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An examination of the reciprocal associations between physical activity and anxiety, depressive symptoms, and sleep quality during the first 9 weeks of the COVID-19 pandemic in Belgium

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ABSTRACT

During the initial outbreak of the global COVID-19 pandemic, many countries imposed a total lockdown (containment at home). Although it was still allowed in Belgium to be physically active or exercise with people from your household in the vicinity of your home, engaging in sports or physical activity in a group or club context was no longer permitted. To examine whether a lack of physical activity was potentially threatening to the mental well-being of citizens and vice versa, the present study examined concurrent and reciprocal relationships between physical activity and anxiety, depressive symptoms, and sleep quality during the COVID-19 lockdown in a 9-week longitudinal design. In a sample of 983 Belgian adults (75.1% female; $M_{age} = 43.78$, range = 18–82 years), we explored these relationships at both the between- and within-person levels through random intercept cross-lagged panel models. The findings indicate that more physical activity was associated with lower symptoms of anxiety and depression and better sleep quality, a finding observed both at the between-person (across weeks; $\beta_{anxiety} = -0.25$, $\beta_{depression} = -0.30$, $\beta_{sleep\ quality} = 0.24$, $p < .001$) and within-person level (within weeks; $\beta_{anxiety} = -0.10$, $\beta_{depression} = -0.14$, $\beta_{sleep\ quality} = 0.11$, $p < .05$). Moreover, at the within-person level, an increase in feelings of anxiety and depression at one moment predicted lower levels of physical activity one week later ($\beta_{anxiety} = -0.04$, $\beta_{depression} = -0.06$, $p < .05$). Since poor mental health poses a threat to the maintenance of physical activity, the current findings suggest that it is critical to invest in the mental health of individuals during distressing times.

1. Introduction

In March 2020, during the global COVID-19 pandemic, Belgium implemented several public health measures to mitigate the spread of the coronavirus. Like other countries, these pre-emptive measures involved the recommendation to stay at home or, in case one had to make essential journeys (e.g., grocery shopping, doctor's appointment), to keep physical distance from others. Moreover, schools and non-essential public spaces (e.g., sports facilities, restaurants, non-essential shops, playgrounds, etc.) were all closed. Outdoor physical activity (PA) was allowed, but only with family members living under the same roof. These measures implied a radical change in lifestyle behaviors and, consequently, also in the degree to which people were physically active. Whereas some people took advantage of the freed-up time to become more physically active, others found it more challenging to stay physically active. Since sports facilities were closed, people spent less time commuting, and were concerned about getting infected when going outside, it is reasonable to assume that PA levels went down (Dunton et al., 2020). Indeed, a large-scale survey among 3800 Spanish adults showed that vigorous PA and walking time decreased, respectively, by 16.8% and 58.2% during the lockdown (Castañeda-Babarro et al., 2020). Another worldwide study using smartphones' daily step count measurements of 455,404 unique users showed that within the first 10 days of the COVID-19 pandemic, there was a 5.5% decrease in mean

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steps, and within 30 days, there was a 27.3% decrease in mean steps (Tison et al., 2020).

Nonetheless, being active may have been especially important as it might help in fostering greater psychological well-being, which was under threat during the initial lockdown in March 2020, as evidenced by an increase in symptoms of anxiety and depression (e.g., Ozamiz-Etxebarria et al., 2020) and poorer sleep quality (e.g., Casagrande et al., 2020). Indeed, research showed that PA and (poor) mental health are related, as people who report being equally or more physically active than usual during the COVID-19 lockdown reported lower levels of anxiety and depression (Frontini et al., 2021; Lesser & Nienhuis, 2020; see Wolf et al., 2021 for a systematic review; Zhao et al., 2022), whereas other studies showed that the reduction of total PA came with more symptoms of poor mental health, such as anxiety and depression (Trabelsi et al., 2021; see Violant-Holz et al., 2020 for a systematic review). Moreover, performing PA during the lockdown was positively associated with people's sleep patterns (Şimşek et al., 2020; Violant-Holz et al., 2020). Yet, most of this COVID-19-related research considered the association in only one direction, namely the effect of PA in the prediction of mental health and sleep quality. Previous research outside the context of the COVID-19 pandemic though showed evidence for reciprocal effects between PA and mental well-being (e.g., Stavrakakis et al., 2012; Steinmo et al., 2014), and between PA and sleep (Chennaoui et al., 2015; Pesonen et al., 2022). This implies that an increase in PA would not only lead to an increase in mental well-being and sleep quality, but also that increases in mental well-being or sleep quality would drive increases in PA levels. To the best of our knowledge, no such reciprocal associations across time were tested within the threatening context of a pandemic; neither on an interpersonal, nor intrapersonal level.

