RUNNING HEAD: MVPA and distress latent changes

Longitudinal Relations Between Psychological Distress and Moderate-to-Vigorous Physical Activity: A Latent Change Score Approach

*Daniel F. Gucciardi^{1,2}, Kwok Hong Law³, Michelle D. Guerrero⁴, Eleanor Quested^{2,5},
Cecilie Thøgersen-Ntoumani^{2,5}, Nikos Ntoumanis^{2,5}, and Ben Jackson³

¹*School of Physiotherapy and Exercise Science, Curtin University;* ²*Physical Activity and Well-Being Lab, Curtin University;* ³*School of Human Sciences (Exercise and Sports Science), The University of Western Australia;* ⁴*Department of Kinesiology, University of Windsor;* ⁵*School of Psychology, Curtin University*

*Address correspondence to Daniel Gucciardi, School of Physiotherapy and Exercise Science, Curtin University, GPO Box U1987, Western Australia, 6845. Phone: +61 8 9266 3653. Email: daniel.f.gucciardi@gmail.com.

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Abstract

Objectives: The effect of physical inactivity on mental health risk is well established; however, less is known about about how psychological distress might deter participation in physical activity. Guided by advancements in the treatment of longitudinal data, the aim of this study was to examine patterns and predictors of change in moderate-to-vigorous physical activity (MVPA) and psychological distress (e.g., feeling nervous, worthless). **Design:** .

Method: Australian adults (4944 females, $M_{\text{age}} = 34.63 \text{ years} \pm 5.34$; 4322 males, $M_{\text{age}} = 37.51 \text{ years} \pm 6.14$) provided baseline data as part of the Longitudinal Study of Australian Children (LSAC) and were followed for measurements every two years for 10 years. **Results:** Latent change score analyses revealed support for a reciprocal effects model, whereby change in MVPA and psychological distress occurred as a function of individuals' prior levels of, and/or prior change in these variables. **Conclusions:** This investigation is the first to document that changes in MVPA and psychological distress are coupled temporally. Notably, we observed that individuals' distress levels at a given time point predicted subsequent change on both MVPA and distress; a finding which provides novel and important insight into how adults' activity levels and psychological distress fluctuate relative to one another.

Keywords: depression; exercise; longitudinal; physical activity; stress

Longitudinal Relations Between Psychological Distress and Moderate-to-Vigorous

Physical Activity: A Latent Change Score Approach

Psychological distress – symptoms of anxiety, depression, and other indices of distress that affect one’s functional abilities – is prevalent in developed countries (e.g., Pratt, 2009) and has long been recognized as a key component of ill-being (see Veit & Ware, 1983; Slade et al., 2011; Russ et al., 2012). The World Health Organization (WHO) estimates that there are up to 350 million cases of depression worldwide, and that depression will represent the leading cause of the global burden of disease by 2030 (WHO, 2012). It is well established that frequent moderate-to-vigorous physical activity (MVPA) is beneficial for one’s overall health, and contributes to improved physical and psychosocial well-being (e.g., Del Pozo-Cruz et al., 2018; García-Hermoso, Saavedra, Ramírez-Vélez, Ekelund, & del Pozo-Cruz, 2017; Wiese, Kuykendall, & Tay, 2017). The presence of well-being, however, does not necessarily indicate the absence of ill-being (Ryff et al., 2006), and accordingly, it is important to understand how activity (and inactivity) align with maladaptive health indices. There remain unanswered questions regarding the precise nature of the relations between MVPA and indicators of ill-being (e.g., Mammen & Faulkner, 2013). Drawing from a longitudinal study of Australian adults, the aim of this investigation was to examine trajectories of change in MVPA and psychological distress over a 10-year timeframe, and to model the way in which change in these variables may be coupled (i.e., inter-related). Throughout, we consider psychological distress as a non-clinical state-like concept, rather than a chronic condition, where our focus is on assessing the frequency (rather than intensity) of distress. This conceptualization and operationalization is underpinned by a substantial body of work in which psychological distress is defined as a state of maladaptive psychological functioning characterized largely by emotional disturbances (Kessler et al., 2002).

