Physical activity and depressive symptoms

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CHAPTER VII

The Dynamic Relationship between Physical Activity and Mood in the Daily Life of Depressed and Non-Depressed Individuals: a Within-Subject Time-Series Analysis

"I get my exercise running to the funerals of my friends who exercise."

Barry Gray, in *New York Magazine*, 1980

"Getting fit is all about mind over matter.
I don't mind, so it doesn't matter."

Adam Hargreaves, in *Mr Lazy's Guide to Fitness*, 2000

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ABSTRACT

Purpose: The association between physical activity and mood found in longitudinal observational studies is generally small to moderate. It is unknown how this association generalizes to individuals. The aim of the present study was to investigate inter-individual differences in the bidirectional dynamic relationship between physical activity and mood, in depressed and non-depressed individuals, using time-series analysis.

Methods: Twenty pair-matched depressed and non-depressed participants (30% males, mean age = 36.6, SD = 8.9) wore accelerometers and completed electronic questionnaires three times a day for 30 days. Physical activity was operationalized as the total energy expenditure (EE) per day segment (i.e., 6 hours). The multivariate time series (T = 90) of every individual were analyzed using vector autoregressive modeling (VAR), with the aim to assess direct as well as lagged (i.e., over 1 day) associations between EE and positive and negative affect.

Results: We observed large inter-individual differences in the strength, direction and temporal aspects of the relationship between physical activity and positive and negative affect. An exception was the direct (but not the lagged) influence of physical activity on positive affect, which was positive in nearly all individuals.

Conclusion: This study showed that the association between physical activity and affect varied considerably across individuals. Thus, while at the group level the effect of physical activity on mood may be small, in some individuals the effect may be clinically relevant.

INTRODUCTION

Physical activity or exercise is considered to be an effective treatment for depression (Dunn, Trivedi, Kampert, Clark, & Chambliss, 2005; Ströhle et al., 2007; Ströhle, 2009). Although this proposition is appealing, since physical activity can be implemented easily and with relative low costs, the empirical evidence of the effectiveness of physical activity is not robust (Chalder et al., 2012; Cooney et al., 2013; Krogh, Nordentoft, Sterne, & Lawlor, 2010). Similarly, observational studies have shown an inverse association between physical activity and depressive symptoms (Dunn, Trivedi, & O'Neal, 2001; Farmer et al., 1988; Salmon, 2001; Strawbridge, Deleger, Roberts, & Kaplan, 2002), with small to moderate effect sizes in different populations (Biddle & Asare, 2011; Johnson & Taliaferro, 2011). Although large cohort studies with a few measurements are useful to detect general patterns and traits in the population, they are not suitable for studying dynamic relationships between variables that fluctuate in daily life (Hamaker, 2012; Hamaker, Dolan, & Molenaar, 2005), which is the case for physical activity and depressive symptoms.

Some studies have adopted a more ecologically valid approach to investigate the association between depressive symptoms and physical activity. Ecological momentary assessment (EMA) studies address the dynamic nature of factors by investigating them repeatedly over time in participants' daily life. Since slight changes in positive and negative affect might accumulate over time to result in depressed mood, it is important to investigate how physical activity influences daily affect levels (Rosmalen, Wenting, Roest, de Jonge, & Bos, 2012). A recent literature overview of EMA studies investigating the relationship between physical activity and momentary affective states in daily life (Kanning, Ebner-Priemer, & Schlicht, 2013) showed a generally consistent positive association between physical activity and positive affect across studies, which became stronger when only high-quality studies were included. In contrast, the influence of physical activity on negative affect, although observed in some studies (see for example: Dunton, Liao, Intille, Wolch, & Pentz, 2011 and LePage & Crowther, 2010), was non-existent in the majority of studies reviewed (see: Kanning et al., 2013).