1.1. Present study

The present study aimed to examine the reciprocal associations between changes in levels of PA as compared to pre-COVID-19-pandemic times on the one hand, and anxiety, depressive symptoms, and sleep quality on the other hand during the first COVID-19 lockdown in a longitudinal design with weekly measurements across 9 weeks (i.e., waves). Particularly during the COVID-19 pandemic, it is interesting to examine these reciprocal effects at the both between- and within-person levels.

First, at the between-person level, it is important to know whether individuals who reported a higher increase in PA during the COVID-19 lockdown relative to other people across all weeks also display lower levels of anxiety and depression, and higher levels of sleep quality relative to others. We hypothesized that, across all weeks, increased levels of PA compared to pre-COVID-19 pandemic times would be associated with better mental well-being (i.e., lower levels of anxiety and depression) and sleep quality (H1).

Yet, examining the same dynamics at the within-person level is equally instructive as the situation at that time was highly uncertain and fluctuated from week to week. Therefore, it is particularly interesting to examine whether individuals display better mental well-being and sleep quality during the same or subsequent week in which their PA level was elevated, and vice versa (relative to their own baseline). We expected that during weeks a person reports positive changes in PA levels relative to his/her own average, this person would also report better mental well-being and sleep quality relative to his/her own average (H2a). Moreover, also at the within-person level, we expect that positive perceived changes in PA levels would predict better mental well-being and sleep quality during the following week, and vice versa (H2b).

2. Method

2.1. Sample and procedure

On February 3rd, 2020, the first infection with the SARS-CoV-2 virus was detected in Belgium. On March 17th, the government declared a lockdown to curb the spread of the virus. Beginning March 19th, an online survey, called "The Motivation Barometer", was conducted among Belgian adults. Participants were recruited through an advertising campaign on social media, as well as by contacting different organizations (e.g., cultural associations) and media (e.g., online newspapers). The current study is part of this broader "Motivation Barometer" survey. During the first week of the lockdown, a baseline measurement (T0) was administered. In addition to a number of variables not relevant to the current study, participants were asked whether they wanted to participate in subsequent waves to assess the long-term effects of the COVID-19 pandemic. Participants who agreed to participate in this longitudinal study at T0 were invited through e-mail in time windows of exactly 7 days. For example, all participants who completed the baseline questionnaire on Thursday received a new invitation each Thursday for the next 9 upcoming weeks. In this invitation, each participant received a unique anonymized code which was used to link all the questionnaires. Each week, participants could decide whether they wanted to continue participating in the survey. From the moment a participant unsubscribed, no further invitations were sent. However, when a participant missed an assessment without unsubscribing, the participant was still invited for the following assessment. Additionally, we provided contact information at the beginning and the end of the questionnaire in case of questions or psychological concerns. The procedure was approved by the ethical committee of Ghent university (nr. 2020/37).

A sample of 1367 participants gave informed consent at T0 for a weekly follow-up assessment (76.8% female; $M_{age} = 39.64$, range = 18–82 years). However, only 983 participants actually participated in one of the follow-up measures (75.1% female; $M_{age} = 43.78$, range = 18–82 years). Of this final sample, 84.9% participated on T1, 76.1% participated on T2, 73.3% on T3, 65.5% on T4, 63.9% on T5, 59.5% on T6 assessment, 49.1% on T7, 51.6% on T8, and 51% on T9. On average, participants filled in the survey six times. Drop-out analyses indicated that only participants' age was related to retention in the dataset. Older participants were more likely to participate twice or more (odds ratio = 1.03, $p < .001$) than younger participants. Neither gender nor the substantive study variables were related to drop-out (all p's > .05).