Our knowledge of the link between MVPA and (non-clinical) psychological distress has, to date, been driven primarily by investigations of the protective effect that MVPA may have upon psychological distress. An inverse relationship between MVPA and psychological distress has been observed in studies with adults (e.g., Brunes, Augestad, & Gudmundsdottir, 2013; Cairney et al., 2009; De Mello et al., 2013; Perales et al., 2014), older adults (e.g., Ku, Fox, Chen & Chou, 2012; Rosqvist et al., 2009), and adolescents (Birkeland, Torsheim, & Wold, 2009; Motl, Birnbaum, Kubik, & Dismen, 2004). In terms of the dose-response relationship between MVPA and psychological distress, researchers have generally found that higher doses of MVPA among adults are associated with lower psychological distress (Hamer, Stamatakis, & Steptoe, 2009; Sloan et al., 2013). There are many mechanisms that may explain the MVPA-psychological distress relationship. For instance, it is theorized that MVPA facilitates adaptive neurobiological (e.g., synthesis and release of neurotransmitters), physiological (e.g., fitness), social (e.g., interpersonal relationships), and psychological (e.g., self-esteem, mood) outcomes, which may in turn collectively buffer against psychological distress (see Salmon, 2001; Cairney et al., 2009; Matta Mello Portugal et al., 2013; Perales et al., 2014).

Just as MVPA may alleviate or prevent symptoms of depression and anxiety, psychological distress may deter participation in physical activity. Several mechanisms have been posited to explain the psychological distress-MVPA association (see Azevedo Da Silva et al., 2012). Symptoms of depression and anxiety are linked with increased risk of weight gain, which subsequently could negatively influence physical activity participation. Furthermore, individuals with depression and anxiety symptoms often experience feelings of social isolation and lower levels of energy or apathy, and therefore may be less motivated to participate in physical activities. Another possibility is that individuals with symptoms of depression may experience anhedonia (Leventhal, 2012), which is the inability to experience

70 pleasure in response to rewarding stimuli. Thus, it is possible that individuals with anhedonia
71 may find physical activity less pleasurable, which could in turn diminish one's desire or
72 intent to engage in physical activity. It is also believed that psychological distress might be
73 particularly disruptive for engaging in more intense (i.e., moderate and vigorous) forms of
74 activity considering the effort that MVPA activities require and the characteristics (e.g.,
75 pattern of fatigue, diminished energy, and low motivation) of those who are psychologically
76 distressed (Allan et al., 2007; Olive, Telford, Byrne, Abhayaratna, & Telford, 2016). The
77 precise mechanism(s), however, underlying the association between psychological distress
78 and MVPA are unclear and remain to be examined.

79 There is some existing empirical research demonstrating that the association between
80 MVPA and non-clinical psychological distress may be bi-directional (Azevedo Da Silva et
81 al., 2012). Similar findings have also been reported in samples with older adults (e.g.,
82 Lindwall, Larsman, & Hagger, 2011) and adolescents (e.g., Gunnell et al., 2016; Jerstad,
83 Boutelle, Ness, & Stice, 2010). However, much of the existing work in this area has relied on
84 designs that do not allow researchers to capture change over time in these variables, despite
85 MVPA and psychological distress being dynamic (i.e., changeable) in nature. As a result,
86 insight into intra-individual change in MVPA and psychological distress (and the drivers of
87 change) is limited. To the best of our knowledge, Gunnell et al.'s (2016) study is the only
88 longitudinal investigation to examine bi-directionality and change in physical activity and
89 symptoms of anxiety and depression using a community-based sample.

90 Using longitudinal data (five repeated measurements over a 10-year period) from a
91 large cohort of Australian adults, our overarching aim was to explore changes in, and
92 temporal coupling between, MVPA and psychological distress. In doing so, we sought to
93 apply an increasingly-used method for modeling longitudinal data that places substantive
94 importance on the concept of 'change', namely latent change score (LCS) analysis (see

McArdle, 2009; McArdle & Grimm, 2010, and for applied examples, Eschleman & LaHuis, 2014; Li et al., 2014). LCS (or latent difference score) analysis enables researchers to examine change over time *and* allows change to be modeled alongside ‘raw’ (e.g., time 1, time 2, etc.) scores as a predictor or outcome in the analysis (e.g., to examine whether alongside MVPA/psychological distress scores at a given time point, prior change in MVPA/psychological distress predicts subsequent change in MVPA and psychological distress). Accordingly, the specific aim of this study was to examine the degree to which prior levels of MVPA and psychological distress, and changes in MVPA and psychological distress, predict subsequent changes in MVPA and psychological distress.

Researchers have yet to (in a single study) examine changes over time in adults’ MVPA and psychological distress, or to identify how these variables may act as dynamic determinants of one another (i.e., how change in each variable may predict subsequent change in each variable). Therefore, this study represents the first attempt to (a) model latent change in MVPA and psychological distress, and (b) estimate coupling effects and salient predictors of change on each variable. For that reason, although we anticipated inverse relations between concepts (e.g., increases on MVPA associated with decreases on psychological distress), our approach was exploratory insofar as we did not have sufficient grounds to formulate specific a priori hypotheses regarding the relative strength of the predictors of latent change between discrete time intervals.

