical activity behaviors are likely to be influenced, both positively and negatively, by a several social agents. Existing studies have explored need-supportive and need-thwarting social interactions independently (e.g., Rocchi, Pelletier, Cheung, Baxter, & Beaudry, 2017; Standage et al., 2005). However, despite these facets of the social environment co-existing (Ryan & Deci, 2017), and thus potentially interacting to influence behavioural outcomes, no SDT-related research with adolescents has simultaneously tested adaptive (i.e., need support, need satisfaction, and autonomous motivation) and maladaptive (i.e., need thwarting, need frustration, and controlled motivation) processes within the same dual-process model. Likewise, and although recent studies of psychological need supportive environments have extended beyond measuring autonomy support to include supports for competence and relatedness (e.g., Emm-Collison et al., 2016; Rocchi et al., 2017), research assessing need thwarting in adolescents has focused on controlling behaviors, and only from singular authoritative figures (e.g., teachers and coaches; Bartholomew, Ntoumanis, Ryan, & Thogersen-Ntoumani, 2011; Fenton et al., 2016). Despite the need for a more comprehensive understanding of the motivational processes related to physical activity behaviors in adolescence, to our knowledge, no existing research has examined the associations between need support and thwarting more comprehensively, considering social interactions with multiple relevant social agents (i.e., peers, parents, and PE teachers) on accelerometer-estimated movement behaviors. In the current study, we describe and test a dual-process mediation model of accelerometer-estimated exercise behavior and sedentary time using SDT as a guiding framework (Ryan & Deci, 2017).

Purpose of the Present Study

We sought to assess several gaps in the extant literature by assessing a dual-process model based on the tenets of SDT (cf. Standage & Vallerand, 2014; Vansteenkiste, Soenens, & Ryan, 2023) and simultaneously to evaluate how effective these processes are in predicting accelerometer-estimated physical activity (i.e., LPA and MVPA) and sedentary time (Figure 1). Within the proposed dual-process model, we modelled adaptive (or the 'bright') processes through need support, need satisfaction and autonomous motivation, and maladaptive (or the 'dark') processes via need thwarting, need frustration and controlled motivation. We also considered the need-supportive and need-thwarting social contexts created by multiple social agents (peers, family, and PE teachers) to examine how these processes combine to support need-satisfaction, need frustration, autonomous and controlled motivation. Finally, we extended the model to include the association of these processes with accelerometer measured physical activity (i.e., LPA and MVPA) and sedentary time.

Method

Participants

Participants were adolescents aged 11-15 years attending state funded mainstream secondary schools in South West England.[3]

Measures

Psychological Need Support and Need Thwarting in Exercise. Perceptions of need support in the context of exercise were assessed using the Adolescent Psychological Need Support in Exercise Questionnaire (APNSEQ; Emm-Collison et al., 2016) and perceptions of need thwarting towards exercise were assessed using 12 items from the Interpersonal

Behaviors Questionnaire (IBQ; Rocchi et al., 2017). The APNSEQ consists of 9 items referring to autonomy support (3 items, e.g., '*They encourage me to do the exercise activities that I want to do'*), competence support (3 items, e.g., '*They help me improve my exercise abilities'*), and relatedness support (3 items, e.g., '*I feel that I am valued by them'*). The 12 items within the IBQ refer to autonomy thwarting (4 items, e.g., '*They pressure me to do things their way'*), competence thwarting (4 items, e.g., '*They question my ability to overcome challenges'*), and relatedness thwarting (4 items e.g., '*They do not connect with me'*). The measures were completed three times in relation to three social agents; i.e., family, friends, and PE teacher. The participants responded to the stem '*In my interactions with my family/friends/PE teacher about exercise…*' using a 7-point Likert scale ranging from 1 (strongly disagree) through 4 (neither agree nor disagree) to 7 (strongly agree). Scores provided to both measures have shown to be reliable in samples of British adolescents (Emm-Collison et al., 2016). For the analyses, the subscales were collapsed to create three aggregated subscales for peer, parents, and PE teacher support and three aggregated subscales for peer, parents, and PE teacher psychological need thwarting.

Psychological Need Satisfaction and Need Frustration in Exercise. Participants' perceptions of satisfaction and frustration of the three basic psychological needs for autonomy, competence, and relatedness as they relate to exercise were assessed through the Basic Psychological Need Scale (Chen et al., 2015). Scores of this 24-item, 6-factor scale have provided support for elements of construct validity in multicultural samples of older adolescents (Chen et al., 2015). The stem used in the present work was '*When I exercise…'* followed by items for need satisfaction (e.g., *'I feel confident that I can do the exercise well'*) and need frustration (e.g., *'I feel like a failure because of the mistakes that I make'*). Participants responded using a 7-point Likert scale ranging from 1 (strongly disagree) through 4 (neither agree nor disagree) to 7 (strongly agree). Factorial validity and composite reliability scores support the amendment of this scale in this manner in research with younger adolescents (Emm-Collison et al., 2016).

Exercise Motivation. Motivation towards exercise was assessed using the Behavioral Regulations in Exercise Questionnaire (BREQ-2; Markland & Tobin, 2004). The BREQ-2 is a 19-item questionnaire that measures the five subscales of intrinsic motivation, identified regulation, introjected regulation, external regulation, and amotivation; the subscales can also be combined to provide composite scores for autonomous motivation and controlled motivation. Participants respond on a 5-point Likert scale ranging from 0 (not true for me) through 2 (sometimes true for me) to 4 (very true for me). Responses to the scale have previously demonstrated adequate psychometric properties in adolescent samples (e.g., Gillison, Standage, & Skevington, 2006; Standage, Gillison, Ntoumanis, & Treasure, 2012).