The above EMA studies all used multilevel analysis to estimate dynamic associations. Although multilevel analysis allows for inter-individual differences when estimating the relationship between physical activity and mood, it is in principle a between-subject (group) approach; individual regression terms are averaged across the group and the same regression model is imposed on all subjects rather than modeling the dynamic relationship for each subject individually. Only under strict conditions can findings at the inter-individual level be generalized to the intra-individual level (see: Hamaker, 2012), and these conditions rarely apply to the study of dynamic psychological processes (Hamaker et al., 2005; Molenaar &

Campbell, 2009). In addition, a within-subject time-series approach may be more suitable for investigating bidirectional relationships than multilevel analysis, because these models are built at the individual level and all variables in the model can be used as both predictors and outcomes (Brandt & Williams, 2007). The added value of such an approach was illustrated by a recent time-series study investigating the dynamic relationship between physical activity and depressive symptoms in four post-myocardial infarction patients (Rosmalen et al., 2012). Inter-individual differences in the magnitude as well as the direction of the association were shown, in spite of the relatively homogeneous study sample.

The present study aimed to further elucidate inter-individual differences in the bidirectional association between physical activity and mood. Adopting an intensive time-series approach, we studied the dynamic relationship between directly measured physical activity (i.e., accelerometers) and affect in the daily life of pair-matched depressed and non-depressed individuals, and individual differences therein.

METHODS

Participants

The sample was part of the 'Mood and movement in daily life' (MOOVD) study, which was set up to investigate the dynamic relationship between physical activity and mood in daily life, and the role of several biomarkers therein. Participants (age 20-50) were intensively monitored in their natural environments for 30 days, by means of electronic diaries, saliva sampling, and continuous actigraphy. The multiple repeated measurements per individual (T = 90) allowed assessing within-person temporal relationships between variables at the individual level. For the current study, 10 depressed and 10 non-depressed participants, who were pair-matched on gender, smoking status, age, and Body Mass Index (BMI), were included (the first 20 participants that finished the study).

Depressed individuals were recruited from the psychiatry department of the University Medical Center Groningen (UMCG) and the Center for Integrative Psychiatry (CIP) in Groningen, the Netherlands. Non-depressed participants were recruited from the general population by means of posters and advertisements in local newspapers. Participants were screened for depressive symptoms with the Beck Depression Inventory version 2 (BDI-II; Beck, Erbaugh, Ward, Mock, & Mendelsohn, 1961) and for several other health conditions with a general health questionnaire. Individuals with a BDI-II score of >14 (i.e., depressed group) and individuals with a BDI-II score of <9 (i.e., non-depressed group) were invited for the inclusion interview. The inclusion interview covered the Composite International Diagnostic Interview (CIDI; World Health Organization, 1990), several questionnaires, and a briefing in which the use of equipment and the electronic diary was explained. Depressed individuals were included if they met DSM-IV criteria for a major depressive disorder (current episode or in remission for no longer than 8 weeks). Non-depressed individuals were included if they were free of mood disorders at the moment of inclusion. Individuals who reported chronic somatic illness or medication use that may directly influence functioning of the Hypothalamic Pituitary Adrenal (HPA) axis or the Autonomic Nervous System (ANS) were excluded. Other reasons for exclusion were: pregnancy, significant hearing or visual impairments, and having a current or recent (within the last two years) psychotic or bipolar disorder as assessed with the CIDI interview. Participants received a fee for participation and a personal report of their daily mood and activity patterns. The MOOVD study design was approved by the Medical Ethical Committee and all participants gave written informed consent.