Methods

Sample

The data for this study were taken from waves 1-5 of the K-cohort of the Longitudinal Study of Australian Children (LSAC), where parents or guardians of children reported their own physical activity behavior and psychological distress over a 10-year period. Full details regarding LSAC sampling, recruitment, and data collection processes are detailed elsewhere

(Nicholson & Sanson, 2003; Sanson et al., 2002; Soloff, Lawrence, & Johnstone, 2005). Parents at wave 1 included 4944 females ($M = 34.63$ years ± 5.34) and 4322 males ($M = 37.51$ years ± 6.14). Overall, study retention across the five measurement points for participants was relatively high (wave 2 = 90%, wave 3 = 87%, wave 4 = 84%, and wave 5 = 79%). In terms of highest level of education for females, 24.8% had completed a certificate, 16.1% achieved a Bachelor's degree, or obtained an advanced diploma (8.9%), graduate diploma (6.3%), or postgraduate degree (5.9%). With regard to the highest level of education for males, 30.6% had completed a certificate, 13% achieved a Bachelor's degree, or obtained an advanced diploma (7%), postgraduate degree (6.8%), or graduate diploma (5.2%). The LSAC was approved by the Australian Institute of Family Studies Ethics Committee; ethical approval to access the LSAC dataset for the purposes of the current analyses was provided by a Human Research Ethics Committee of the lead author's institution.

Measures

MVPA. A single item was employed to measure MVPA: "About how many days each week do you do at least 30 minutes of moderate or vigorous physical activity (for example, walking briskly, riding a bike, gardening, tennis, swimming, running, etc)." This question was asked of parents in a section in which participants reflected on their own health and feelings about life in general. Participants entered a numerical value of 0 – 7 in a blank form to indicate the number of days¹. This measure is similar to single-item measures of MVPA that have been employed in past work (e.g., van Bree et al., 2017).

Psychological distress. Parents indicated the degree to which they felt six indicators of nonspecific psychological distress over the past four weeks (i.e., nervous, hopeless, restless or fidgety, so depressed that nothing could cheer you up, everything was an effort,

¹ Two participants recorded a response of 8 for this variable; given that the true maximum for this variable should be 7, we recoded these two values as missing for the purposes of the analyses in this study.

worthless) using the Kessler Psychological Distress Scale (K6; Kessler et al., 2002). Responses were recorded using a 5-point scale with the following anchors: 1 (*all of the time*), 2 (*most of the time*), 3 (*some of the time*), 4 (*a little of the time*), and 5 (*none of the time*). To aid interpretation, items were reversed scored then averaged to create a composite score for psychological distress, such that higher scores reflected greater psychological distress. A composite score of more than two on the K6 scale would indicate prevalence of serious mental illness (Kessler et al. 2003). Reliability and validity evidence from test scores obtained with large community samples support the utility of the K6 as a short measure of psychological distress (e.g., Batterham, Sunderland, Slade, Caelear, & Carragher, 2018; Kessler et al., 2010).

Covariates. In addition to age and sex, we considered family socioeconomic status (SES) as a potential confounder in the main analyses. In the LSAC, family SES represents a composite of parent reports of equivalized annual family income, calculated by dividing total income by total weightings for the family (each member has a different weighting), years of education, and current or most recent occupational status. This variable is coded as a standardized summary with a mean of 0 and standard deviation of 1 (Blackmore et al., 2006).

Data Analyses

Latent change scores (LCS; also referred to as latent difference scores) were computed within a structural equation modeling framework to examine the temporal dynamics between MVPA and psychological distress. Combining the strengths of latent growth curve and cross-lagged structural models, LCS permits inferences regarding dynamic forms of growth within specific temporal segments as well as multivariate relations (e.g., antecedents, moderators). Given our focus on the temporal coupling of MVPA and psychological distress, LCS is the preferred approach because it permits an understanding of which variables *lead* (i.e., change in construct A leads to change in construct B) and *lag* (i.e.,

development of construct B is coupled with yet lags behind construct A) in longitudinal associations (Grimm, Mazza, & Mazzocco, 2016). As depicted in Figure 1, change in a variable is considered a function of (i) one's individual linear trajectory over time that encompasses the additive sum of changes (i.e., slope) and (ii) a quantity that is proportional to the lagged effect of the previous status or level of itself (β). When the model includes two or more variables, the change score in one variable can be predicted by the previous level or status (coupling effect) or change in an alternative variable (change-to-change effect); these effects are depicted in Figures 2a-2d. Constraints are placed on various parameters to model the true latent change between two assessments, and test a range of different substantive questions (e.g., equality constraints to ascertain if the same dynamics are at play across all assessments). Interested readers are referred elsewhere for a comprehensive overview of the underlying statistical properties of LCS models (McArdle & Hamagami, 2001), a user-friendly description of their utility for modeling changes in psychological research (Ferrer & McArdle, 2010), and treatment of the differences between various types of analytical frameworks for analyzing change (Stenling, Ivarsson, & Lindwall, 2016).