***LPA, MVPA, and Sedentary Time*.** Actigraph™ GT1M, GT3X and GT3X+ accelerometers were used to estimate physical activity and sedentary time. Research has shown the use of different ActiGraph™ models within a single study to be acceptable (Robusto & Trost, 2012) and, in the present study, there were no significant between-person differences in LPA, MVPA, or sedentary time from the different monitors.[4] Accelerometers were waist mounted on the right side of the body by an elasticated belt. Participants were asked to wear the accelerometer for 24 hours a day for eight days (one adjustment day and seven measurement days) including two weekend days to maximize adherence and wear-time (Tudor-Locke et al., 2015). In line with previous studies, the minimum amount of data to be considered valid was four days, with at least 10 hours of wear time per day and including one weekend day (Katzmarzyk et al., 2013; Tudor-Locke et al., 2015). The data were processed using 10-second epochs to accurately classify different levels of physical activity (e.g., Reilly et al., 2008; Trost, McIver, & Pate, 2005) and categorized using cut-points proposed by Evenson, Catellier, Gill, Ondrak, and McMurray (2008) which are recommended for estimating sedentary, light, moderate, and vigorous activity in adolescents.

Fifty-one (14.8%) participants did not wear their accelerometers while sleeping. These participants did not differ from the rest of the sample on any motivation variables but were more likely to be female (p<.05). To ensure sleep and sedentary time were not conflated, data collected during periods of sleep for each individual participant were excluded from analysis. Sleep periods were identified via very low levels of both light activity and MVPA and high levels of sedentary time for several consecutive hours during nighttime hours.

Anthropometric Measures

Anthropometric measurements were obtained from participants via a standardized protocol used in previous studies with children and adolescents (Katzmarzyk et al., 2013). Participants' body mass was measured using a portable Tanita SC-240 Body Composition Analyzer (TANITA Corporation, Tokyo, Japan). Height was measured using a Seca 213 Portable Stadiometer (Hamburg, Germany). Participants removed their shoes and any items from their pockets. Each measurement was repeated twice, with a third measurement obtained if the difference between the first two was larger than 0.5cm or 0.5kg for body height and body mass, respectively. The average of the closest two measurements was used to calculate BMI (body mass (kg) divided by height (m^2) and used in the subsequent analyses.

Procedure

Ethical approval was sought and granted from the authors' institutional ethics committee prior to commencing the research. Schools were invited to take part in the study via telephone and email when the purpose and nature of the study were explained, and consent was sought from senior members of school staff. In line with the British Psychological Society (2014), information sheets were sent out to parents providing the opportunity to opt their child out of participating in the study. Informed assent was obtained from students whose parents did not opt out and who wished to personally participate. Questionnaires were completed individually during a normal school day, with a researcher present to answer any questions about the questionnaire. To ensure consistency, and in line with established good practice (cf. Katzmarzyk et al., 2013), questions were not re-interpreted to participants, but definitions of words were provided if required. Following completion of the questionnaire anthropometric measures were taken and participants were fitted with the accelerometers. They were instructed to wear the accelerometers as much as possible over the measurement period, taking them off only for water-based activities (i.e., swimming, showering, bathing) or if there was a risk of injury to them or someone else (e.g., contact sports). The researcher returned to the school eight days later to collect the accelerometers and the data were downloaded, validated with respect to wear-time, and analyzed using ActiLife™ software version 6 (ActiGraph™, Pensacola, FL).

Data Analysis

Structural equation modelling using AMOS version 28.0 (Arbuckle, 2021) and employing maximum likelihood estimation formed the primary data analysis approach. In all models, the need support and thwarting, need satisfaction and frustration, and motivation regulation variables were modelled using latent variables, whereas LPA, MVPA, and sedentary time were modelled as manifest variables. Subscales were used as the measured variables for psychological need satisfaction (three indicators; autonomy satisfaction, competence satisfaction, and relatedness satisfaction) and psychological need frustration (three indicators; autonomy frustration, competence frustration, and relatedness frustration). Random two-item parcels were created from the BREQ subscales to form the latent factors for autonomous motivation (four indicators), controlled motivation (three indicators), and amotivation (four indicators).

Confirmatory factor analysis was first employed to assess the measurement model, the error free correlations, and the composite reliabilities. This was followed by an assessment of the hypothesized structural model (Anderson & Gerbing, 1988). Due to their measurement interdependence, the hypothesized structural model incorporated covariances between the disturbance terms of LPA, MVPA, and sedentary time. Similarly, and to reflect the proposed theoretical associations among SDT variables (cf. Ryan & Deci, 2017), the disturbance terms among psychological need satisfaction and psychological need frustration as well as the motivation types were covaried. All models also controlled for accelerometer wear time. Model fit for the structural model was assessed using four indices proposed by Hu and Bentler (1999). These were the Chi-square value (χ^2), and three additional indices – the comparative fit index (CFI), the standardized root mean square residual (SRMR), and the root mean square error of approximation (RMSEA) – to account for limitations with χ^2 as an indicator of model fit (e.g., falsely identifying ill-fitting models with large data sets; Cheung & Rensvold, 2002). We used the thresholds of >.90 for acceptable fit and >.95 for an excellent fit for the CFI, < .08 for the SRMR, and < .06 for the RMSEA (Hu & Bentler, 1999).