Ambulatory Sampling

Participants completed questionnaires on an electronic diary, the PsyMate (PsyMate BV, Maastricht, the Netherlands) (Myin-Germeys, Birchwood, & Kwapil, 2011) for a total of 32 days, with the first two days used to get familiar with the device. The PsyMate was programmed to generate beeps at three predetermined moments a day with equidistant intervals: in the morning (mean≈10:00 AM), six hours later in the afternoon (mean≈4:00 PM), and six hours later in the evening (mean≈10:00 PM). This fixed interval design was chosen to allow the application of time-series analysis. To capture most of participants' daily life without intruding with their sleep habits, beeps were planned at the end of the morning, afternoon, and evening, with the exact time points depending on the individual participant's sleep-wake schedule. This schedule was assessed by the Munich Chronotype Questionnaire (MCTQ; Roenneberg et al., 2007) and an extra question regarding the time they would go to bed if they were to go to bed 'on time'. After every alarm beep, participants were asked to fill out the electronic diary. They were instructed to do so immediately after the beep, but a time window of one hour was used for situations in which this was not possible. Throughout the study period, participants wore the ActiCal® (Respironics, Bend, OR, USA), an omnidirectional water-resistant accelerometer, on the wrist of the non-writing arm. They were instructed never to remove the ActiCal except when entering a sauna (high temperatures). The ActiCal recorded data over 1-min sampling intervals. For more details about the ActiCal, see Heil (2006).

Measures

The electronic diary questionnaire contained 60 items on mood, cognition, and daily activities. Positive and negative affect scores were computed from mood items adopted from Bylsma, Taylor-Clift, and Rottenberg (2011), rated on a 7-point Likert scale. For positive affect, seven positive mood items were averaged, namely feeling talkative, enthusiastic, confident, cheerful, energetic, satisfied, and happy (range 1-7). For negative affect, seven negative mood ratings were averaged, namely feeling tense, anxious, distracted, restless, irritated, depressed, and guilty (range 1-7).

Energy expenditure (EE) data from the ActiCal was used as a measure for physical activity. For each participant, the amount of EE (kcal/min) across all sampling minutes over one day segment (i.e., 360 minutes per segment) was summed. This resulted in total EE per day segment (kcal/day segment).

Person characteristics including age, gender, educational level, smoking status, coffee and alcohol intake, and the average amount of exercise per week (min) were obtained from questionnaires filled out at the baseline assessment. BMI was calculated from the weight and height of each individual.

Statistical Analysis

Missing diary data were imputed by means of Expectation-Maximization imputation in IBM SPSS Statistics 20. For every participant, all variables used in the time-series model as well as auxiliary variables that were significantly associated with these variables were used as predictor variables in the imputation. On average, participants had 8 missing values on the diary variables (8.8%). Of the 20 participants, three participants had missing actigraphy data at the last 9 or 10 days of their study, because of technical problems. These relatively large periods without activity records were discarded and not imputed, leaving 60-63 valid data points for these three participants, which is still considered sufficient for the application of time-series analysis (Lütkepohl, 2007; Rosmalen et al., 2012).

The multiple time series of every individual were analyzed using vector autoregressive (VAR) modeling. A VAR model is a multivariate autoregressive model that consists of a set of regression equations for a system of two or more variables, in this case positive affect, negative affect, and EE (Brandt & Williams, 2007). All three variables in the system were treated as endogenous, which means that they could be both determinant *and* outcome. Each of the three endogenous variables was regressed on its own p lagged values and the p lagged values of the other variable. The errors of the VAR model should be serially uncorrelated but can be contemporaneously correlated. VAR analysis is especially suitable for investigating the dynamic relationships between two or more variables: inferences can be made about the temporal order of effects, which can involve bidirectional effects and feedback loops (Brandt & Williams, 2007). Moreover, by analyzing all variables in one system, the most important effects will be identified. For more details about VAR modeling and a non-technical introduction, see Brandt & Williams (2007) and Rosmalen et al. (2012), respectively.