Given our interest in lag-leading and reciprocal effects over time, we estimated four models in a sequential framework². First, we estimated a baseline model for comparison with subsequent representations whereby MVPA and psychological distress were unable to predict changes in each other. To explore the utility of MVPA and psychological distress as a leading indicator of change, we then estimated two separate models that excluded reciprocal effects whereby one variable (e.g., MVPA) was allowed to predict subsequent change in the other

² The rationale to use measurement wave rather than chronological age as the time metric was statistically informed rather than substantive in nature. Specifically, the covariance coverage was problematic (i.e., < .18) when using chronological age as the time metric, particularly for participants aged 19-27 years and 49-70 years at the commencement of the study. This finding is unsurprising given that approximately 90% of participants were aged between 27 and 45 years, and therefore missing data for the age groups at the extremes of the age continuum was substantial (e.g., see Figures S1-S5 of the supplementary material for visual depictions). As such, the results of the analyses with age as the time metric cannot be trusted.

variable (e.g., psychological distress). Finally, we modeled reciprocal effects of MVPA and psychological distress on each other such that each variable was permitted to affect upcoming change in the other construct. Proportional change effects were constrained to be the same across time in all four models. Visual displays of these models are provided in Figures 2a-2d.

Model-data fit at each stage of the analysis was assessed using multiple indices and typical interpretation guidelines, namely the χ^2 goodness-of-fit index, comparative fit index (CFI), Tucker-Lewis index (TLI), and root mean square error of approximation (RMSEA), with evidence of adequate fit indicated by CFI/TLI $\geq .90$ and RMSEA $\leq .08$ (Marsh et al., 2005). We performed all analyses with *Mplus* 7.4 (Muthén & Muthén, 1998-2015) using a robust maximum likelihood estimator (MLR) and full information maximum likelihood (FIML). Missing data we handled using FIML with the assumption that the data were missing at random. FIML makes full use of all available data and is the preferred choice for handling missing data (Graham, 2009) because it provides minimally biased parameter estimates (Enders & Bandalos, 2001). To account for the non-independence in the data (i.e., mother/father dyads), we used the TYPE = COMPLEX function in *Mplus* to appropriately adjust parameter estimates, standard errors, and the χ^2 statistic (Muthén & Muthén, 1998-2015). Given the sensitivity of the χ^2 difference test with large samples (Meade et al., 2008), we prioritized the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC), and its sample size adjusted version (ABIC) in the comparison of competing models, where smaller values indicate a better fitting model (Vrieze, 2012). We also performed robust chi-square difference tests to compare nested models (Bryant & Satorra, 2012; Satorra & Bentler, 2001).

Results

Preliminary Analyses

We excluded parent informants who did not have any data on the study variables across all five waves ($n = 1082$) or at least one full wave of completed responses ($n = 108$). The means, standard deviations, and indices of univariate normality for MVPA and psychological distress at each assessment point using FIML provide a descriptive overview of the overall change in these variables (see Table 1). Mean psychological distress decreased somewhat over the 10-year period (8.59%), whereas mean MVPA increased slightly (10.71%). Bivariate correlations among the individual item scores are provided in the online supplementary material.

Model Comparisons and Parameter Estimates

All four models exhibited excellent model-data fit (see Table 2), though the reciprocal effects model was the best fitting model with the data as it had the lowest AIC, BIC and ABIC values. The likelihood ratio test also support the superiority of the reciprocal effects model (see Table 2). There were improvements in MVPA days per week between waves 1 and 3 ($\Delta 1 = .32$, $SE = .03$; $\Delta 2 = .04$, $SE = .03$), yet these gains diminished in the latter two waves where decrements were observed ($\Delta 3 = -.03$, $SE = .02$; $\Delta 4 = -.06$, $SE = .02$). Latent change scores indicated that there were decrements in psychological distress across most assessment periods ($\Delta 1 = -.11$, $SE = .01$; $\Delta 3 = -.03$, $SE = .01$; $\Delta 4 = -.03$, $SE = .01$), with the exception of a small increase in psychological distress was observed between waves 2 and 3 ($\Delta 2 = .04$, $SE = .01$). The standard errors indicated that the degree of interindividual variability in change scores was large for MVPA days per week, but small for psychological distress.