2.2. Materials

2.2.1. Physical activity

Perceived changes in PA (as compared to before the national lockdown) were measured using a single item (Constandt et al., 2020): "How physically active were you during the past week in comparison with an average week (before measures were imposed in the context of the COVID-19 pandemic)? Physical activity is more than just sports. In addition to sports, it includes active transportation (e.g., walking or biking to the bakery), being active in the household (e.g., mopping, vacuuming, etc.), being active in leisure time (e.g., walking the dog), and so on." Participants were provided with a 5-point response scale with the following answering options "much less active (1)", "less active (2)", "equally active (3)", "more active (4)", and "much more active (5)".

2.2.2. Anxiety

Five items were selected from the State-Trait Anxiety Inventory (STAI; Marteau & Bekker, 1992) to assess people's feelings of anxiety during the past week. Four items were selected based on their relevance to the context of the COVID-19 pandemic (e.g., "During the past week, I felt tense"), whereas one item tapped into anxiety more directly (i.e., "During the past week, I felt anxious"). Items were rated on a 4-point response scale with the following options: "Seldom or never, less than 1 day (1)", "A few times, 1–2 days (2)", "Now and then or regularly, 3–4 days (3)", and "Mostly or all the time, 5–7 days (4)". Cronbach's alpha was 0.95 at the between-person level and 0.66 at the within-person level.

2.2.3. Depressive symptoms

People's depressive feelings during the past week were assessed with a 6-item version (Van Hiel & Vansteenkiste, 2009) of the Center for Epidemiological Studies – Depression scale (CES-D; Radloff, 1977). An example item reads: "During the past week, I felt sad". Items were rated on a 4-point response scale with the following options: "Seldom or never, less than 1 day (1)", "A few times, 1–2 days (2)", "Now and then or regularly, 3–4 days (3)", and "Mostly or all the time, 5–7 days (4)". Cronbach's alpha was 0.89 at the between-person level and 0.62 at the within-person level.

2.2.4. Sleep quality

Sleep quality was measured through one item (i.e., "How would you rate your overall sleep quality over the past week?") that is used in the Pittsburgh Sleep Quality Index (Buysse et al., 1989) to measure the subjective sleep quality component. This item was selected because previous psychometric evaluation research showed that this single-item component was most highly correlated with global scores of sleep quality (Carpenter & Andrykowski, 1998). Participants rated their global sleep quality during the past week. They were provided with a 4-point response scale with the following options "very bad (1)", "rather bad (2)", "rather good (3)", and "very good (4)".

2.3. Plan of analysis

All analyses were performed in R (R Core Team, 2020). A graphical representation of the evolution of the study variables over time can be found in the online supplementary material (Fig. 1S).

2.3.1. Preliminary analysis

First, the intraclass correlation coefficient was calculated for each of the study variables to examine how much of the total variance in each outcome can be attributed to between- and within-person differences. Second, the Pearson correlation coefficients between age and the study variables were calculated at the between-person level, as well as the correlation coefficients between the study variables at both the between- and within-person levels. Finally, a MANOVA was conducted with gender as the independent variable and all study variables as dependent variables to examine whether there were gender-related differences in our study variables.

2.3.2. Primary analysis

We conducted random intercept cross-lagged panel models to examine the reciprocal associations between PA and anxiety, depressive symptoms, and sleep quality across nine weekly assessments (Fig. 1). The between-person effects (i.e., stable, trait-like effects) regarding the study variables PA, anxiety, depressive symptoms, and sleep quality are reflected by the random intercepts between participants. In each model, the correlation (covariance) between the random intercepts reflects the strength of the association of between-person differences in PA with between-person differences in anxiety, depressive symptoms, or sleep quality (respectively). Within-person effects are reflected by both autoregressive and cross-lagged pathways. The autoregressive paths in the models indicate the extent to which within-person deviations in all variables (PA, anxiety, depressive symptoms, and sleep quality) can be predicted by deviations from their own expected scores. The cross-lagged paths in the models indicate the extent to which variables are

