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A Tale of Two Models: Changes in Psychological Need Satisfaction and Physical Activity over 3  
Years

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### Abstract

**Objective:** (a) Examine longitudinal measurement invariance of scores from psychological need satisfaction (PNS) scales and (b) examine if changes in PNS were associated with change in moderate-to-vigorous physical activity (MVPA). **Methods:** Adolescents ( $N=842$ ,  $M_{\text{age}} = 10.8$ ,  $SD = .6$ ) enrolled in the Monitoring Activities of Teenagers to Comprehend their Habits (MATCH) study completed measures of PNS and MVPA every 4 months over a 3 year period (2011-14) for a total of nine times. **Results:** PNS scores demonstrated strong longitudinal measurement invariance (i.e., invariant factor loadings and intercepts). Latent growth curve modeling indicated that a factor representing perceptions of all three PNS variables was positively associated with MVPA at Time 1 ( $\beta = .566$ ,  $p < .05$ ), and that increases in the common PNS factor were associated with increases in MVPA ( $\beta = .545$ ,  $p < .05$ ) with a large effect size ( $R^2_{\text{initial MVPA}} = .316$ ;  $R^2_{\text{change in MVPA}} = .301$ ). In an alternative model, MVPA at Time 1 was associated with perceived common PNS at Time 1 ( $\beta = .602$ ,  $p < .001$ ), and increases in MVPA were associated with increases in common PNS ( $\beta = .667$ ,  $p < .001$ ) with a large effect size ( $R^2_{\text{initial PNS}} = .363$  of the  $R^2_{\text{change in PNS}} = .426$ ). **Conclusions:** Longitudinal measurement invariance was supported, and therefore PNS scores could be used to study change over time. Further, two equally well fitting models were found suggesting that change in PNS can be both an antecedent and an outcome of MVPA. As such, both PNS and MVPA could be targeted in interventions aimed at increasing need satisfaction or MVPA.

**Key words:** psychological need satisfaction; physical activity; longitudinal; adolescent; self-determination theory

As society grapples with the childhood obesity epidemic and the overwhelming prevalence of physical inactivity (World Health Organization [WHO], 2010), strategies to prevent inactivity are being investigated. Moderate-to-vigorous physical activity (MVPA) contributes to improving muscular and cardiorespiratory fitness, bone health, cardiovascular health, and reducing symptoms of depression (WHO, 2010). These benefits extend to youth which led the WHO (2010) to conclude that “physical activity provides fundamental health benefits for children and youth” (p. 18). However, the majority of youth remain insufficiently active (Colley et al., 2011). Research is needed to understand psychological factors that influence adolescents’ MVPA to provide guidance on the development of MVPA programming.

Although there is a large body of research that has examined psychological factors that influence adolescents’ MVPA behavior, gaps in knowledge remain as most researchers have used short-term longitudinal study designs. Longitudinal studies with frequent measurement points examining psychological perceptions experienced in physical activity in general are needed to better understand the factors associated with the decline in MVPA that occurs during the transition from childhood to adolescence (Wall, Carlson, Stein, Lee, & Fulton, 2011). In addition, many researchers have examined if psychological factors experienced during physical education classes predict overall MVPA (e.g., McDavid, Cox, & McDonough, 2014; Standage, Gillison, Ntoumanis, & Treasure, 2012). Moving beyond physical education contexts is necessary to determine the extent to which results obtained in one physical activity context (e.g., physical education) can generalize across all MVPA contexts (i.e., overall MVPA). As such, this investigation aimed to examine the longitudinal associations between key psychological variables – perceptions of competence, autonomy, and relatedness – experienced during physical

activity in general in relation to MVPA over the course of nine measurement points spanning 3 years that characterizes the shift from childhood to adolescence.

### **Basic Psychological Needs Theory**

Basic psychological needs theory (BPNT; Deci & Ryan, 2000) can be used to explain behavior. Deci and Ryan contend that humans are born with key psychological needs for competence (i.e., person's perception of successfully completing optimally challenging tasks), autonomy (i.e., person's perception of agency and volition), and relatedness (i.e., person's perception of belongingness). Satisfying these three psychological needs leads to sustained adaptive behaviors such as MVPA, healthy eating, and less involvement in maladaptive behaviors such as smoking (Ryan, Patrick, Deci, & Williams, 2008). Further, engaging in behaviors can lead to further satisfaction of the psychological needs (Deci & Ryan).

Studying adolescents, several researchers have examined the associations between psychological need satisfaction (PNS) in physical education classes and MVPA over time (Cox, Smith, & Williams, 2008; McDavid, et al, 2014; Standage et al., 2012; Taylor, Ntoumanis, Standage, & Spray 2010). For example Standage et al. found that initial levels of perceived competence and autonomy in physical education classes were marginally, but positively, related to overall step counts 4 days later in adolescents ( $M_{\text{age}} = 12.6$ ,  $SD = .7$ ). Taylor et al. found that students (11- 16 years old) with high initial levels of perceived competence increased their physical activity levels over one school semester (i.e., 3 months) more than those with low initial levels of perceived competence. However, at the within-person level, changes in PNS were not associated with changes in MVPA (Taylor et al.). In contrast, Cox et al. found that increases in perceived competence, autonomy, and relatedness experienced in physical education classes positively predicted increases in physical activity in adolescents ( $M_{\text{age}} = 12.4$  years,  $SD = .7$ ) over

two time points separated by 1 year. Most recently, McDavid et al. demonstrated that in adolescents (11-13 years old), increases in perceived competence and relatedness during physical education classes predicted increases in MVPA over six time points spanning three years.

### **Justification for the Research and Purpose**

In general, PNS has been assessed at different levels – situational (i.e., daily; Gagné, 2003), contextual (i.e., in physical education classes; Taylor et al., 2010), and global (i.e., in general, in life; Sheldon & Elliot, 1999). However, in the majority of studies focused on adolescents in the physical activity literature, researchers assessed perceptions of PNS in physical education classes specifically (McDavid et al., 2014; Taylor et al., 2010; Standage et al., 2012). The focus on physical education is likely because experiences in this context are thought to influence psychological factors (e.g., motivation, PNS) that lead to greater physical activity outside of physical education classes (Standage et al.). Although these findings provide insight into the associations between PNS and behavioral outcomes, it is important to note that physical education is only one aspect of physical activity that may fulfill adolescents' psychological needs. Therefore, assessing PNS in physical education classes may offer a narrow interpretation of adolescents' perceptions of all physical activity-related PNS, thus underestimating the relationship/s between PNS and MVPA. In support of this contention, Barkoukis et al. (2010) found evidence that perceived competence, autonomy, and relatedness assessed in general physical activity contexts were associated with physical activity over five weeks in bivariate analyses ( $M_{\text{age}} = 16.9$  years,  $SD = .7$ ). It is important to extend these findings and examine if adolescents' experiences of PNS in physical activity in general are longitudinally associated with general MVPA in multivariate analyses.