To determine the statistical significance of the mediated pathways in the hypothesized structural model, indirect effects were calculated, and their 95% bias corrected and accelerated confidence intervals were calculated from 5,000 bootstrap iterations with replacement (Hayes, 2009). The 95% bias corrected and accelerated confidence interval denotes the upper and lower boundary of an indirect effect. Provided that a null or zero effect is not observed between the upper and lower bound of the 95% confidence interval, the indirect effect is deemed significant at the $p < .05$ level.

Supplementary Analyses. As past findings have shown the processes within SDT models to be invariant across gender (e.g., Standage et al., 2005), we tested the current dual-process model of SDT across gender. Here, a sequential model testing approach was adopted to test the model for invariance across gender (Byrne, 2004; 2010). This process involves the creation of an unconstrained model (or configural model) that serves as the baseline representation of the theoretical relationships among the latent constructs and observed variables. Next, equality constraints are imposed on sets of parameters and tested in an increasingly restrictive fashion. In the present study, the equality constraints were added in the logically ordered sequence of *measurement weights*, *measurement intercepts*, *structural weights*, *structural covariances*, *structural residuals*, and *measurement residuals*. To evaluate for model equivalence, a value of ΔCFI smaller than or equal to–0.01 is used to indicate that the null hypothesis of invariance should not be rejected (Cheung & Rensvold, 2002). Lastly, and consistent with past work (e.g., Standage et al., 2008), we also tested the model when controlling for BMI.

Results

Participant Characteristics

Five hundred and fifty-three adolescents aged 11-15 years (Mean age= 12.77, *SD* = .93; 63.1% female) were recruited through four schools in the South-West of England (63.1% female, 89.4% White British). Of these, 209 were removed due to insufficient accelerometer measurement (Katzmarzyk et al., 2013; Tudor-Locke et al., 2015).[5] Results from t-tests showed that girls were more likely to adhere to accelerometer protocol (p<.001) and those with complete accelerometer data reported higher autonomous motivation (p<.01). There were no significant differences for the other study variables. There were also no significant differences across the four schools in the variance structure of LPA, MVPA, or sedentary time.

Preliminary Analyses

Prior to our main analyses, the data were screened for missing data and outliers. In line with recommendations of Tabachnick & Fidell (2012), three cases containing a high amount of missing data (≥ 10%) were identified and removed. The remaining missing data were replaced using the mean of the available items from the subscale for each individual case (i.e., individual-level mean substitution; Graham, Cumsille, & Elek-Fisk, 2003). Subsequently univariate (z scores exceeding 3.29) and multivariate outliers (p > 0.001) were removed from the dataset (n = 3; Tabachnick & Fidell, 2012). This data screening and cleaning procedure yielded a final sample of 338 adolescents (69.2% female; M_{age} = 12.75 years; SD = .90). Although this process resulted in data that was approximately univariate normal, estimates of multivariate kurtosis indicated the data remained multivariate asymmetrical (Mardia's normalized coefficient = 142.16). Therefore, we employed a bootstrapping procedure that drew 5,000 replication samples with replacement (Efron, 1979).

Assessment of the measurement models

The measurement model consisted of seven inter-correlated latent factors and three observed dependent variables. All standardized factor loadings for the measured variables on their latent factors were significant and each of these latent factors demonstrated acceptable composite reliability (see Table 1). Fit indices showed the measurement model to have acceptable fit to the data: χ^2 = 534.03 (251), p< 0.001; CFI = 0.93; SRMR = 0.06; RMSEA = 0.06 (90% CI = 0.05 to 0.07). The correlations among the study variables were in the expected directions and ranged from small to large in magnitude (Table 1).

Assessment of the Hypothesized Structural Equation Models

The hypothesized structural equation model is shown in Figure 1. Fit indices showed the hypothesized model to yield an acceptable fit to the data: χ^2 = 705.74 (275), p< 0.001; CFI = 0.90; SRMR = 0.06; RMSEA = 0.07 (90% CI = 0.06 to 0.07). In line with theory, perceptions of psychological need support were positively associated with psychological need satisfaction and negatively associated with psychological need frustration. Likewise, psychological need thwarting was positively associated with psychological need frustration, yet contrary to our hypothesis need thwarting was also positively associated with psychological need satisfaction. Psychological need satisfaction was positively associated with autonomous motivation and negatively associated with amotivation, whereas psychological need frustration was positively associated with both controlled motivation and amotivation. Finally, autonomous motivation was positively associated with time spent in MVPA and LPA. None of the SDT variables were significantly associated with sedentary time in the model. The model accounted for 4% of the variance in LPA, 5% in MVPA, and 1% in sedentary time.

Indirect Effects

Significant two- and three-way standardized indirect effects and the 95% upper and lower limits of bootstrap-generated bias-corrected confidence intervals (CI) are reported in Table 2. Psychological need support had a significant positive indirect effect on autonomous motivation via psychological need satisfaction, and a significant negative indirect effect on amotivation via psychological need frustration. Via psychological need satisfaction and autonomous motivation, psychological need support also had significant positive indirect effects on time spent in LPA and MVPA. Psychological need support did not have any significant indirect effects on controlled motivation or time spent sedentary. Psychological need thwarting had a significant positive indirect effect on both amotivation and controlled motivation through psychological need frustration. These indirect effects did not extend to any of the behavioral outcomes, and psychological need thwarting had no indirect effects on autonomous motivation. Psychological need satisfaction had significant positive indirect effects on time spent in LPA and MVPA via autonomous motivation. Psychological need frustration had no significant indirect effects on any of the behavioral outcomes.