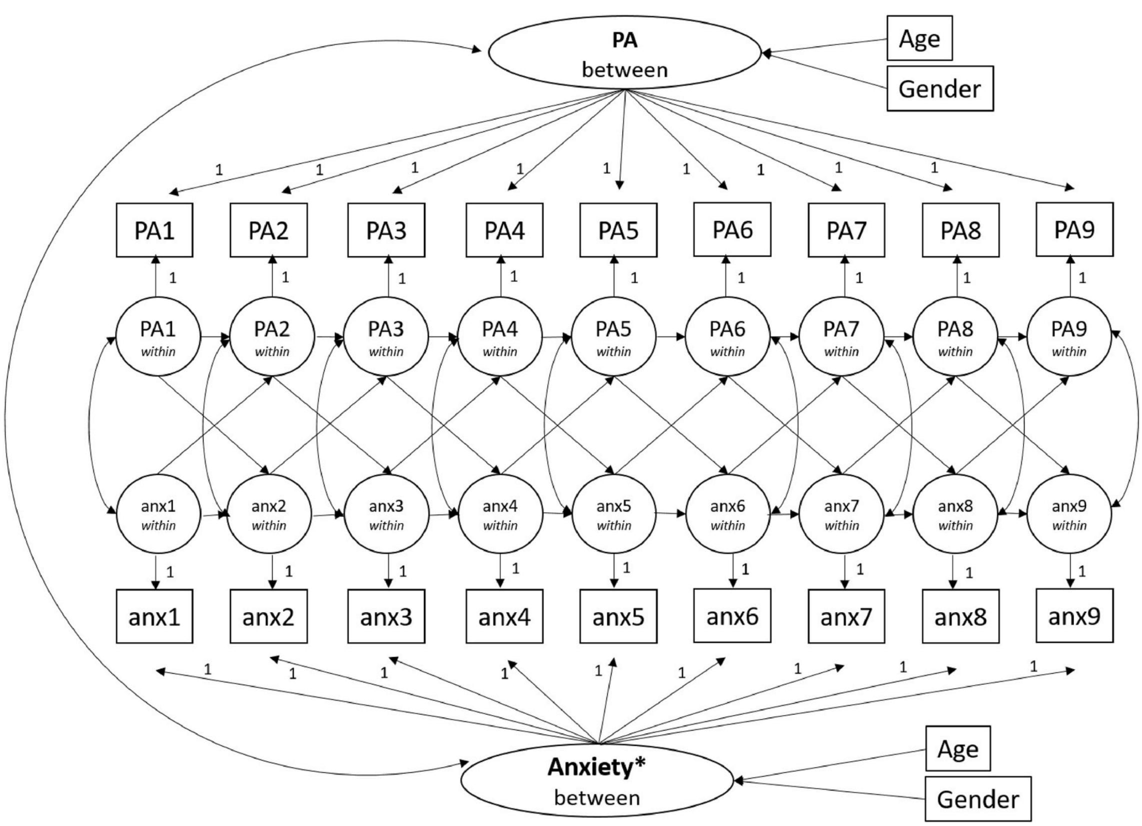

Fig. 1. Random Intercept Cross-Lagged Panel Model (RI-CLPM) of the relationship between Physical Activity (PA) and anxiety (anx) across 9 waves, with one-week lags

Note. The figure shows two random intercepts (PA between and anxiety between) that reflect between-person effects. Age and gender (at T1) represent time-invariant covariants that influence between-person differences in PA and anxiety. Within-person effects are reflected in auto-regressive paths between the latent factors of PA across waves and latent factors of anxiety across waves, and by cross-lagged paths between latent factors of PA and anxiety to indicate the reciprocal relationship between these variables.

*This figure serves as an example of the similar relationships examined between PA and depressive symptoms, and between PA and sleep quality.

linked reciprocally, i.e., they indicate whether a within-person deviation in PA predicts a deviation from their own expected score in anxiety, depressive symptoms, or sleep quality one week later (and vice versa). We specified gender and age at week 1 as time-invariant covariates (between-person) to control for gender and age differences, respectively.