Previous research has also been limited by short periods of follow up (e.g., Taylor et al., 2010), measuring PNS at a single time point (e.g., Standage et al., 2012), or using only two measurement occasions which precludes investigation of trajectories over time (e.g., Cox et al., 2008). Moreover, many studies examined adolescents who were on average, approximately 11 to 13 years of age. To advance knowledge investigators have called for more research examining the relationships between PNS and MVPA over longer periods of time and during different developmental stages of the school cycle (Standage et al.). Indeed, Wigfield and colleagues (1991) found that transitions into a new school had negative effects on self-concept and self-esteem in adolescents. Consequently, previous research with older youth may have had their initial/baseline scores confounded by the child's reaction to changing schooling procedures. Therefore, research is needed to examine younger children prior to school transitions.

Before examining trajectories of change, longitudinal measurement invariance should be established to ensure that the same variables are assessed on the same metric across time (Widaman, Ferrer, & Conger, 2011). If longitudinal invariance does not hold, it is difficult to know if the patterns of change observed are caused by change in the variables or caused by change in the measurement of the variables over time (Brown, 2006). Despite the notion that factors associated with time (e.g., cognitive development) can distort the pattern of responding over time, researchers examining the longitudinal relationship/s between PNS and MVPA have yet to examine invariance over time. Also, most have based their analyses on manifest variables which do not account for measurement error (Brown, 2006). To ensure results are not biased from measurement error associated with manifest variables and/or from scores potentially not maintaining the same meaning or metric over time, establishing longitudinal invariance is critical.

The first purpose of this study was to examine longitudinal invariance of scores from the PNS scales to ensure results reflect changes in reported levels rather than changes in the constructs meaning over time. The second purpose was to examine if changes in PNS in general physical activity contexts were associated with change in MVPA over nine measurement occasions spanning 3 years that characterize the transition from childhood to adolescence. Because Deci and Ryan (2000) suggest that engaging in behaviors can lead to further increases in perceptions of PNS, and based on the results of emerging research in work and organizational (Devloo, Anseel, De Beuckleer, & Salanova, 2014) and educational (Jang, Kim, & Reeve, 2012) psychology that have demonstrated reciprocal relationships between PNS and behaviors, an alternative model was tested. The alternative model examined PNS as an outcome of MVPA rather than as an antecedent to MVPA.<sup>1</sup>

## **Methods**

### **Participants and Procedures**

Participants were adolescents enrolled in the Monitoring Activities to Comprehend their Habits (MATCH) study. The MATCH study was approved by the Comité d'Éthique de la Recherche du Centre Hospitalier de l'Université de Sherbrooke and all participating adolescents and their parents completed informed consent. Details about the MATCH study are provided elsewhere (Bélanger et al., 2013). Briefly, MATCH is a cohort study that involved English- and French-speaking adolescents from 17 schools in New Brunswick, Canada. Adolescents from grades five and six in schools situated in rural and urban areas representing diverse backgrounds were recruited in the Fall of 2011 to complete self-report questionnaires three times per year

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<sup>1</sup> We thank an anonymous reviewer for suggesting we test an alternative model that is based within SDT, yet rarely tested.

(Fall, Winter, and Spring) every year until they graduate from grade 12. At each time point, participants completed the questionnaires in a classroom with supervision from a trained research assistant at a time that was deemed convenient for the teachers. Initially, the questionnaires took 45-60 minutes to complete, whereas subsequent questionnaires took 20-30 minutes to complete. Data for nine survey cycles were available for this study. In total, data from 842 adolescents ( $n_{\text{male}} = 470$ ,  $n_{\text{female}} = 372$ ) were analyzed. At study inception, they ranged in age from 8.9 to 12.5 years ( $M = 10.8$ ,  $SD = .6$ ), 53.2% were in grade five, and over half of the students were attending French schools (67.3%).

### **Measures**

**Translation of measures.** Participants completed scales in the language of their preference (English or French). When French versions were not available, English scales were translated into French by a bilingual kinesiologist whose first language was French. Emphasis was placed on conceptual translation rather than literal translations. Next, three bilingual members of the research team reviewed and edited the translation to ensure consistency with the English versions. Finally, the French items were back-translated by an independent individual whose primary language was English. The final English and French versions were compared for consistency to ensure validity evidence based on content.

**MVPA.** MVPA was assessed with a 2-item measure developed specifically for adolescents (Prochaska, Sallis, & Long, 2001). Participants were asked to read the following statement: “Physical activity is an activity that increases your heart rate and makes you get out of breath some of the time. Physical activity can be done in sports, playing with friends, or walking to school. Some examples of physical activity are running, brisk walking, rollerblading, biking, dancing, skateboarding, swimming, soccer, basketball, football, and surfing.” They were then



asked to respond to the following two questions: “Over the course of the week (past 7 days), how many days were you physically active for a total of at least 60 minutes per day?” and “Over the course of a typical or usual week, how many days are you physically active for a total of at least 60 minutes per day?” Response options ranged from 0 to 7 days. In addition to being a measure recommended to assess MVPA (Biddle, Gorely, Pearson, & Bull, 2011), scores have demonstrated reliability and validity (Prochaska et al.). Also, scores have shown a sensitivity (i.e., correct classification of children not meeting guidelines based on self-report scores compared to accelerometer scores) of 71%, correct classification of 63% and false positive rate of 40% (Prochaska et al.).