Supplementary Analyses

Results of multi-sample SEM analysis provided support for the equivalence of the model across gender and are shown in Table 3. Here, a non-significant change in CFI value (≤ .01) across boys and girls provided support for gender invariance (Cheung & Rensvold, 2002). When the model was tested controlled for BMI, results showed the model to adequately fit to the data: χ^2 = 785.59 (298), p < 0. 001; CFI = 0.89; SRMR = 0.07; RMSEA = 0.07 (90% CI = 0.06 to 0.08), yet BMI was not a significant predictor of LPA, MVPA, or sedentary time in the context of the dual-process model.

Discussion

Grounded within SDT, this study was the first to test a comprehensive dual-process model of motivation to predict accelerometer estimates of daily LPA, MVPA, and sedentary time in adolescents. The data largely supported the proposed SDT dual-process model which outlined positive and negative associations between psychological need support and need thwarting environments, basic psychological need satisfaction/frustration, motivation types, and in this study, the behavioral outcomes of interest (i.e., LPA, MVPA, sedentary time) (Ryan & Deci, 2017; Ryan & Vansteenkiste, 2023; Standage & Vallerand, 2014). Significant indirect effects also supported the proposed theoretical relationships from psychological need support to psychological need satisfaction, to autonomous motivation, and via autonomous motivation greater engagement in LPA and MVPA. Despite positive indirect effects from perceptions of need thwarting social contexts and controlled motivation and amotivation, our data showed no significant indirect effects from perceptions of need thwarting environments to the behavioral outcomes.

Past work in the context of sport and physical activity has largely focused on the extent to which participants perceive environments created by others (e.g., sport coaches, PE teachers, peers) to be autonomy supportive or controlling. Yet, these studies have often focused on a single social agent, and few studies have adopted broader assessments to also encompass perceptions of need supportive (e.g., Ntoumanis, 2005; Standage et al., 2005) or need thwarting contexts (e.g., Haerens et al., 2015; Jotie De Meyer et al., 2014). Such extensions are important as within SDT all three psychological needs (i.e., autonomy, competence, and relatedness) are fundamental. Our work shows that perceptions of need supportive and thwarting behaviors from family, friends, and PE teachers all contribute simultaneously to overall perceptions of need satisfaction and need frustration. Such findings offer initial evidence for the importance of these three social agents in promoting autonomous motivation for exercise and subsequent exercise behavior in adolescents via providing social contexts that are conducive to need satisfaction. Whilst there is a need for future work to explore the unique contibutions of each social agent, these findings offer a theoretical basis for previous evidence highlighting that adolescent physical activity interventions extending beyond the school day to include family, sport settings, and/or the community are more effective than those that are solely school-focused (van Sluijs, McMinn, & Griffin, 2007).

Consistent with SDT and previous research in PE settings (Standage et al., 2005), perceptions of psychological need support were positively associated with psychological need satisfaction. Our results also extend past work by demonstrating perceptions of need supportive contexts to (1) negatively predict psychological need frustration; and (2) perceptions of a need thwarting context to positively predict psychological need frustration.

An unexpected finding and one that departs from theory and past empirical work (cf. Ryan & Deci, 2017) was the positive path coefficient between psychological need thwarting and psychological need satisfaction. Here, the direction of association changed from a negative bivariate correlation (r =-.26) to a positive path coefficient (β =.15; Figure 2). After systematically removing predictor variables from the model (cf., Massen & Bakker, 2001), the path coefficient between need thwarting and need satisfaction reverted to being negative (β -.39). In the context of our data, past work, and theory, we interpret this finding as a suppression effect resulting from the substantial positive path from need support to need satisfaction (β=.91).

The indirect effects from psychological need-supportive contexts showed a significant impact on LPA and MVPA (Table 2). Such findings support the tenets within SDT that psychological need support contributes to LPA and MVPA through the serial mediation of psychological need satisfaction and autonomous motivation, a finding that has been demonstrated in several previous studies (e.g., Adie et al., 2012; Haerens et al., 2015). Despite our results showing need thwarting to influence controlled motivation indirectly through need frustration, there was no significant effect of need thwarting on the behavioral outcomes.

In line with SDT and past findings from school PE settings (Haerens et al., 2015), psychological need satisfaction was found to positively predict autonomous exercise motivation. Further, indirect effects showed that exercise psychological need satisfaction had positive indirect effects on LPA and MVPA. Collectively, these results support the utility of SDT's basic needs approach and add to a cogent body of literature that documents the satisfaction of the basic psychological needs to be necessary for supporting high quality forms of motivation as well as behavioural engagement in exercise settings (Standage & Ryan, 2012, 2020).

Psychological need frustration positively predicted controlled exercise motivation. No association between need frustration and adolescents' participaton in LPA, MVPA, or sedentary time was found. It may be that psychological need frustration is more pertinent to reported levels of ill-being. Here, previous research in the youth sport context has found need frustation to be related to disordered eating, burnout, depression, and negative affect (Bartholomew et al., 2011; Curran et al., 2014; Haerens et al., 2015). Future research would also do well to test whether behavioural variables are better predicted by more proximal moment-to-moment variations in need-satisfactions and need-frustations than the contextual-level assessments used in the present work (e.g., via experience sampling methods; e.g., Standage & Ryan, 2020).