The number of lags included in the models was *a priori* set to three, which is equivalent to a period of one day. A fixed number of lags was chosen to ease comparison of results for different participants. Considering the study's exploratory nature, a relatively high number of lags was chosen, allowing for the investigation of relatively long-term lagged effects (i.e., over 3 time intervals = 1 day). To account for structural lower morning values for total EE, compared to afternoon and evening values – participants spent part of the morning lying in bed – as well as diurnal rhythms in mood, dummy variables for morning and evening were included (afternoon served as a reference category). Variables for time and the square of time were included into the model if this was necessary to render the series stationary. Total EE was divided by 100 to accommodate the difference in scaling between EE and positive and negative affect. Maximum likelihood estimation with a degrees-of-freedom adjustment advocated for small samples was used for estimating the VAR coefficients (Lütkepohl, 2007).

VAR model assumptions, namely stability of the model, independence, homoscedasticity and normality of residuals, were assessed using diagnostic checks (Lütkepohl, 2007). If one of the tests indicated a violation of the model assumptions, models were adjusted, re-estimated, and re-evaluated, in an iterative model-building process, until all assumptions were met. Outlier modeling was applied only if this was required to meet model assumptions, using the criterion of residual SD>3 (stepwise lowering to SD>2, if necessary; Field, 2009). Log transformation of the variables was applied if the residuals remained skewed. If scatterplots of skewed variables with other variables suggested curvilinear relationships, non-skewed variables were left untransformed. In other cases, all endogenous variables were log-transformed.

To assess the direct effect of EE on positive and negative affect, we examined the contemporaneous correlations between the variables, which can be retrieved from the residuals of the final models. These correlations represent the simultaneous correlations between the variables, i.e., between the scores at the same assessment point. To assess the overall lagged effects of EE on positive and negative affect, and vice versa, the effect size coefficients of lags 1 to 3 were averaged into one net effect size coefficient, and standardized so that they could be compared across participants. To test the significance of the overall lagged effects the Granger causality Wald test was used. This is a test for the directionality of the influence between two time series (Granger, 1969; Lütkepohl, 2007). In view of the exploratory nature of the study, a significance level of 0.05 was used for all tests. All analyses were done in STATA 11 using the suite of VAR commands (StataCorp., 2009).

RESULTS

Descriptive Statistics

The demographic and clinical characteristics of the depressed and non-depressed participants are presented in Table 1.

Analysis

Short-Term Effect of Physical Activity on Positive and Negative Affect

As depicted in Figure 1a, the majority of depressed (red bars) and non-depressed (blue bars) participants showed a positive contemporaneous association between EE and positive affect. As the EE scores covered the period directly before the mood rating, this can be interpreted as a direct effect of EE on positive affect. For five individuals (three non-depressed and two depressed) these positive associations were significant ($p<0.05$). The size of the correlations was small to moderate, according to the suggestions provided by Cohen (1992).

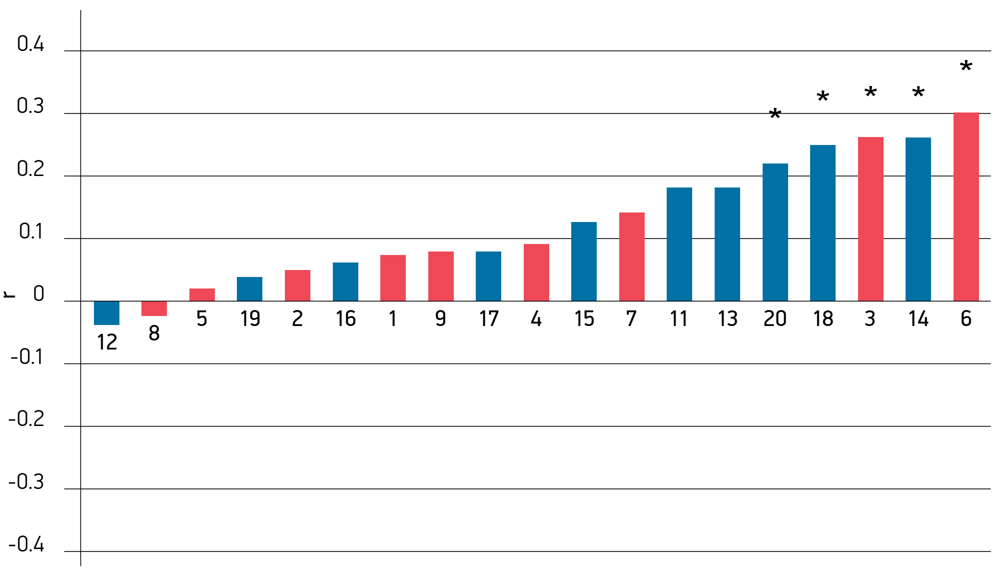
Figure 1b shows the direct association between EE and negative affect for depressed (red bars) and non-depressed (blue bars) participants. Eight of them showed a positive (non-significant) contemporaneous association between EE and negative affect, while nine participants showed a negative association, without any apparent differences between the groups (depressed and non-depressed). For two individuals (one depressed and one non-depressed) the negative association between EE and negative affect was significant ($p<0.05$). The size of these correlations was again small to moderate.