**PNS in physical activity.** The next set of questionnaires participants completed were designed to assess PNS in relation to physical activity, which participants now recognized as a general behavior because they had read the above definition of physical activity. To ensure perceived competence, autonomy, and relatedness were assessed in this context, the following instructions were provided: “The following statements represent different feelings people have when they engage in physical activity. Using the scale provided, please answer the following questions by considering how you typically feel when participating in physical activity.” Perceived competence was assessed with the 6-item subscale from the Intrinsic Motivation Inventory (IMI; McAuley, Duncan, & Tammen, 1989). It consists of five positively worded items (e.g., “I think I am pretty good at physical activity”) and one negatively worded item (e.g., “Physical activity is not something I can do very well”). Perceived autonomy was assessed with the 7-item autonomy subscale from the Basic Psychological Needs in Life Scale (BPNLS; Gagné, 2003) adapted to physical activity contexts. It contains four positively worded items (e.g., “When I participate in physical activity, I feel like I can pretty much be myself”) and three

negatively worded items (e.g., “When I participate in physical activity, I frequently have to do what I am told”). Participants were asked to respond to each item on a scale ranging from 1 (*not at all true*) to 7 (*very true*). Negatively worded items were reverse coded. The IMI and BPNLS subscales were selected because they have been used in previous research with adolescents and have demonstrated good score reliability (Standage et al., 2012; Taylor et al., 2010). Perceived relatedness was assessed using the 6-item Relatedness to Others in Physical Activity Scale (ROPAS; Wilson & Bengoeachea, 2010). All items were positively worded (e.g., “I feel like I am part of a group who share my goals”). Participants were asked to respond to each item on a scale of 1 (*false*) to 7 (*true*). While the ROPAS was developed to assess adults’ perceptions of relatedness in physical activity contexts, evidence of score reliability and validity for ROPAS scores has been demonstrated for adolescents (Sebire, Jago, Fox, Edwards, & Thompson, 2013).

### **Data Analyses**

Analyses were conducted using Mplus 7.3 using Full Information Maximum Likelihood Robust (MLR) estimation to account for the possible non-normality of the data and missing data. Individual confirmatory factor analyses (CFA) were estimated for perceived competence, autonomy, and relatedness satisfaction scales within a single model at each time point by setting the first factor loading of each latent variable to 1.0 (Brown, 2006). Coefficient H was calculated for each PNS scale at each cycle based on these CFA results (Hancock & Mueller, 2001).

**Measurement invariance.** Invariance testing was conducted to test the longitudinal invariance of scores derived from the PNS scales. Following Meredith’s (1993) recommendations, invariance testing involved comparing nested models with increasingly restrictive constraints. In each model, error covariances between matching indicators over time were estimated freely because the same items were used at each time point and therefore

expected to contain the same sources of error (Geiser, 2013). The first level of invariance assessed was *configural* whereby no constraints were placed on the parameters. Configural invariance examines if the same factor structure (i.e., the same latent factor predicts the same items) held across time. Next, *weak* invariance was tested whereby factor loadings were constrained to equality across time. Weak invariance tests if the strength of the relationships between the latent factors (i.e., competence, autonomy, and relatedness) and their respective items were the same across time and if the latent factors had the same meaning across time (Cheung & Rensvold, 2002; Gregorich, 2006). *Strong* invariance was tested by constraining factor loadings and item intercepts to equality across time. Strong invariance tests if the latent variable means were unbiased (i.e., are the latent variables scaled identically across time) and represents the necessary level of invariance to examine change over time. Finally, *strict* invariance was examined by constraining factor loadings, item intercepts, and error covariances to equality across time. Strict invariance tests if items had the same degree of measurement error over time (Cheung & Rensvold, 2002).

**Longitudinal Models of PNS and MVPA.** Multiple indicators latent growth curve modeling (LGM) was used to examine if changes in PNS were associated with change in MVPA over time. LGM focuses on the form of change (Geiser, 2013) and is used to examine trajectories of change while modeling group and individual differences (Duncan, Duncan, & Strycker, 2006). In LGM, two latent factors are modelled for each construct: (1) *intercepts*, which represent Time 1 scores, and (2) *slopes*, which represent change from Time 1 to Time 9, inclusively. In this study, PNS was modelled as latent variables and MVPA was modelled as a manifest variable.

As a first step, an intercept-only model which did not specify slope factors was examined (Model 1). Next, an intercept and slope model (Model 2; i.e., a model that assumes change over

time) was tested and compared to Model 1 to determine if change in the variables over time was tenable (approach to compare models is explained below). The intercept latent factor was specified to have factor loadings of 1.0 for both these models, and the slope factor for Model 2 was specified to have loadings of 0, 1, 2, 3, 4, 5, 6, 7, and 8 corresponding with each of the nine assessments. Furthermore, both models were tested with longitudinal invariance constraints, correlated errors between identical indicators over time, and freely estimated error covariances between each latent PNS item at each time point (e.g., autonomy at Time 1 was allowed to covary with relatedness and competence at Time 1). Then, a third model was tested to determine if there was a decrease or increase in rate of change by adding quadratic slope factors (i.e., additional factors with factor loadings set to 0, 1, 4, 9, 16, 25, 36, 49, 64, and 81), and was compared to Model 2. The better fitting model was retained for further analyses and results from the better fitting model were interpreted for descriptive statistics and correlations between variables' intercepts (i.e., correlations at Time 1) and slopes (i.e., correlations among change).

Next, based on the high degree of covariation between each PNS variable observed in Model 2, a *factor-of-curves LGM* (Duncan et al., 2006) was tested (Model 4). The factor-of-curves model allows researchers to examine if a higher-order factor (i.e., a common PNS intercept and slope) accounts for the covariation between first-order factors (i.e., intercepts and slopes of competence, autonomy, and relatedness). In this model, the covariances between each PNS intercept and slope were constrained to zero and factor loadings between the second-order and first-order factors were constrained to equality (Duncan et al.). As such, a common intercept for PNS was created by regressing this latent factor onto the latent intercept factors of competence, autonomy, and relatedness with equality constraints. Similarly, a common slope for PNS was created by regressing this factor onto the latent slopes of competence, autonomy, and

relatedness with equality constraints. The factor loadings from the common PNS intercept and slopes to competence were set to 1.0 to identify the latent factors. This model was then compared to the previously retained model.

***LGM Path Models.*** The main model (Model 5) and an alternative model (Model 6) were then estimated based on the best fitting model (Models 2, 3, or 4) from the steps outlined above. Model 5 was tested by having regression paths from: (1) the intercepts of competence, autonomy, and relatedness (or common PNS intercept if Model 4 was selected) to the intercept and the slope of MVPA, and (2) the slopes of competence, autonomy, and relatedness (or common PNS slope if Model 4 was selected) to the slope of MVPA. In Model 6, regression paths from: (1) the intercept of MVPA to the intercept and slopes of competence, autonomy, and relatedness (or a common PNS intercept and slope if Model 4 was selected), and (2) the slope of MVPA to the slopes of competence, autonomy, and relatedness (or common PNS slope if Model 4 was selected) were tested.