Consistent with the tenets within SDT and previous research (e.g., Aelterman et al., 2012; Fenton et al., 2014; Owen et al., 2013; Standage et al., 2008), the present results showed autonomous exercise motivation to positively predict time spent in MVPA. The current data therefore supplement similar results from PE (Aelterman et al., 2012), leisure time activity (Owen et al., 2013), and sport and active games (Fenton et al., 2014) settings in the context of exercise. Accordingly, our data provides support for our argument that autonomous exercise motivation provides a vitalizing basis for action, providing the energy and direction required to spend more purposeful time being active (Standage & Ryan, 2012). This said, the magnitude of the relationship was small, which indicates that there are additional processes at play, which that may moderate and/or mediate the relationship between motivation and behavior (e.g., self-regulatory processes, proximal determinants, environmental characteristics; Martin, Bremner, Salmon, Rosenberg, & Giles-Corti, 2012).

No significant direct associations between controlled exercise motivation or amotivation were found for LPA, MVPA, or sedentary time. Such findings are consistent with previous evidence assessing accelerometer-estimated exercise with both adults and adolescents (e.g., Fenton et al., 2014; Standage et al., 2008). Here, we based our hypothesis on the reasoning that exercising for controlled or amotivated reasons would manifest in little purposeful, energized, and effortful activity due to depleted energy. This was not directly tested in the current research, yet it would be an interesting thesis to explore via future work.

Autonomous motivation positively predicted daily LPA, yet our results showed no significant direct associations between controlled or amotivation and LPA. This is potentially due to the incidental and often necessary nature of a large proportion of LPA activities (e.g., walking to meet friends, helping around the home, shopping with friends or family), which are not underpinned by exercise-specific motivational processes that align with the structured, more intense, and intentional forms of activities that comprise MVPA activity. A pertinent example of a necessary activity for many children and adolescents is the commute to school. Here, many students report that they walk to school because they “have to” as it represents their only form of transport (e.g., White et al., 2018). Future research in which researchers examine multiple forms of motivation across differing life contexts and their relationships with a measurement approach that better teases out structured and intentional forms of PA is warranted.

Practical recommendations, limitations, and future directions

The findings provide some useful practical insights. Indeed, the results suggest that fostering a psychologically need-supportive environment may serve to facilitate greater engagement in LPA and MVPA behavior among adolescents. In doing so, interventions may facilitate more autonomous motivation through the satisfaction of the basic psychological needs, ultimately influencing adolescent engagement in movement behaviors. To this end, SDT provides several explicit avenues for intervention which can be best considered by using the basic psychological needs as a core basis for integrating and organizing the motivational phenomena related to promoting need supportive environments (Gillison, Rouse, Standage, Sebire, & Ryan, 2019; Standage & Ryan, 2012, 2020).

Although there are numerous strengths to the current research, there are also several limitations. First, the measures for the SDT constructs were completed with respect to motivation for exercise and did not include items relating to motivation for sedentary time nor lighter forms of exercise/PA. Evidence consistently demonstrates the independence of physical activity and sedentary behaviors (e.g., Marshall, Biddle, Sallis, McKenzie, & Conway, 2002), and differences in their determinants (Biddle et al., 2004). This highlights the importance of measures specifically designed to assess the predictors of sedentary behavior and light exercise/PA, which should be incorporated in future work. Relatedly, sedentary behavior is not just the absence of physical activity, but that rather it involves purposeful engagement in activities involving little bodily movement (Reilly et al., 2008). As such, the measurement of both exercise and sedentary time using the same accelerometer does not represent this independence. Future motivation-related work coexamining the two behaviors would benefit from employing supplementary units to those designed to assess physical activity. Such assessments could include devices designed to assess and quantify free-living sedentary, upright, and ambulatory activities (e.g., activPAL) as well as units that would provide a better understanding of the contexts and timings that specific movement behaviors occur (e.g., via SenseCam technology).

A large proportion (37.8%) of the recruited sample was excluded from the final analyses due to insufficient accelerometer measurement, despite following a protocol designed to encourage compliance (Tudor-Locke et al., 2015). It was necessary to exclude participants with lower levels of accelerometer wear time to ensure that the accelerometer estimates align with empirically supported approaches. However, in this work, those excluded from the analyses were, on average, less-autonomously motivated individuals, which may have impacted on the current findings. Participant compliance is a key issue in accelerometer-based research (Ridgers & Fairclough, 2011) and a priority of future research should be the evaluate methods for engaging and encouraging compliance, particularly in underrepresented populations.

Although SDT was developed as a person-centered theory of human motivation and thriving, the present data were collected from children nested within the school setting. To this end, our analyses were constrained by the small number of participating schools (i.e., complete data were collected from 338 participants nested within 4 schools). To avoid obscuring the relationships at the individual level on which the current work focused, we used the bootstrapping method, an approach that is highly suitable for assessing the validity of intricate theoretical frameworks such as the dual-process model of SDT tested in this work (i.e., a complex model with multiple latent variables, observed variables, and paths). Bootstrapping also offers further advantages to the present analyses, including being robust against violations of assumptions such as normality and homoscedasticity, it aids with power analyses within covariance structures, and it provides the basis for more robust tests of indirect/mediation effects via bootstrap-generated bias-corrected standard errors (Hancock & Liu, 2012; Preacher & Hayes, 2008). These advantages aside, there is a clear need for future research that is be appropriately powered by design to account for school/class clustering within multi-level SEM approaches.

In terms of clustering and behavioral assessments (e.g., recent work adopting a 24-hour approach to movement behaviors), an interesting challenge in future work relates to the presence of multiple nesting variables that extend past the school day. For example, the sampling period of movement behaviors in the present work spanned 168 hours in total, including two weekend days (or 48 hours). Across the whole 168-hour time-period that we sought to obtain accelerometer data, only 32.5 hours (or 19.3%) of the assessment period represented time spent at school (including breaks and lunch time). Therefore, 135.5 hours (or 80.7%) of the overall assessment period reflects time spent alone or coupled with being nested in differing family structures, friendship groups, sport teams, social groupings, etc. Adding further to the complexity is the evolving nature of the dynamic interactions among these differing clusters.