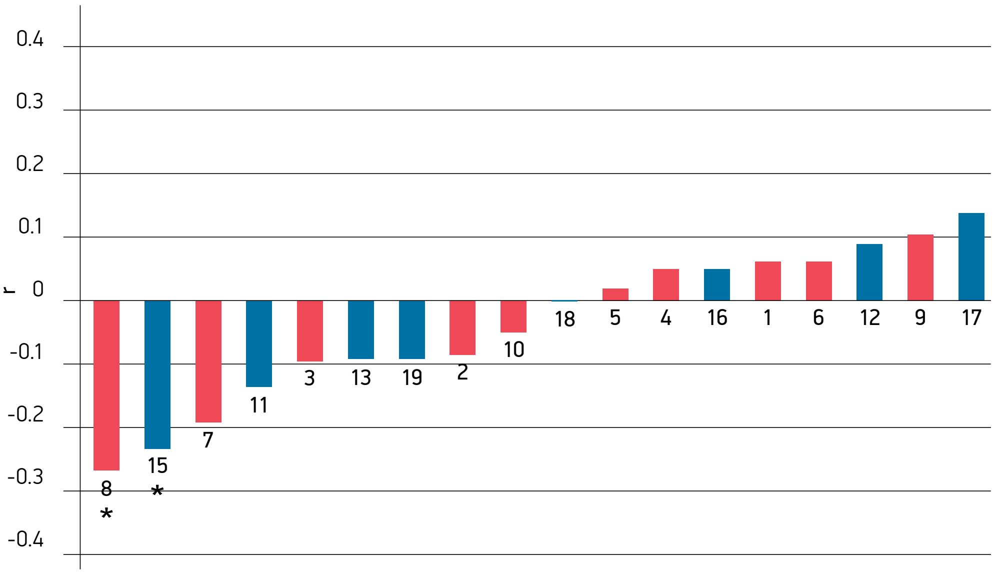
Table 1. Demographic and Clinical Characteristics for the Depressed and Non-Depressed Group.

	Depressed Group (n = 10)				Non-Depressed Group (n = 10)			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Demographics								
Age	36.4	10.3	22	49	36.7	7.9	24	46
Gender (% male)	30.0	—	—	—	30.0	—	—	—
Body Mass Index (BMI)	23.8	4.9	17.4	34.9	22.2	2.3	19.5	26.9
Educational Level (0-3)	2.6	0.5	2	3	2.6	0.5	2	3
Lifestyle								
Coffee Intake (per day)	2.2	2.5	0	8	1.8	1.4	0	4
Alcohol Intake (per month)	10.8	14.5	0	40	8.4	14.4	0	48
Self-Reported Exercise Frequency (per week)	1.7	1.5	0	4	2	1.5	0	4
Self-Reported Duration of Exercise (min. per week)	83	89	0	240	133	109	0	240
Average EE over one day segment	233	77	126	385	258	69	120	369
Mood and Depressive Symptoms								
Pre-BDI-II	32.5	10	20	51	2.8	3.4	0	10
Post-BDI-II	25.9	15.8	2	47	4.4	4.6	0	13
Average PA (1-7)	3.1	1.3	1.1	4.5	4.6	1.3	1.7	6.1
Average NA (1-7)	3.6	1.2	1.4	5.3	1.6	0.6	1.0	2.8