### **Assessing Model Fit**

Chi-square values are reported; however, they were not used exclusively to interpret model fit as they are known to be overly stringent with large sample sizes (Brown, 2006). Parameter estimates, effect sizes, and alternative indexes of fit were also reported and interpreted (Brown, 2006). The following goodness-of-fit statistics were examined to assess overall model fit: comparative fit index (CFI) and Tucker Lewis index (TLI) values close to .90 and .95 were deemed acceptable; root mean square error of approximation (RMSEA) values close to or below .08 were deemed acceptable (Brown, 2006; Hu & Bentler, 1999). Because LGMs commonly have ‘bad’ fit by conventional criteria (Preacher, 2010), when interpreting the fit of the LGMs

we focused on theory and interpreting values *close to* the guidelines rather than making data driven modifications to obtain a model that met stringent cut-off criteria.

Invariance models were acceptable if the change in CFI was equal to or below  $|\Delta CFI| \leq .01$  (Cheung & Rensvold, 2002) combined with a change in RMSEA equal to or below  $|\Delta RMSEA| \leq .015$  in RMSEA (Chen, 2007) from the less constrained model. MLR-chi-square difference tests were also examined using an online calculator that employs chi-square difference testing using the Satorra-Bentler Scaled Chi-square (Colwell, 2014) between nested models but more weight was placed on interpretation of the delta CFI and RMSEA based on the evidence that chi-square is overly stringent (Brown, 2006). Comparisons of LGMs (i.e., Model 1 to Model 6) were made using the goodness-of-fit of each model in addition to comparing the Akaike's Information Criterion (AIC), and Bayesian Information Criteria (BIC) whereby models with a better fit and smaller AIC and BIC values were deemed superior. Effect sizes (i.e.,  $R^2$ ) were interpreted as small = .01, medium = .09, or large = .25 (Cohen, Cohen, West, & Aiken, 2002). Given that Models 5 and 6 were empirically indistinguishable based on fit indices alone, parameter estimates and  $R^2$ 's were considered to determine if one model provided a better fit to the data compared to the other.

## Results

Missing data on MVPA ranged between 12.83% and 29.10% and on the items of PNS subscales between 15.8 % and 49.41% across time points (see Table 1 for sample sizes for each latent variable at each time). Results of the CFA for the PNS subscales assessed at Time 1 indicated room for improvement ( $\chi^2_{(149)} = 437.24, p < .001, CFI = .858, RMSEA = .061, 90\%CI [0.054, 0.067]$ ). Examination of the factor loadings indicated that the negatively worded items for autonomy (factor loadings: -.471 to -.693) and competence (factor loading: .290) were

problematic. After negatively worded items were removed, the model provided a better fit to the data at each time points (see Table 1), and model fit increased over time.

Results of the longitudinal invariance testing of the PNS scale responses indicated the tenability of strong invariance based on criteria of change in CFI and RMSEA. Strict invariance testing led to a drop in fit (see Table 1), and was therefore not considered tenable. Nonetheless, given that strong invariance was established and is the prerequisite for assessing change (Brown, 2006), analyses proceeded to the LGMs.

Both the intercept-only model (Model 1;  $\chi^2_{(9808)} = 16750.877, p < .001, CFI = .888, TLI = .883, RMSEA = .029, 90\%CI [0.028, 0.030], AIC = 290603.841, BIC = 294278.806$ ) and the intercept and slope model (Model 2;  $\chi^2_{(9778)} = 15981.301, p < .001, CFI = .900, TLI = .895, RMSEA = .027, 90\%CI [0.027, 0.030], AIC = 289817.231, BIC = 293634.270$ ) had some fit indices that fell slightly below conventional cut-off criteria, while others met the cut-off criteria. Modification indices suggested the presence of numerous small cross-loadings and correlated errors over the nine measurement occasions. Based on theory and contentions that LGM notoriously fail to meet standard SEM cut-off criteria (Preacher, 2010), we did not pursue data driven modifications. Furthermore, the RMSEA values were good and the associated confidence intervals were narrow. Based on the AIC and BIC, Model 2 provided a better fit to the data than Model 1, indicating that there were changes in PNS and MVPA. As seen in Table 2, the means and variances for all variables were statistically significant. On average, adolescents engaged in 4.42 days of MVPA per week, with significant variability in that mean across individuals as reflected by the intercept variance score. All PNS variables were on average endorsed above the mid-point of their scales and there was significant variability around their Time 1 means as reflected by the variance scores. Perceptions of PNS decreased over time whereas MVPA

increased. The variances for all slope factors were statistically significant indicating that there was variability in adolescents' change in PNS and MVPA. Bivariate correlations are presented in Table 2.

The addition of the quadratic term in Model 3 caused the model to terminate before successfully converging. As such, quadratic terms were not pursued in any subsequent analyses. Next, the factor-of-curves LGM (Model 4), which included a common PNS intercept and slope factor to account for the covariation between each PNS intercept and slope had a better fit compared to Model 2 (Model 4:  $\chi^2_{(9796)} = 16069.964, p < .001$ . CFI = .899, TLI = .894, RMSEA = .028, 90%CI [0.027, 0.028], AIC = 289876.959, BIC = 293608.753). Further, it was considered more parsimonious and therefore used to test the associations between PNS and MVPA variables. In this model, common PNS decreased over time ( $M_{\text{intercept}} = 5.355$ , variance = 0.768,  $ps < .05$ ;  $M_{\text{slope}} = -0.064$ , variance = 0.016,  $ps < .05$ ). The means and slopes of MVPA in this model were identical to those presented in Table 2.