Different models were fit for each of the three outcomes (i.e., anxiety, depressive symptoms, and sleep quality) separately, each time starting with a baseline, unconstrained model with all variances, covariances, autoregressive and cross-lagged effects allowed to vary across waves, followed by models in which constraints were systematically added, ending with the most simple, parsimonious model with variance, covariances, autoregressive and cross-lagged effects constrained to be equal across waves. Model fit was evaluated using several fit indices (i.e., CFI, RMSEA, and SRMR) (Hu & Bentler, 1999). The CFI is a comparative fit index with values that can vary between 0 and 1, values of 0.95 and higher indicate a good fit. The RMSEA is an absolute fit index, a good fit is indicated by values of ≤ 0.05, an acceptable fit by values between 0.05 and 0.08, and values of 0.10 and above show a poor fit. Finally, the SRMR is also an absolute fit index with values between 0 and 0.08 indicating an acceptable range of model fit. In the final models that are presented in this paper, variances and covariances, autoregressive and cross-lagged paths were constrained to be equal because the model comparisons showed no better fit for the less constrained, less parsimonious models.

2.4. Results

2.4.1. Preliminary analysis

Based on the intraclass correlation coefficient, 52.28% of the total variation in PA was attributable to differences among participants rather than changes over time within participants. With respect to the outcomes, 75.04% of the total variance in anxiety, 75.01% in depressive symptoms, and 57.11% in sleep quality could be ascribed to differences between participants.

Table 1 summarizes the means, standard deviations, and Pearson correlations of all variables at the between- (Table 1a) and within- (Table 1b) person levels. Older participants reported lower levels of anxiety ($r = -0.24$, $p < .001$) and depression ($r = -0.27$, $p < .001$), and better sleep quality ($r = 0.13$, $p < .001$). People who had higher PA scores (indicating that they self-reported having increased their PA as compared to pre-COVID-19 pandemic times), reported on average lower levels of anxiety ($r = -0.23$, $p < .001$) and depression ($r = -0.27$, $p < .001$), and better sleep quality ($r = 0.21$, $p < .001$). Moreover, in weeks participants reported higher PA scores (indicating that, in that week, they reported increases in their PA as compared to pre-COVID-19 pandemic times), they also reported lower levels of anxiety ($r = -0.15$, $p < .001$) and depression ($r = -0.16$, $p < .001$), and better sleep quality ($r = 0.09$, $p < .001$) compared to weeks in which they had lower PA scores. However, all associations were rather small (Cohen, 1992).

Results of the MANOVA analyses showed a multivariate effect for gender (Wilk's $\Lambda = 0.96$, $F(1,5572) = 25.10$, $p < .001$, $\eta^2 = 0.02$). Men reported higher PA-scores ($M = 2.83$, $SD = 0.92$) and better sleep quality ($M = 3.02$, $SD = 0.69$) compared to women ($M_{PA} = 2.79$, $SD_{PA} = 1.04$; $M_{sleep} = 2.84$, $SD_{sleep} = 0.72$); whereas women reported higher levels of anxiety ($M = 2.06$, $SD = 0.76$) and depression ($M = 1.63$, $SD = 0.59$) as compared to men ($M_{anx} = 1.74$, $SD_{anx} = 0.68$; $M_{dep} = 1.42$, $SD_{dep} = 0.50$).

Table 1a
Means, standard deviations, and pearson correlations of all variables at the between-person level.

Variables	*M*	*SD*	1	2	3	4
1. Age	43.78	14.71	–	–	–	–
2. Physical activity	2.80	1.01	.02	–	–	–
3. Anxiety	1.98	.75	−.24***	−.23***	–	–
4. Depressive symptoms	1.58	.58	−.27***	−.27***	.80***	–
5. Sleep quality	2.88	.71	.13***	.21***	−.61***	−.57***

***$p < .001$.

Table 1b
Pearson correlations of all variables at the within-person level.

Variables	1	2	3
1. Physical activity	–	–	–
2. Anxiety	−.15***	–	–
3. Depressive symptoms	−.16***	.51***	–
4. Sleep quality	.09***	−.30***	−.26***

***$p < .001$.

2.4.2. Primary analysis

The final (constrained) models to explore reciprocal relations between PA and anxiety (CFI = 0.98, RMSEA = 0.03, SRMR = 0.04), depressive symptoms (CFI = 0.97, RMSEA = 0.04, SRMR = 0.05), and sleep quality (CFI = 0.97, RMSEA = 0.03, SRMR = 0.06) all revealed a good fit (Table 2).