BDI-II = Beck Depression Inventory, EE = energy expenditure, PA = positive affect, NA = negative affect, SD = standard deviation.

Figure 1a and 1b. Direct Association between Physical Activity and Positive (1a) and Negative (1b) Affect for the Depressed (red bars) and Non-Depressed (blue bars) Individuals.





EE = energy expenditure.
* significant at the 0.05 level. Values on y-column depict correlation coefficients (r).

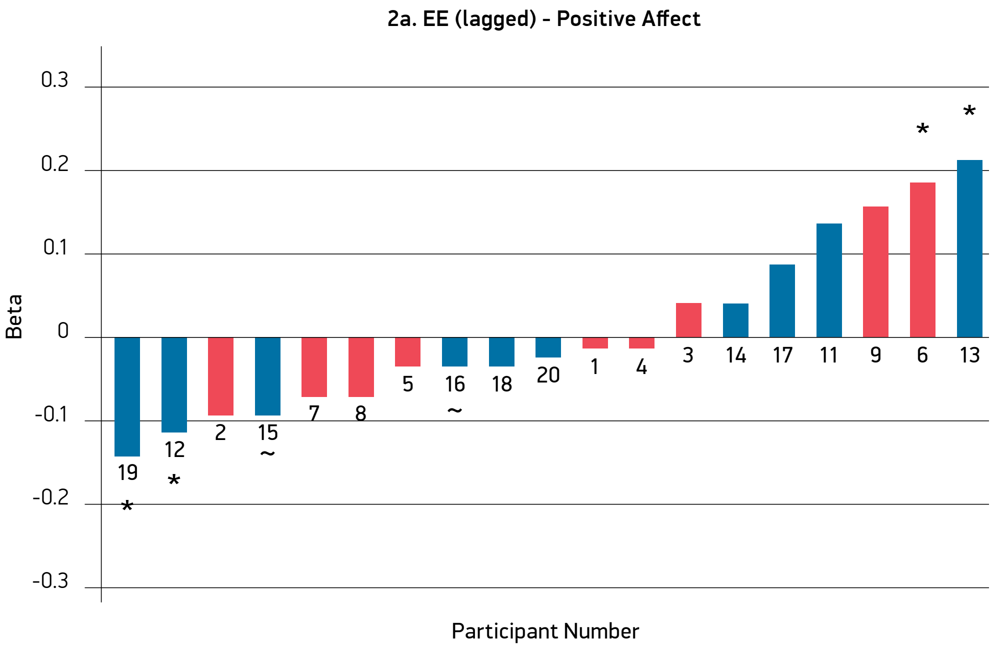
Lagged Association between Physical Activity and Positive, and Negative Affect