An overview of the unstandardized parameter estimates of the reciprocal effects model is presented in Table 3. To facilitate interpretation of the effects, we describe briefly the key findings regarding different parameters of the model. The slope means, which express constant linear changes for each individual, indicate that MVPA days per week decreased

over time, whereas psychological distress increased throughout the 10-year period; these findings are in contrast to the aggregate scores depicted in Table 1. It is important to note that these estimates are made once all effects in the model are controlled, such as the effects of change in MVPA days per week, psychological distress, and demographic factors on the intercept and slope of constant change. There was salient variability in the slopes of both MVPA days per week and psychological distress, thereby indicating individual differences in the natural growth or change in these variables. With regard to the correlations between the slope and intercepts factors, the results revealed that psychological distress changed more rapidly in people who started with higher levels of psychological distress thereby indicative of a ceiling effect. The correlation between intercepts revealed that people with higher levels of psychological distress reported lower levels of exercise at the start of the collection period; equally, individuals with higher levels of exercise at the first data collection point reported lower levels of psychological distress.

Findings indicated that there was a positive linear change component for psychological distress. That change component was proportional to prior status on psychological distress and MVPA days per week, such that higher levels of psychological distress and MVPA days per week at the previous measurement wave were associated with lower increases in distress at subsequent waves. The MVPA days per week findings shared both similarities with, and differences from, psychological distress. Changes in psychological distress predicted future MVPA days per week changes, such that upward changes in psychological distress downregulated future MVPA. Although changes in psychological distress predicted changes in MVPA days per week, the reverse was untrue. **Change in MVPA days per week was not proportional to prior status of itself but was contingent upon previous levels of psychological distress.** Specifically, the higher the level of distress reported

the previous measurement wave, the greater the increase in MVPA days per week at the subsequent wave.

Discussion

It has been demonstrated that regular participation in MVPA is linked with lower psychological distress (e.g., Perales et al., 2014). It has been suggested that psychological distress may, in turn, limit MVPA involvement (e.g., Olive et al., 2016); however, there is limited longitudinal evidence to verify this assertion. Despite our knowledge of the potential reciprocal relationships between these concepts, limited attention has been directed toward understanding how these variables change relative to one another over time. Using data collected as part of a 10-year, multi-wave longitudinal study, we modeled latent change in these variables with the goal of providing insight into patterns and predictors of change in MVPA days per week and psychological distress.

Analyses revealed support for the fit of a reciprocal effects model, whereby change on MVPA days per week and psychological distress occurred as a function of prior levels of, and prior change in, each variable. In terms of noteworthy overarching findings, negatively correlated intercepts revealed that – at the outset of the collection period – higher psychological distress was associated with lower MVPA days per week (and vice versa), lending support to previous similar findings (e.g., Hamer et al., 2009). In terms of understanding intra-individual change over the 10-year study period, results showed that the constant linear change component of MVPA days per week decreased over time, whereas psychological distress increased. In addition, the slopes for MVPA days per week and psychological distress were negatively correlated, indicating that linear growth in one variable (e.g., increased MVPA) was broadly associated with reductions in the other variable (e.g., decreased psychological distress). Supporting evidence for the relations between growth patterns of MVPA and psychological distress is limited; however, the correlated slopes that

we observed align with the reductions in psychological distress that have been observed in physical activity promotion trials (e.g., Li et al, 2001; Bilderbeck et al., 2013).

Analyses also revealed that change over time in psychological distress was catalyzed by one's prior level of both psychological distress and MVPA days per week, such that higher previous levels of MVPA and psychological distress predicted smaller increases in psychological distress at subsequent waves. In other words, higher MVPA days per week at a given time appeared to buffer against increases in psychological distress in the future (i.e., a protective role of MVPA), and higher levels of psychological distress at a given time resulted in a reduced possibility for that distress to increase in the next wave (i.e., a ceiling effect).

Regarding the predictors of change in MVPA days per week, one's prior level of, and change in, psychological distress (but not MVPA) were substantively important. Specifically, higher previous levels of psychological distress were associated with larger decreases in MVPA days per week at the subsequent wave, and previous upward change on psychological distress promoted subsequent downward change on MVPA. Collectively, these findings support the role of frequent MVPA in dampening increases in psychological distress; however, psychological distress level was the most salient predictor of change in this study. In particular, individuals' distress levels predicted subsequent change on *both* variables of interest. Future work designed to replicate this finding for psychological distress and MVPA is encouraged.