At both the between- and within-person level, results showed that higher PA scores (indicating a self-reported increase in PA as compared to pre-COVID-19 pandemic times) were negatively related to anxiety levels, and depressive symptoms, while being positively related to sleep quality. These associations indicate that, across all weeks, participants who reported increased PA scores compared to pre-COVID-19 pandemic times also reported, on average, lower levels of anxiety ($\beta = -0.25$, $p < .001$) and depression ($\beta = -0.30$, $p < .001$) and better sleep quality ($\beta = 0.24$, $p < .001$) (between-person level; H1) and that, in weeks participants reported higher PA scores compared to their intra-personal level, they also reported lower levels of anxiety ($\beta = -0.10$, $p < .05$) and

Table 2
Results of the random intercept cross-lagged panel models for physical activity (PA) with anxiety, depressive symptoms, and sleep quality.

	Model 1 Anxiety	Model 2 Depressive symptoms	Model 3 Sleep quality
	β (*SE*)	β (*SE*)	β (*SE*)
Between-person			
Gender → outcome	.18 (.05)***	.14 (.04)***	−.13 (.04)***
Age → outcome	−.22 (.00)***	−.27 (.00)***	.12 (.00)**
Covariance (PA, outcome)	−.25 (.02)***	−.30 (.01)***	.24 (.02)***
Within-person			
Autoregressive			
PA wave x → PA wave x+1	.38 (.02)***	.37 (.02)***	.39 (.02)***
Outcome wave x → outcome wave x+1	.41 (.02)***	.37 (.02)***	.29 (.02)***
Cross-lagged			
PA wave x → outcome wave x+1	−.03 (.01)	−.01 (.01)	.02 (.01)
Outcome wave x → PA wave x+1	−.04 (.03)*	−.06 (.04)***	.03 (.03)
Covariances			
PA and outcome at wave 1	−.10 (.02)*	−.14 (.01)**	.11 (.02)**
Residuals PA and residuals outcome at wave 2–9 (constant)	−.15 (.00)***	−.15 (.01)***	.09 (.01)***

*$p < .05$, **$p < .01$, ***$p < .001$.
Note. These are models with variance and covariances across waves constrained to equality; controlled for age and gender differences (between-person level).

depression (β = −0.14, $p < .01$), and better sleep quality (β = 0.11, $p < .01$) compared to their intra-individual level (within-person level, H2a).

After controlling for autoregressive associations, cross-lagged path coefficients showed no significant effect of PA on either anxiety (β = −0.03, $p = .190$), depressive symptoms (β = −0.01, $p = .806$), or sleep quality (β = 0.02, $p = .410$) at the within-person level. However, results did show a significant association in the other direction in two of the three models, that is, a negative effect of both anxiety (β = −0.04, $p < .05$) and depressive symptoms (β = −0.06, $p < .001$) (but not of sleep quality, β = 0.03, $p = .145$) on PA levels one week later. This indicates that if participants experienced higher anxiety and depression levels in a given week relative to their own intra-individual level, they also reported being less physically active in the next week compared to their own average (H2b).

3. Discussion

The present study provided a unique insight into the associations between levels of PA and anxiety, depressive symptoms, and sleep quality during the first COVID-19 lockdown in a longitudinal design with weekly measurements across 9 weeks. This weekly assessment of all key constructs allowed us to go beyond the study of between-person dynamics. Instead, we could additionally examine whether dips and increases in citizens' PA would predict concomitant mental health benefits and even drive improvements in one's own mental health or vice versa, with poor mental health being a vulnerability factor for reduced PA. Several interesting findings emerged.