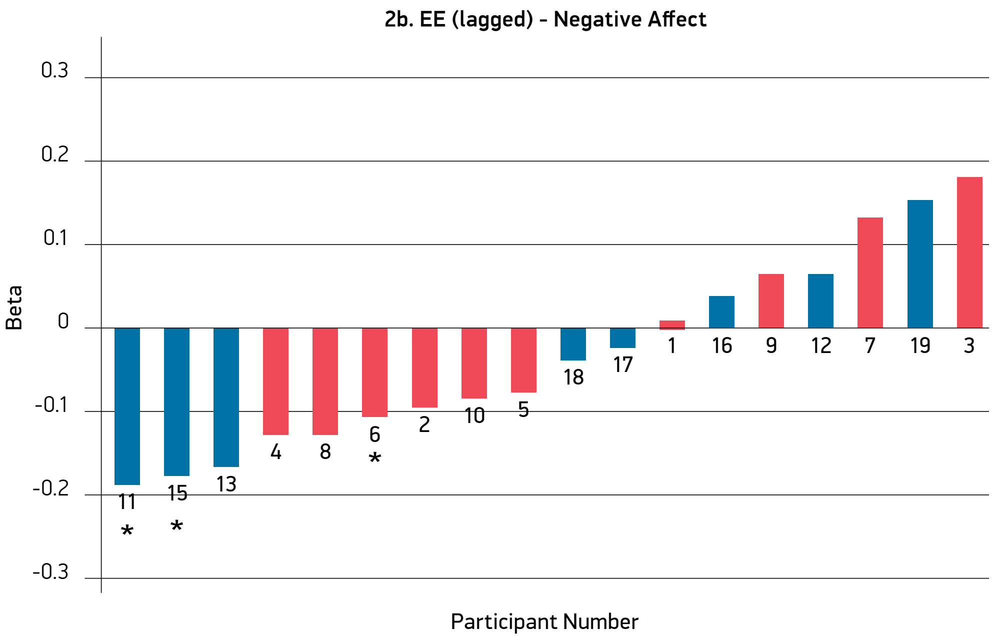
The lagged associations between previous values of EE (i.e., the joint effects of lag 1, lag 2, and lag 3) and current values of positive affect varied greatly between individuals (Figure 2a), without any apparent differences between the groups (depressed versus non-depressed). Seven participants showed a positive lagged association between EE and positive affect, but only for two (one depressed and one non-depressed individual) this effect was significant. For the remaining 12 participants a negative lagged association of EE on subsequent positive affect was observed, and for four individuals (all non-depressed) this association was significant. Mixed effects (i.e., both positive and negative associations on different lags) were present in two of them (participant 15 and 16). Figure 2b shows the results for EE and negative affect. The majority of participants (eleven compared to seven participants) showed a negative lagged association between EE and subsequent negative affect, which was significant in three participants (one depressed and two non-depressed). Overall, the effect sizes of the lagged associations between EE and positive and negative affect were small.

Lagged Association between Positive and Negative Affect and Physical Activity

With regard to the lagged association between positive affect and subsequent EE (Figure 3a), the majority of the participants ($n = 15$) showed a positive association between positive affect and subsequent EE. For two participants (both depressed) this association was significant. Four participants (two depressed and two non-depressed) showed a non-significant negative association. The majority of participants also showed a positive lagged association between negative affect and subsequent EE (eleven compared to six participants) (see Figure 3b). For only one (depressed) participant this association reached statistical significance ($p<0.05$). Overall, the effect sizes of the lagged associations between positive and negative affect and EE were small.