### LGM Path Models

Model 5, in which PNS was modeled as an antecedent to MVPA, indicated an acceptable fit to the data ( $\chi^2_{(9797)} = 16073.311, p < .001$ . CFI = .899, TLI = .894, RMSEA = .028, 90%CI [0.027, 0.028], AIC = 289878.417, BIC = 293605.476; see Figure 1), albeit the CFI and TLI were slightly below the recommended levels. Perceived common PNS at Time 1 was positively associated with MVPA at Time 1. Increases in common PNS were associated with increases in MVPA over time. Model 5 accounted for 31.6% of the variance in MVPA at Time 1 and 30.1% of the variance in change in MVPA over time<sup>2</sup>. The alternative model (Model 6) with PNS

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<sup>2</sup> We did not statistically control for any variables in this model based on the theoretical rationale that psychological needs are universal and innate. As a supplemental analysis, we re-ran additional models examining sex as a covariate. First, we tested the PNS subscale scores for sex invariance at each time point and found evidence of strict invariance. Next we re-ran Models 5 and 6 controlling for sex. For



modelled as an outcome of MVPA indicated a near-equivalent fit to Model 5 ( $\chi^2_{(9797)} = 16072.488, p < .001$ . CFI = .899, TLI = .894, RMSEA = .028, 90%CI [0.027, 0.028], AIC = 289877.849, BIC = .293604.908; see Figure 2). MVPA at Time 1 was positively associated with perceived common PNS at Time 1. Increases in MVPA were associated with increases in common PNS over time. Model 6 accounted for 36.3% of the variance in perceived common PNS at Time 1 and 42.6% of the variance in change in perceived common PNS over time<sup>2</sup>. Given that both Models 5 and 6 demonstrated near-equivalent model fit, had statistically significant paths that were theoretically meaningful, and had large effect sizes, both models were retained as equally plausible explanations of the data (MacCallum, Wegener, Uchino, & Fabrigar, 1993).

### Discussion

As an important first step, this study found evidence that responses to the scales used to assess perceived PNS in physical activity retained their meaning over nine separate measurement points spanning 3 years during the transition from childhood to adolescence – a period characterized by significant cognitive developmental changes (Steinberg, 2005). Second, this study provided evidence that, on average, adolescents' perceptions of competence, autonomy, and relatedness decreased over time, and the same pattern was observed when a higher-order common PNS variable was examined. Last, it provided insight into the longitudinal associations between BPNT constructs and MVPA. Results from two competing models suggested that in one model, a common factor of PNS was an antecedent to MVPA whereas in a second equally well

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Model 5, sex did not significantly predict the common PNS or MVPA intercepts and slopes ( $p > .13$ ). In Model 6, sex significantly predicted only initial MVPA ( $p = .04$ ) but no other variables ( $p > .85$ ). Because we found that the inclusion of sex did not alter the interpretation of any of the main paths between common PNS and MVPA in Models 5 or 6 and model fit was slightly worse when sex was included we present the results without controlling for sex. Results are available from the first author upon request.

fitting model, PNS was an outcome to MVPA over time. This finding is important and novel to the literature because it supports Deci and Ryan's (2000) proposition that fulfilling psychological needs is essential for behavioral persistence and that engaging in behavior can also lead to increases in PNS. Results also extended previous research focusing on PNS in the context of physical education by examining PNS in general physical activity.

### **Assessing PNS over Time**

The analytical approach used herein (i.e., LGM) has two important advantages compared to past research that has examined change in PNS over time. First, measurement error can be reduced by modeling latent variables and therefore the results provide a truer approximation of predictors of change in outcomes (Duncan et al., 2006). Second, LGM allows for the examination of measurement invariance. Considering few researchers have employed latent variable techniques that allowed for the removal of measurement error and the direct examination of longitudinal invariance despite the potential consequences of using non-invariant measures to draw conclusions about change over time, the results from the current investigation fill an important gap in the literature. Specifically, we found evidence to support strong invariance during a key developmental life period. As a result, one can infer that changes in the latent variables representing PNS can be meaningfully interpreted without contamination from additive response bias (i.e., biases unrelated to the construct of interest such as age) when using these measures. This has implications for research where it is important to test changes in PNS over time and/or whether interventions can effectively change PNS.

### **Changes in PNS and MVPA over Time**

Consistent with previous research among adolescents assessing PNS in physical education classes (McDavid et al., 2014; Taylor et al., 2010) and academic contexts (Ratelle &

Duchesne, 2014), perceptions of competence, autonomy, and relatedness, as well as a common factor of PNS generally decreased over time in this study. Considering that the current findings extend contextual PNS in relations to general physical activity, it would be interesting to assess the impact of school-related factors (e.g., see Ratelle & Duchesne, 2014) and motivational factors (e.g., McDavid et al., 2014; Taylor et al., 2010) on PNS. For example, adolescents' become more extrinsically motivated for physical education (i.e., engage in to avoid guilt or shame) over time and less autonomously motivated (i.e., engaging in it because they value it; McDavid et al.). Based on Deci and Ryan's (2000) contention that extrinsic motivation can be detrimental to PNS and results from the PE literature (McDavid et al., 2014), researchers could examine if general physical activity participation becomes more externally regulated as youth develop and these shifts in motivation explain the observed decreases in PNS.

The finding that self-reported MVPA increased over time is contrary to research showing that MVPA declines with age (Wall et al., 2011), although exceptions have been noted in the literature (Knuth & Hallal, 2009). It is possible that the use of LGM explains these divergent findings. In the past, researchers have either correlated MVPA with age in cross-sectional studies or examined *mean-level* changes, thereby treating individual variability as error which could lead to any individual differences in change being concealed. LGM allows for the examination of trajectories at the *within-* and *between-person* levels of analysis. In other words, LGM allows researchers to examine different types of trajectories of change (e.g., linear, quadratic) while accounting for individual variability in change. To this end, researchers who have used similar longitudinal analyses as LGM such as hierarchical linear modelling have also observed an increase in MVPA over time in adolescents aged 11 to 16 years (Taylor et al., 2010) and 11 to 13 years of age (McDavid et al., 2014).

In addition to the analytical explanation, the decrease in MVPA observed could also be related participants' age. Researchers have noted that declines in MVPA are particularly salient from mid-to-late adolescents (Knuth & Hallal, 2009) whereas the current sample was assessed during early-to-mid adolescence. Over time, it will be interesting to examine if adolescents from the MATCH study decline in MVPA as they enter late adolescence. Alternatively, it is possible that frequent administration of the self-report MVPA measure led participants to increase their level of MVPA over time. This is nevertheless unlikely as results from literature reviews indicate that to successfully increase MVPA, interventions need to be theory-driven, complex, and multi-factorial (van Sluijs, McMinn, Griffon, 2007). Finally, although the MVPA measure has been used extensively, it does not provide precise estimates of frequency, intensity, or time engaged in MVPA. Researchers should replicate the present analyses using more direct measures of MVPA.