First, at the between-person level, as hypothesized, people who reported positive changes in PA levels compared to pre-COVID-19 pandemic times, reported fewer feelings of anxiety and depression, and better sleep quality *across* the nine-week survey period. These findings align with the limited body of work with other research during the COVID-19 pandemic, showing that levels of PA are related to feelings of anxiety (e.g., Frontini et al., 2021; Lesser & Nienhuis, 2020), depression (Trabelsi et al., 2021; Violant-Holz et al., 2020), and sleep quality (Şimşek et al., 2020; Violant-Holz et al., 2020). However, based on these between-person analyses, we cannot comment on the direction of the relationship. Thus, this result may imply that persons who sleep better and feel mentally well are better capable of uplifting their PA level compared to persons with poor mental health status (e.g., because they have more energy for it). However, it may also imply that persons who are more physically active in comparison with pre-COVID-19 pandemic times feel better and sleep better as a result when compared to those persons who are not more physically active.

Second, at the within-person level, our findings showed that the week-to-week variation in individuals' PA was associated with week-to-week variation in their mental well-being and sleep quality. Again, since we cannot make any statements about the direction of the relationship here, this result can mean either that PA within a week leads to better mental well-being and sleep quality (e.g., one feels good thanks to PA), but also that better mental well-being and sleep in that week leads to more PA (e.g., one has more energy and desire to be physically active when one feels good and/or has slept well). Because few studies have used analysis techniques that can estimate within-person effects, comparison with prior research is difficult. Findings from the only study that has reported within-subject covariances between PA and mental health are consistent with the results of the present study as they found a significant within-subject covariance between PA and depression (Stavrakakis et al., 2012).

While these two findings above are interesting, only the cross-lagged associations at the within-person level reported herein allow one to derive conclusions with respect to the direction of the effects. Again, two meaningful findings emerged. First, the cross-lagged associations suggested that changes in a person's sleep quality at one moment were not related to perceived PA levels one week later, nor vice versa. Perhaps more than the quality of sleep, it is the number of hours of sleep that may affect PA in the subsequent days or week by increased fatigue (Campbell et al., 2018; Pesonen et al., 2022). However, these findings deviate from previous research which found a cross-lagged effect of sleep quality on PA (Pesonen et al., 2020).

Second, the cross-lagged associations in this study suggested that mental health primarily predicts PA rather than the other way around. Specifically, if participants reported more anxiety and depressive complaints in a given week (e.g., due to changing circumstances), they report being less physically active during the next week. These findings suggest that a temporary increase in poor mental health may serve as a vulnerability factor for reduced PA one week later. Presumably, the rumination and worry that go along with anxiety and depression prevent individuals from taking action to stay physically active. Also, depressive symptoms are characterized by feelings of fatigue, which makes individuals have less desire and energy to be physically active. In fact, the current findings suggest that it is mainly critical to invest in the mental health of individuals during distressing times. Several e-health interventions were developed and offered to the broader public during the COVID-19 pandemic to better cope with the situation. As an illustration, an intervention that aids individuals in getting their basic psychological needs for autonomy, competence, and relatedness fostered greater psychological well-being (Laporte et al., 2022). Such need crafting may eventually lead one to stay physically active by offsetting symptoms of poor mental health.

Although no research has been done on cross-lagged associations within the context of the COVID-19 pandemic, the current findings deviate from previous longitudinal research outside the context of the COVID-19 pandemic, which found bidirectional cross-lagged relations between PA and depressive symptoms (Stavrakakis et al., 2012) or which found a cross-lagged effect of PA on mental health rather than the other way around (Kroesen & De Vos, 2020). Several explanations can be put forward. First, the broader context of the present study was remarkably different as the study took place during distressing times, with people facing unusually high levels of uncertainty and unpredictability while also having to process and regulate various anxiety-inducing messages on the news and social media (Vermote et al., 2021). During these extreme times, more may be needed to safeguard one's mental health than to preserve one's PA level. This may be the reason why our findings suggest that PA has a rather short-lived positive effect on our mental well-being, but is not robust enough to generate mental health benefits carried over to the next week. Second, an alternative explanation may have to do with the operationalization of PA. The measure of PA was comparative in nature, with participants being asked to compare their current PA levels with their pre-COVID-19 pandemic routine level of PA. Such a comparative measure might have less predictive power for people's mental well-being than their absolute level of PA. For example, if a person moves more than he/she did before the COVID-19 pandemic, but this level of PA is still low, that person may not cross a critical threshold to benefit in terms of mental well-being. Conversely, a person may move less than before, but still, do it a lot in absolute terms and, hence, still recruit psychological well-being benefits from his/her PA level.