Conclusion

The present work provides support for the role of psychological need support, psychological need satisfaction, and autonomous motivation in predicting time spent in LPA and MVPA behavior in adolescents. In line with tenets within SDT and previous research, the present data showed perceived need support within exercise to positively predict exercise-related need satisfaction, autonomous motivation toward exercise, and adaptive exercise outcomes. Contrary to the proposed theoretical relationships, the findings presented in this study indicate that the purportedly maladaptive SDT constructs (i.e., psychological need thwarting, psychological need frustration, and controlled motivation) are not predictive of adolescents' LPA, MVPA, or sedentary time. It is likely that these constructs are more pertinent to reported levels of exercise-related well and ill-being (e.g., Curran et al., 2014; Haerens et al., 2015). With a view to behavioral intervention and considering the small magnitude of the relationship between motivation and behavior, future research should explore supports for motivation across the day as well as consider more proximal processes to given behaviors as these may be instrumental in explaining how motivation may better manifest in behavior.

Footnotes

[1] Integrated regulation (i.e., when the value placed on the behavior assimilates with one's sense of self) also contributes towards autonomous motivation but is not measured in the current work.

[2] In line with recommendations to optimize correspondence between behavioral predictors and outcomes (Atkin, van Sluijs, Dollman, Taylor, & Stanley, 2016), we concentrate on exercise defined as a subcomponent of physical activity that is '*planned, structured, repetitive, and purposeful in the sense that the improvement or maintenance of one of more components of physical fitness is the objective*' (World Health Organization, 2010, p52). Focusing on exercise this way appropriately delineates exercise from physical activities of daily living and captures exercise as a behavioral enactment that is sufficiently purposeful to require cognitive processes pertaining to the psychology of motivation (Standage & Ryan, 2012).

[3] Data used in the current manuscript are from the lead authors' unpublished PhD dissertation (Emm-Collison, 2016).

[4] Between subjects effects controlling for wear time: LPA ($F_{(2)}$ =1.416, p=.2.44), MVPA ($F_{(2)}$ =1.335, p=.264), sedentary time ($F_{(2)}$ =.1.213, p=.298)

[5] Specifically, 15 devices were not returned, 27 were excluded due to no weekend wear time, 12 because of insufficient valid days (i.e., 3 valid days or less), and 155 owing to insufficient wear time per day (i.e., wear time of less than 10 hours per day).

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Table 1

Descriptive Statistics, Composite Reliability, and Bivariate Correlations Among the Study Variables

Variable	M (SD) or %	Range	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Gender			-																	
Male	30.8																			
Female	69.2																			
2 Age	12.75 (.90)	11.09-14.74	.11*	-																
3 BMI	20.79 (4.25)	11.35-39.17	.11*	.33**	-															
4 Need Support	5.45 (.81)	2.30-7.00	-.09	-15**	-.22**	***.73***														
5 Peer	5.03 (.98)	1.67-7.00	-.06	-.10*	-.12*	.78**	***.75***													
6 Family	5.73 (1.00)	2.33-7.00	-.08	-.14**	-.21**	.82**	.48**	***.80***												
7 PE teacher	5.60 (1.03)	1.33-7.00	-.07	-.12*	-.20**	.81**	.42**	.51**	***.85***											
8 Need Thwarting	2.63 (.85)	1.03-6.89	.02	.14**	.12*	-.40**	-.19**	.39**	-.28**	***.80***										
9 Peer	2.52 (.89)	1.00-7.00	-.01	.13**	.06	-.28**	-.26**	-.26**	-.15**	.80**	***.74***									
10 Family	2.49 (1.07)	1.00-7.00	.01	.16**	.16**	-.34**	-.14**	-.47**	-.21**	.87**	.58**	***.81***								
11 PE teacher	2.87 (1.08)	1.00-6.67	.04	.05	.08	-.29**	-.10*	-.26**	-.33**	.84**	.50**	.60**	***.77***							
12 Need Satisfaction	5.33 (.93)	2.17-7.00	-.05	-.05	-.31**	.68**	.47**	.61**	.55**	-.26**	-.23**	-.26**	-.18**	***.73***						
13 Need Frustration	2.90 (1.09)	1.00-7.00	.05	.21**	.25**	-.37**	-.19**	-.42**	-.28**	.65**	.52**	.60**	.52**	-.48**	***.70***					

14	Autonomous Motivation	2.89 (.76)	.50-4.00	-.07	-.15**	-.25**	.46**	.31**	.43**	.38**	-.14**	-.06	-.20**	-.09*	.60**	-.38*	***.82***					
15	Controlled Motivation	1.48 (.87)	.00-4.00	-.03	-.03	.15**	-.04	-.02	-.06	-.02	.26**	.21**	.26**	.17**	-.14**	.41**	.05	***.79***				
16	Amotivation	.53 (.84)	.00-4.00	.05	.12*	.06	-.12**	.42**	-.30**	.34**	.34**	.18**	.39**	.28**	-.35**	.47**	-.50**	.17**	***.79***			
17	Daily MVPA (hours)	.69 (.30)	.02-1.65	.02	.06	-.13*	.11*	.07	.05	.13*	-.02	.01	-.04	-.01	.18**	-.01	.18**	.03	-.10	-		
18	Daily LPA (hours)	2.38 (.79)	.13-5.39	.04	-.15**	-.08	.13*	.14*	.05	.12*	-.04	-.06	-.05	.00	.12*	-.04	.17**	.06	-.10	.57**	-	
19	Daily Sedentary Time (hours)	7.26 (1.76)	.38-10.24	-.03	-.06	.01	.09	.12*	-.01	.08	-.07	-.05	-.05	-.09	-.03	.00	-.02	.04	-.06	.19**	.51**	

Note. Significant relationship at * $p<.05$ and ** $p<.01$ (one-tailed). Composite reliability scores (Raykov, 1997) are shown on the diagonal. The cut point for Daily MVPA is ≥2296 counts per minute, the cut point for light activity is 101-2295 counts per minute, and the cut point for daily sedentary time is ≤100 counts per minute (Evenson et al., 2008).