### **Relationships between PNS and MVPA at Time 1 and Overtime**

Initial PNS did not predict changes in MVPA, yet increases in PNS over time predicted increases in MVPA over time. Although these results are generally consistent with previous research (e.g., McDavid et al., 2014; Standage et al., 2012), it is important to note that comparatively less empirical attention has been devoted to examining MVPA as a predictor of PNS. Emerging empirical evidence in education and work and organizational psychology has found that PNS is both an antecedent and outcome of behavior (see Devloo et al., 2014; Jang et al., 2012). To this end, the results of our alternative model in which PNS was an outcome of MVPA indicated that engaging in more MVPA over time is associated with increases in PNS during the same time period, regardless of baseline PNS.

Taken together, the finding that both models fit the data equally well represents an avenue for future research and theory testing (MacCallum et al., 1993). Although our analyses

are correlational in nature, our results supported both models of development over time and suggest that researchers should consider examining reciprocal effects models in the future (e.g., cross-lagged, auto-regressive latent trajectory models). LGM was appropriate for examining our research question about the form of change over the entire measurement period (unlike cross-lagged analysis which assesses change between two time points over multiple occasions).

Moving forward, researchers testing SDT could consider developing investigations that allow for tests of causality. Such investigations may yield insight into which variables should be targeted in interventions, and in what order they should be targeted (i.e., PNS or MVPA first). Based on our results, it is possible that intervening on both PNS and MVPA could result in increases in MVPA and PNS.

### **Practical Implications**

Based on current and previous findings (McDavid et al., 2014; Taylor et al., 2010) showing that PNS declines during the transition from childhood to adolescence, more research is needed to develop interventions that seek to maintain or enhance adolescents' perceptions of PNS. Such interventions might include strategies to (a) facilitate integration of physical activity and help adolescents identify autonomous methods for coping with barriers or resistance to behavioral engagement (i.e., autonomy), (b) provide adolescents with opportunities for mastery and avoid over challenging situations (i.e., competence), and (c) provide adolescents with respect, caring, and understanding to bolster perceptions of relatedness (Ryan et al., 2008). The current results which support both models of PNS as an antecedent and outcome of MVPA call for more research to identify which variables should be targeted in interventions or if targeting both variables simultaneously is beneficial. More research is also needed to delineate causal mechanisms and potential moderators of the relationship between PNS and MVPA.

### Limitations and Future Directions

In addition to the limitations acknowledged above, other limitations should be considered when interpreting the results of this investigation. First, the goodness-of-fit statistics for the invariance models and the LGM indicated that the CFI and TLI values fell below conventional cut-off values of close to .95 (Hu & Bentler, 1999). The justification for not pursuing post-hoc modifications was threefold: (1) given the *a priori* hypotheses about the factor structure, there was no theoretical rationale to make modifications by adding correlated errors, (2) Marsh and colleagues (2004) argued that the cut-off values proposed by Hu and Bentler (1999) are “...largely unobtainable in appropriate practice” (p. 326), and Preacher has stated that LGMs “are notoriously poor fitting by traditional criteria” (p. 196), and (3) there have been arguments made that model evaluations should take into account parameter estimates, amount of variance accounted for, and previous research findings (Brown, 2006; Marsh, Hau, & Wen, 2004). In line with these contentions, researchers have found goodness-of-fit statistics similar to ours for structural equation models with PNS and MVPA (see McDonough & Crocker, 2007 for example). Moreover, the models produced large effect sizes and robust parameter estimates. Second, we used a self-report assessment of MVPA. Our MVPA data suggested that 12.7 %-20.3% of participants met Canada’s MVPA guidelines across survey cycles compared to only 9% of Canadian children meeting the guidelines when measured via accelerometer data in a population-based sample (ParticipACTION, 2015). Nonetheless, sample statistics from the MVPA data suggest that our sample was comparable to the sample used by Prochaska and colleagues (2001) as evidenced by similar mean level MVPA scores. Third, the generalizability of our findings may have been affected by a non-probabilistic sample of schools, a low recruitment proportion of participants at study inception and some loss to follow-up.

Nevertheless, the aim of the study was not to describe population-level characteristics (for which a representative sample would be required), but to assess relationships across variables.

Fourth, the sample size was relatively small for the complexity of the models and there was a high proportion of missing data at selected survey cycles. Although full information maximum likelihood estimation was been shown to be less biased than listwise deletion (Enders & Bandalos, 2001), the low coverage (e.g., the minimum coverage between MVPA and PNS items was .374) may have biased the parameter estimates and therefore results should be interpreted with caution. Researchers should seek to obtain larger sample sizes when replicating and extending the findings presented here. Similarly, we were unable to analyze the nested structure due to an error produced by Mplus. This error could be attributable to the low number of groups ( $n_{\text{schools}} = 17$ ) or the presence of missing data at various schools across survey cycles. Researchers should conduct *a priori* power analysis using Monte Carlo techniques to determine required sample sizes and seek to collect data from a larger number of schools to allow for an examination of multi-level latent growth models. Fifth, despite the advantages associated with using LGM, we were unable to determine if each PNS variable predicted MVPA because the high covariation between each need caused model misfit. Researchers may wish to use exploratory structural equation modeling or bi-factor modeling techniques to circumvent problems associated with high item cross-loadings and covariations. Finally, as LGM analytic techniques continue to develop, researchers should investigate how baseline scores (i.e., intercepts) interact with change scores (i.e., slopes) to predict MVPA or PNS.

### **Conclusion**

The present study contributes new knowledge on how changes in PNS across grades five and six to eight and nine are associated with change in MVPA. Overall, findings supported the

use of the PNS scale scores across this developmental period, and demonstrated that perceptions of competence, autonomy, and relatedness assessed within global physical activity contexts decreased over time. Further, consistent with the BPNT perspective (Deci & Ryan, 2000) results from two competing models indicated that PNS can be modeling as either an antecedent or outcome of MVPA over time.