Although no beneficial effects of increased PA on mental health remain the week after, PA may well have a short-term impact on mental health (given the bidirectional within-week associations were found to be significant). Therefore, in addition to the wellness interventions discussed earlier, it may also be important to focus on interventions that ensure or increase PA during pandemic times. Fortunately, numerous recommendations have appeared in both scientific and popular media on how to stay physically active during quarantine periods. For instance, scientific research promoted bodyweight training, dance, staircase walking, playing with pets, etc. (see Bentlage et al., 2020 for a systematic review). Concerning the popular media, inspiration to stay physically active during housebound quarantine can be found on YouTube, Facebook, and exercise apps, taking into account the limited space and lack of specialized training equipment. Also, modern technology (e.g., wearables) can motivate and enhance home-based workouts, although specific recommendations on their use and associated goals remain scarce (Dwyer et al., 2020).

3.1. Limitations and suggestions for future research

This study was the first to explore the reciprocal associations between PA and mental well-being and sleep quality during the pandemic using a longitudinal approach, which made it possible to distinguish effects at the between- and within-person levels. Specifically, the random intercept cross-lagged panel model used goes beyond the unidirectional approach often used where one variable is considered a cause and the other an effect. Another important strength is that we managed to recruit a large sample that participated in multiple waves of this longitudinal study, which is not evident in times of pandemic. Although this study had several strengths, some important limitations need to be mentioned.

First, we relied on a convenience sampling approach to recruit participants. This sampling strategy may have produced an unrepresentative sample in which people with low social-economic status or with poor physical and/or mental health were underrepresented. Future research would do well to confirm the relationships found within a representative sample, or, at the very least, assess participants' socio-economic status and physical/mental health status so that this information can be included as covariates in the model.

Second, all measurements were based on self-reports, which may have caused shared method variance. Therefore, future research should supplement self-reporting measures with physiological and objective indicators of PA (e.g., Dyrstad et al., 2014) and sleep quality (e.g., de Arriba-Pérez et al., 2018); for instance using wearables that include accelerometers and heart rate sensors to improve the quality of assessment. Such an objective measure of PA would increase the sensitivity and interpretability of the results, since the herein-assessed self-reported change in PA says nothing about its quantity. For instance, someone who is less physically active than before the pandemic can still meet the World Health Organization guidelines and vice versa. In addition, an experience sampling methodology would allow for the collection of self-report ratings of anxiety and depressive symptoms several times during the day, thereby enhancing accuracy by reducing the retrieval from memory (Barrett & Barrett, 2001).

Third, as the current study was part of the larger "Motivation Barometer" survey, the questionnaires used for this study had to be short to minimize drop-out during the nine consecutive waves. Therefore, PA and sleep quality were measured using single items (Allen et al., 2022). Although previous research refers to single-item measures as good alternatives to measure PA (Milton et al., 2011) and sleep quality (Snyder et al., 2018), future research would do well to use more elaborate measures. With regard to PA, in particular, it would be useful for future research to also include absolute levels of PA (e.g., minutes per day) in addition to the current relative comparison measure.

4. Conclusion

Our findings confirm that people who report engaging in more PA than others across the first nine weeks of the COVID-19 pandemic, experience lower anxiety and depressive symptoms, and better sleep quality. This link is also observed at the within-person level, such that in weeks people reported being more physically active compared to pre-lockdown times, they also reported fewer feelings of anxiety and depression, and better sleep quality. Yet, over weeks, especially poor mental health seems to pose a threat to the maintenance of PA, while we did not find evidence for PA to serve as a protective factor against an increase in poor mental health. From the public health perspective, the current findings show it is of primary importance to invest in the mental health of individuals during distressing times. Moreover, the results highlight the importance that cross-sectional associations between physical activity and mental health should be interpreted with caution, since they can be the results of associations in either direction. Therefore, in future research, it is important to examine the reciprocal relationships in a longitudinal design that allows distinguishing between-person from within-person effects.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.mhpa.2022.100500.

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