The strengths of this study include the use of a large, broadly population representative sample, the longitudinal nature of the data, and the implementation of a latent change modeling strategy. Also, these findings are important in a practical sense; strategies designed to monitor and alleviate (or at least, prevent increases in) individuals' psychological distress, for example, may prove fruitful for encouraging positive subsequent change in MVPA. Moreover, efforts to stimulate higher levels of MVPA over time (e.g., interventions

that are designed to stimulate manageable and persistent increases in MVPA) may in turn protect against increases in psychological distress.

Balanced against these strengths, it is important to acknowledge design limitations and to highlight associated future research directions. First, although the reliance on self-report MVPA assessment methods is understandable given the scope of data collection, this approach is accompanied by limitations relating to inaccurate reporting, a lack of sensitivity, and social desirability concerns. It would be worthwhile in future to supplement self-report assessments with objective MVPA tracking, and capture more detailed information about participants' activity patterns (e.g., modality, intensity, duration). In addition, it is recognized that psychological factors – such as one's body image, depression, and anxiety – may contribute to biased estimates of behavior and health status (e.g., Maurer et al., 2006; Gil & Mora, 2011). It is possible, therefore, that the psychological distress (i.e., depression, anxiety symptoms) experienced by participants may have resulted in some inaccuracy in MVPA estimation, which may explain, at least in part, why MVPA levels/change predicted psychological distress but not MVPA.

A more sensitive and frequent assessment protocol than every two years may also be valuable for the measurement of psychological distress. As well as being subject to recollection biases, the scheduling of this assessment may have resulted in a failure to capture important variation in distress, and more frequent assessment schedules (e.g., using experience sampling, diary-based methods) would be worthwhile in future work. Finally, despite controlling for important demographic factors (i.e., sex, age, SES) in this study, researchers are encouraged to assess other life events (e.g., childbirth, bereavements) and related factors (e.g., social support) that may predict patterns of change in, and relations between, MVPA and psychological distress. To conclude, by modeling latent change over a 10-year period, this study advances our knowledge of the dynamic interplay between

337 trajectories of MVPA and psychological distress, and offers methodological and analytical
338 innovation for future work aimed at exploring dynamic coupling between physical activity
339 and other physical and mental health indices.

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Figure 1. Univariate latent change score model.

Year of Assessment

Model 1

Year of Assessment

Model 2

Year of Assessment

Model 3

Year of Assessment

Model 4

Figure 2. Visual representations of latent change score models tested. Note: model 1 = baseline; model 2 = effects of MVPA on distress only; model 3 = effects of distress on MVPA only; model 4 = reciprocal effects of MVPA and distress. For clarity of presentation, latent slope and intercept factors, observed variables, residual variances are excluded.

Table 1. *Descriptive statistics for study variables at each measurement wave using full-information maximum likelihood estimation.*

	N	Mean	SD	Skewness	Kurtosis	Range
MVPA at wave 1	7479	2.80	2.01	.48	-.61	0-7
MVPA at wave 2	6183	3.11	2.00	.34	-.73	0-7
MVPA at wave 3	6198	3.14	1.97	.32	-.75	0-7
MVPA at wave 4	6601	3.08	2.00	.31	-.78	0-7
MVPA at wave 5	6005	3.10	2.02	.25	-.83	0-7
Distress at wave 1	7424	1.63	.60	1.52	3.05	1-5
Distress at wave 2	7138	1.53	.57	1.90	4.96	1-5
Distress at wave 3	6320	1.56	.58	1.72	3.77	1-5
Distress at wave 4	6607	1.51	.57	1.96	5.02	1-5
Distress at wave 5	6207	1.49	.58	2.08	5.74	1-5
Age	8564	36.04	5.81	.46	1.28	19-70
Socioeconomic status ¹	8564	.10	.97	.28	-.40	-3.73-3.00

¹ Socioeconomic status was standardized.

Table 2. *Model-data fit indices and likelihood ratio tests for latent change score models for frequency of weekly sessions of moderate-to-vigorous physical activity and psychological distress.*

	Baseline (1)	MVPA → Distress (2)	Distress → MVPA (3)	Reciprocal (4)
χ^2 (df)	465.55 (65)	404.62 (63)	426.13 (63)	344.49 (61)
p	<.001	<.001	<.001	<.001
RMSEA (90% CI)	.027 (.025 to .029)	.025 (.023 to .028)	.026 (.024 to .028)	.024 (.021 to .026)
CFI	.972	.976	.975	.980
TLI	.968	.972	.970	.976
AIC	177149.76	177057.50	177091.70	177000.55
BIC	177361.42	177283.27	177317.47	177240.44
ABIC	177266.08	177181.58	177215.79	177132.39
Model 1 vs 2 [#]	39.25 (2), $p < .001$			
Model 1 vs 3 [#]	30.86 (2), $p < .001$			
Model 2 vs 4 [*]	4.86 (2), $p = .044$			
Model 3 vs 4 [#]	570.43, $p < .001$			

Note: [#] = model comparison performed using a robust chi-square difference test (Satorra & Bentler, 2001); ^{*} = the robust chi-square difference test can sometimes produce a negative value; we utilized an alternative approach (Bryant & Satorra, 2012) to circumvent this issue for the comparison of model 2 with 4.