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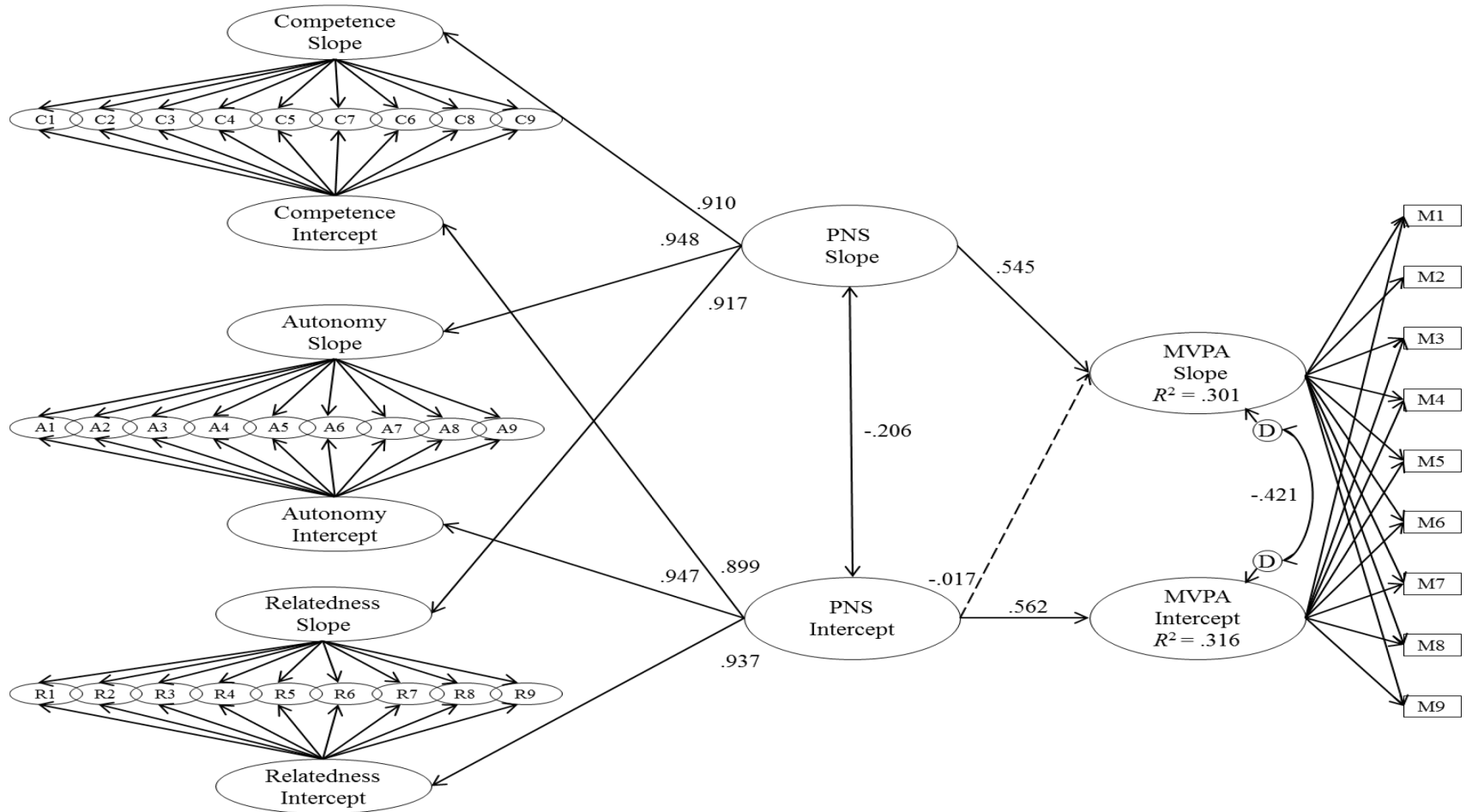


Figure 1. Results of Model 5. Double headed arrows represent standardized covariances, single headed arrows represent standardized regression paths. Squared boxes represent manifest variables. Ovals represent latent factors. For simplicity, error covariances between item indicators are not shown nor are factor loadings from each PNS intercept and slope to indicators. Values for item indicators for each psychological need satisfaction latent variable are not shown. C = competence, A = autonomy, R = relatedness, M = moderate-to-vigorous physical activity, D = disturbance term. Solid line  $p < .05$ , dashed line  $p > .05$ .