Table 2

Standardized Indirect Effects for the Significant Pathways Between SDT-Related Variables and Daily LPA, MVPA and Sedentary Time

Parameter							Standardized Indirect Effect	Unstandardized Indirect Effect	95% BCa CI
Psychological Need Support	→	Psychological Need frustration	→	Amotivation			-.26**	-.31	-.47, -.07
	→	Psychological Need satisfaction	→	Autonomous motivation			.68**	.85	.57, 85
	→	Psychological Need satisfaction	→	Autonomous motivation	→	LPA	.14**	.15	.05, .25
	→	Psychological Need satisfaction	→	Autonomous motivation	→	MVPA	.16**	.08	.06, 26
Psychological Need Thwarting	→	Psychological Need frustration	→	Amotivation			.26*	.23	.03, .45
	→	Psychological Need frustration	→	Controlled Motivation			.43**	.47	.03, .59
Psychological Need Satisfaction	→	Autonomous motivation	→	LPA			.16*	.15	.05, .29
	→	Autonomous motivation	→	MVPA			.18*	.07	.07, .31

Note. 95% BCa CI = 95 percent bias-corrected and accelerated confidence interval. * Denotes significance at the p<.01 level, ** indicates significance at the p<.001 level

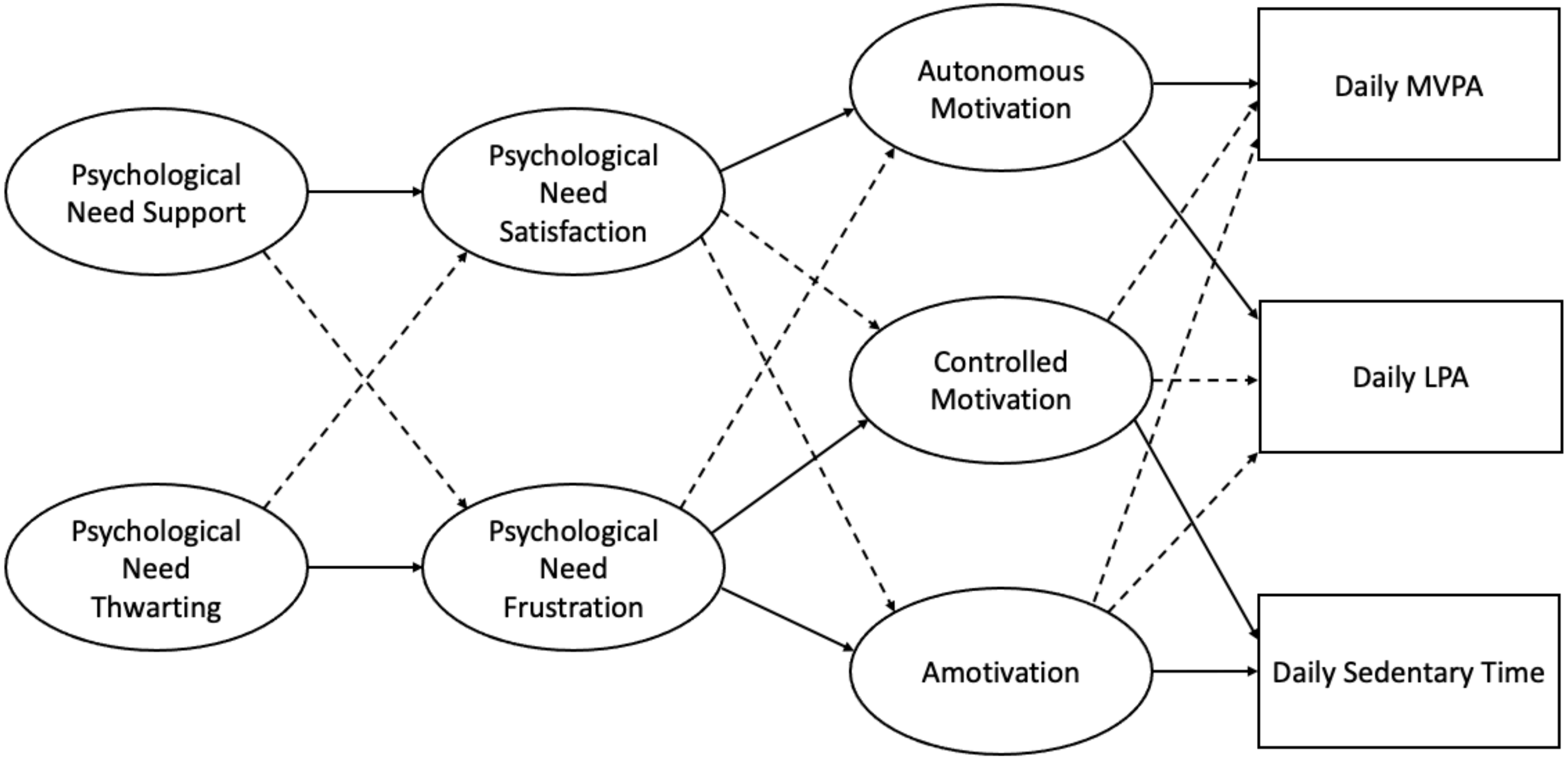
Table 3

Results of Multigroup Analysis Exploring Measurement Invariance by Gender

	χ^2	*df*	*p*	CFI	RMSEA (90% CI)
Unconstrained model	1008.15	550	.000	.89	.05 (.05-.06)