Table 3. *Unstandardized parameter estimates of reciprocal latent difference score model.*

	B	SE	<i>p</i>	95% CI
MVPA slope (μ)	-8.15	2.61	.002	-13.26, -3.05
MVPA intercept (μ)	3.65	.19	<.001	3.29, 4.02
Distress slope (μ)	3.54	.58	<.001	2.41, 4.68
Distress intercept (μ)	1.48	.05	<.001	1.37, 1.58
MVPA slope (σ^2)	4.34	2.11	.04	.20, 8.47
MVPA intercept (σ^2)	2.07	.06	<.001	1.95, 2.18
Distress slope (σ^2)	.68	.20	.001	.28, 1.07
Distress intercept (σ^2)	.20	.01	<.001	.18, .21
<i>Correlations</i>				
Distress slope $\leftrightarrow$ distress intercept	.34	.05	<.001	.24, .44
Distress slope $\leftrightarrow$ MVPA slope	-1.69	.66	.01	-2.99, -.39
Distress slope $\leftrightarrow$ MVPA intercept	.20	.09	.02	.03, .37
Distress intercept $\leftrightarrow$ MVPA slope	-.87	.20	<.001	-1.28, -.49
Distress intercept $\leftrightarrow$ MVPA intercept	-.10	.01	<.001	-.12, -.07
MVPA slope $\leftrightarrow$ MVPA intercept	-.19	.39	.63	-.95, .58
<i>Proportional Effects</i>				
MVPA status $\rightarrow$ MVPA change	.24	.25	.34	-.25, .72
Distress status $\rightarrow$ distress change	-1.92	.27	<.001	-2.45, -1.38
<i>Coupling Effects</i>				
MVPA status $\rightarrow$ distress change	-.18	.05	.001	-.28, -.07
Distress status $\rightarrow$ MVPA change	4.84	1.18	<.001	2.53, 7.15
<i>Change to Change Effects</i>				
MVPA change $\rightarrow$ distress change	-.03	.05	.51	-.13, .06
Distress change $\rightarrow$ MVPA change	-1.72	.55	.001	-2.79, -.66
<i>Covariates</i>				
Sex $\rightarrow$ distress slope	.11	.03	<.001	.05, .16
Age $\rightarrow$ distress slope	-.005	.002	.03	-.01, .00
SES $\rightarrow$ distress slope	-.12	.02	<.001	-.16, -.08
Sex $\rightarrow$ distress intercept	.12	.01	<.001	.09, .14
Age $\rightarrow$ distress intercept	.00	.001	.74	-.003, .002
SES $\rightarrow$ distress intercept	-.06	.01	<.001	-.08, -.05
Sex $\rightarrow$ MVPA slope	-.36	.07	<.001	-.52, -.22
Age $\rightarrow$ MVPA slope	.01	.01	.07	-.001, .02
SES $\rightarrow$ MVPA slope	.33	.09	<.001	.17, .53
Sex $\rightarrow$ MVPA intercept	-.34	.04	<.001	-.42, -.24
Age $\rightarrow$ MVPA intercept	-.01	.004	.04	-.02, -.001
SES $\rightarrow$ MVPA intercept	-.11	.03	<.001	-.16, -.06

Note: B = unstandardized effect; SE = standard error; μ = mean; σ^2 = variance.

Supplementary Material

Chronological Age as the Time Metric

As noted the manuscript, the rationale to use measurement wave rather than chronological age as the time metric was statistically informed rather than substantive in nature. In Mplus, zero coverage is not an issue when data on a variable is totally missing because it would not be used as part of the estimation process (e.g., consider a hypothetical situation in which we include ages 16, 17, and 18 in the statistical model). However, low coverage is a problem when there are data points for a variable (Linda Muthén, personal communication; January 29th, 2019). Even using 3-year age ranges such as 19-21, 22-24, and so on, as the time metric (e.g., Finkel et al., 2007) cannot alleviate this covariance coverage problem in the current sample. Essentially, we would need to remove participants at these age extremes for the analyses to be trustworthy, something we opted not to do because it could be interpreted as “p hacking”, etc. For example, there were only a handful of data points for the 3-year age groups of 67-69 ($n = 10$), 70-72 ($n = 10$), and 73-75 ($n = 5$), compared with 37-39 ($n = 4606$), 40-42 ($n = 4734$), and 43-45 ($n = 3727$). Nevertheless, some readers may be interested in a comparison of the results obtained with chronological age as the time metric (using 3-year age ranges) with those obtained using measurement wave; full details of these results are provided in Tables S1 and S2 below.