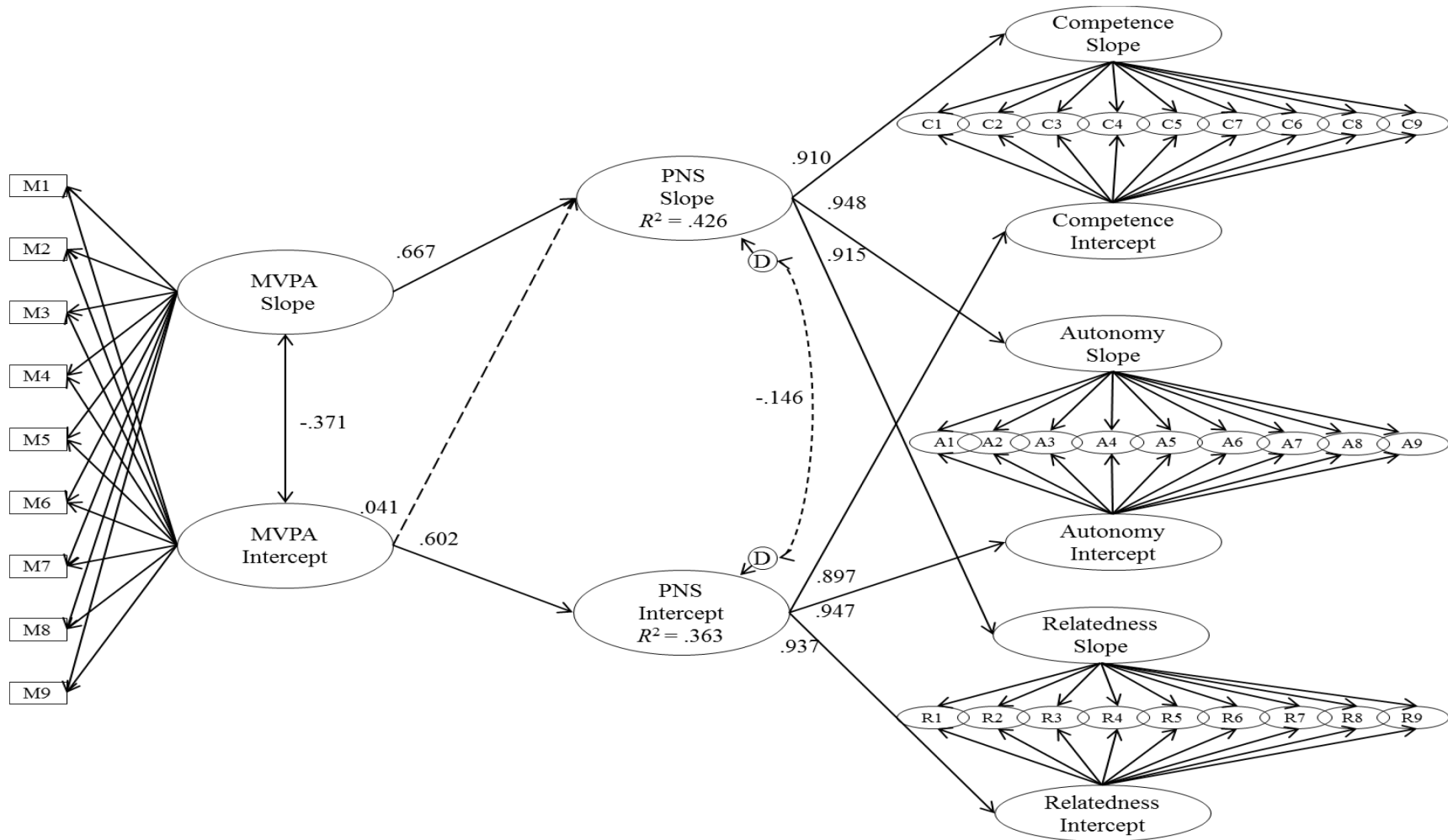


Figure 2. Results of Model 6. Double headed arrows represent standardized covariances, single headed arrows represent standardized regression paths. Squared boxes represent manifest variables. Ovals represent latent factors. For simplicity, error covariances between item indicators are not shown nor are factor loadings from each PNS intercept and slope to indicators. Values for item indicators for each psychological need satisfaction latent variable are not shown. C = competence, A = autonomy, R = relatedness, M = moderate-to-vigorous physical activity, D = disturbance term. Solid line  $p < .05$ , dashed line  $p > .05$ .



Table 1  
*Results of the Confirmatory Factor Analyses and Longitudinal Invariance Tests*

Model	<i>n</i>	$\chi^2_{(df)}$	$\Delta\chi^2_{(df)}$	TLI	CFI	$\Delta$ CFI	RMSEA A	RMSEA 90%CI	$\Delta$ RMSEA	Com H	Aut H	Rel H
Individual CFAs at each time point												
Time 1	528	222.428* <sub>(87)</sub>	--	.904	.921	--	0.054	[0.046, 0.063]	--	.828	.674	.830
Time 2	699	286.982* <sub>(87)</sub>	--	.917	.931	--	0.057	[0.050, 0.065]	--	.835	.769	.875
Time 3	718	355.419* <sub>(87)</sub>	--	.913	.928	--	0.066	[0.059, 0.073]	--	.875	.784	.892
Time 4	684	292.980* <sub>(87)</sub>	--	.924	.937	--	0.059	[0.051, 0.066]	--	.855	.797	.895
Time 5	673	372.123* <sub>(87)</sub>	--	.905	.921	--	0.070	[0.063, 0.077]	--	.868	.821	.914
Time 6	620	278.409* <sub>(87)</sub>	--	.943	.952	--	0.060	[0.052, 0.067]	--	.899	.877	.942
Time 7	650	362.196* <sub>(87)</sub>	--	.920	.934	--	0.070	[0.062, 0.077]	--	.910	.854	.933
Time 8	634	407.435* <sub>(87)</sub>	--	.915	.930	--	0.076	[0.069, 0.084]	--	.915	.888	.951
Time 9	606	371.407* <sub>(87)</sub>	--	.920	.933	--	0.073	[0.066, 0.081]	--	.890	.887	.954
Measurement invariance												
Config	840	12971.725* <sub>(8019)</sub>	--	.904	.915	--	0.027	[0.026, 0.028]	--	--	--	--
Weak	840	13105.387* <sub>(8115)</sub>	132.066* <sub>(96)</sub>	.904	.914	0.001	0.027	[0.026, 0.028]	0	--	--	--
Strong	840	13575.508* <sub>(8235)</sub>	498.401* <sub>(120)</sub>	.899	.908	0.006	0.028	[0.027, 0.029]	0.001	--	--	--
Strict	840	14445.031* <sub>(8350)</sub>	601.803* <sub>(115)</sub>	.886	.895	0.013	0.029	[0.029, 0.030]	0.001	--	--	--

*Notes.* \*  $p < .05$ . Config = configural invariance (all parameters freely estimated), Weak = weak invariance (factor loadings constrained to equality), Strong = strong invariance (factor loadings and item intercepts constrained to equality), Strict = Strict invariance (factor loadings, item intercepts, and residuals constrained to equality).  $\chi^2_{(df)}$  = Chi-square and degrees of freedom, CFI = Comparative Fit Index, RMSEA = Root Mean Square Error of Approximation. CI = confidence interval. H = coefficient H, Com = competence, Aut = autonomy, Rel = relatedness.

Table 2

*Means, Variances, and Bivariate Associations between Study Variables based on Model 2*

	Mean	Variance	MVPA Initial	MVPA Slope	Comp Initial	Comp Slope	Aut Initial	Aut Slope	Rel Initial	Rel Slope
1. MVPA_Initial	4.418*	2.020*	--							
2. MVPA_Slope	0.047*	0.030*	-.384*	--						
3. Competence_Initial	5.355*	1.027*	.582*	-.064	--					
4. Competence_Slope	-0.064*	0.019*	-.257*	.593*	-.191*	--				
5. Autonomy_Initial	4.292*	0.745*	.496*	-.161*	.787*	-.229*	--			
6. Autonomy_Slope	-0.026*	0.019*	-.178*	.532*	-.112	.763*	-.329*	--		
7. Relatedness_Initial	4.301*	0.554*	.455*	-.132	.741*	-.102	.810*	-.164*	--	
8. Relatedness_Slope	-0.017*	0.015*	-.072	.482*	-.002	.652*	-.170*	.803*	-.214*	--

*Notes.* I = intercept S = slope, comp = competence, aut = autonomy, rel = relatedness. \* $p < .05$