Measurement weights	1040.79	575	.000	.89	.05 (.04-.05)
Measurement intercepts	1058.84	601	.000	.89	.05 (.04-.05)
Structural weights	1077.85	611	.000	.89	.05 (.04-.05)
Structural covariances	1082.31	614	.000	.89	.05 (.04-.05)
Structural residuals	1092.86	623	.000	.89	.05 (.04-.05)
Measurement residuals	1140.18	652	.000	.89	.05 (.04-.05)

Figure 1

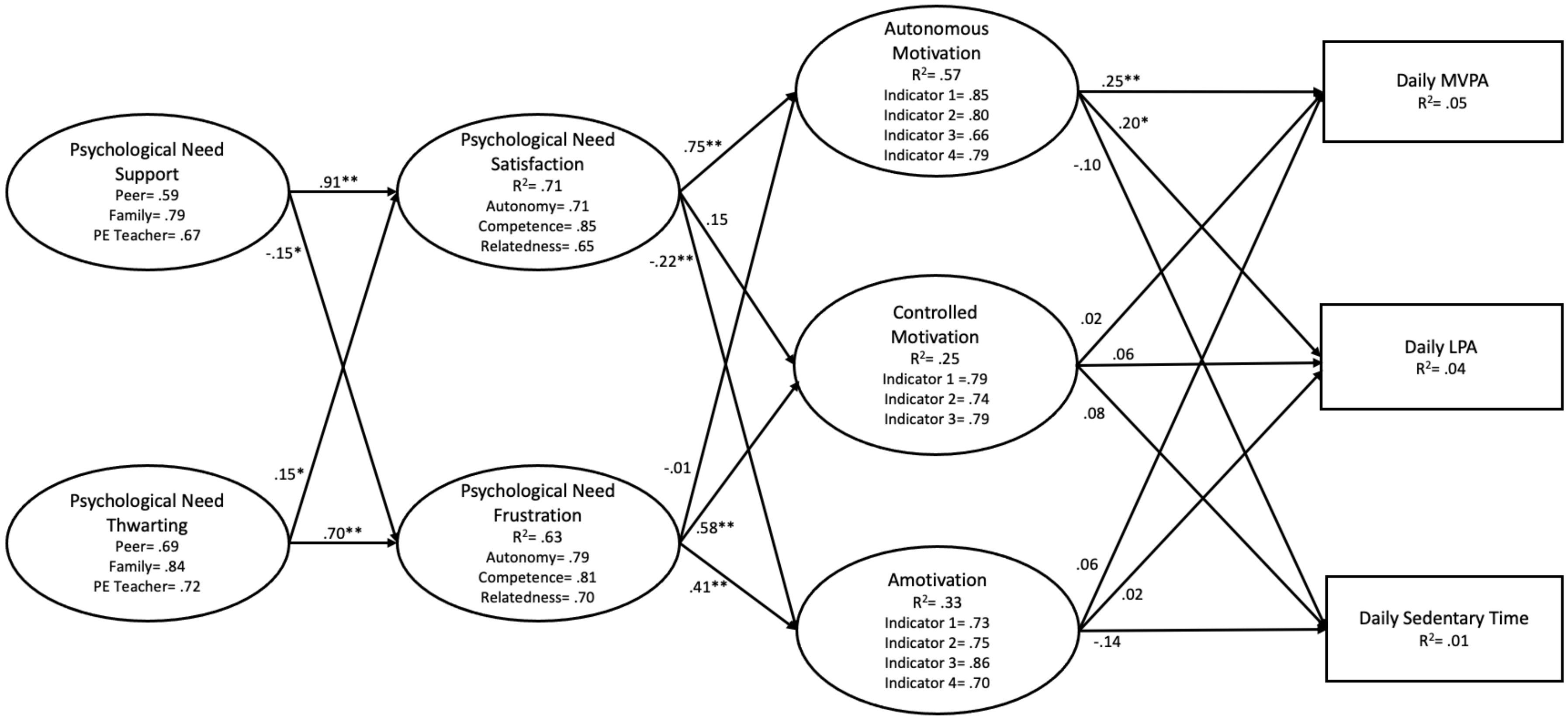
The Hypothesized Dual-Process Model Based on Self-Determination Theory (Ryan & Deci, 2017; Ryan & Vansteenkiste, 2023; Standage & Vallerand, 2014)



Note. Solid lines depict positive hypothesized associations whereas dashed lines depict negative hypothesized associations.

Figure 2

Standardized Regression Weights for the Proposed Model Predicting Daily LPA, MVPA, and Sedentary Time



Note: Standardized regression weights for the manifest variables are presented within each latent variable circle. Path significant at * p<.05, ** p<.01. Standardized covariances between the disturbance terms for need support and need thwarting social contexts (-.51), need satisfaction and frustration (-.86), and autonomous motivation and controlled motivation (.29), autonomous motivation and amotivation (-.48), and controlled motivation and amotivation (-.06) were included in the model but are not shown in Figure 2 for simplicity.