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Table S1. *Model-data fit indices and likelihood ratio tests for latent change score models with age as the time metric for frequency of weekly sessions of moderate-to-vigorous physical activity and psychological distress.*

	Baseline (1)	MVPA → Distress (2)	Distress → MVPA (3)	Reciprocal (4)
χ^2 (df)	-	-	-	-
p	-	-	-	-
RMSEA (90% CI)	-	-	-	-
CFI	-	-	-	-
TLI	-	-	-	-
AIC	134809.19	134799.37	134808.07	134772.57
BIC	134992.63	134996.92	135005.62	134984.23
ABIC	134910.00	134907.94	134916.64	13488.89

Note: the robust chi-square could not be computed for all models due to low covariance coverage.

Table S2. *Unstandardized parameter estimates of reciprocal latent difference score model.*

	B	SE	<i>p</i>	95% CI
MVPA slope (μ)	2.31	2.09	.26	-1.78, 6.40
MVPA intercept (μ)	4.15	.38	<.001	3.39, 4.90
Distress slope (μ)	.89	.69	.19	-.45, 2.24
Distress intercept (μ)	1.55	.45	.001	.67, 2.43
MVPA slope (σ^2)	.30	.48	.54	-.64, 1.23
MVPA intercept (σ^2)	3.70	1.91	.052	-.04, 7.44
Distress slope (σ^2)	.05	.07	.48	-.08, .18
Distress intercept (σ^2)	.57	.28	.043	.02, 1.12
<i>Correlations</i>				
Distress slope $\leftrightarrow$ distress intercept	.10	.06	.12	-.03, .22
Distress slope $\leftrightarrow$ MVPA slope	.10	.06	.08	-.01, .21
Distress slope $\leftrightarrow$ MVPA intercept	-.01	.14	.94	-.29, .26
Distress intercept $\leftrightarrow$ MVPA slope	.24	.17	.15	-.09, .57
Distress intercept $\leftrightarrow$ MVPA intercept	-.03	.37	.94	-.75, .69
MVPA slope $\leftrightarrow$ MVPA intercept	.35	.93	.71	-1.47, 2.16
<i>Proportional Effects</i>				
MVPA status $\rightarrow$ MVPA change	-.31	.31	.32	-.92, .30
Distress status $\rightarrow$ distress change	-.52	.21	.015	-.93, -.10
<i>Coupling Effects</i>				
MVPA status $\rightarrow$ distress change	-.05	.12	.67	-.28, .18
Distress status $\rightarrow$ MVPA change	-.85	.71	.23	-2.24, .54
<i>Change to Change Effects</i>				
MVPA change $\rightarrow$ distress change	-.51	.43	.23	-1.36, .33
Distress change $\rightarrow$ MVPA change	.01	.18	.94	-.34, .37
<i>Covariates</i>				
Sex $\rightarrow$ distress slope	.04	.02	.007	.01, .07
SES $\rightarrow$ distress slope	-.02	.01	.19	-.04, .01
Sex $\rightarrow$ distress intercept	.18	.12	.11	-.04, .41
SES $\rightarrow$ distress intercept	.04	.03	.23	-.02, .10
Sex $\rightarrow$ MVPA slope	.01	.04	.75	-.07, .10
SES $\rightarrow$ MVPA slope	-.04	.07	.62	-.18, .11
Sex $\rightarrow$ MVPA intercept	-.55	.21	.008	-.95, -.14
SES $\rightarrow$ MVPA intercept	-.21	.37	.57	-.93, .51

Note: B = unstandardized effect; SE = standard error; μ = mean; σ^2 = variance.

Figure S1. Spaghetti plots of MVPA (top) and psychological distress (bottom) over time by a function of chronological age of participants.

Figure S2. Spaghetti plots of MVPA over time by a function of chronological age of participants.

Figure S3. Spaghetti plots of psychological distress over time by a function of chronological age of participants.

Figure S4. Bivariate correlation between age and MVPA among the total sample for all waves (top) and by each measurement wave (bottom).

Figure S5. Bivariate correlation between age and psychological distress among the total sample for all waves (top) and by each measurement wave (bottom).