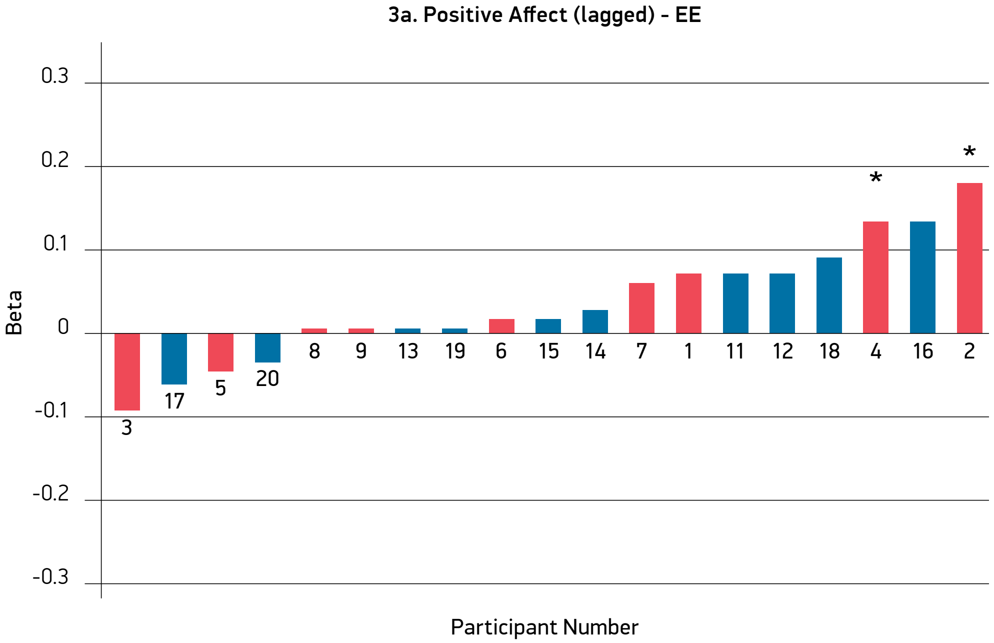
Figure 2a and 2b. Lagged Associations between Physical Activity and Positive (2a) and Negative (2b) Affect in the Depressed (red bars) and Non-Depressed (blue bars) Individuals.

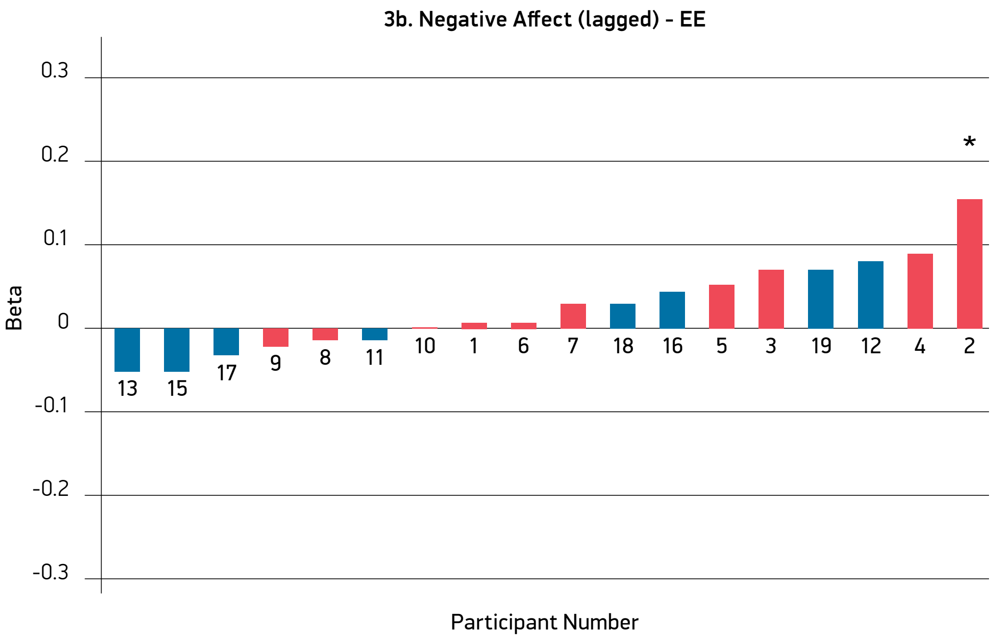




EE = energy expenditure; * significant at the 0.05 level; ~significant association with mixed sign of coefficients at different lags. Values on y-column depict standardized coefficients (beta).

Figure 3a and 3b. Lagged Associations between Positive (3a) and Negative (3b) Affect and Physical Activity in the Depressed (red bars) and Non-Depressed (blue bars) Individuals.





EE = energy expenditure.
* significant at the 0.05 level. Values on y-column depict standardized coefficients (beta).

DISCUSSION

To our knowledge, this is the first study to use a within-subject time-series approach to investigate the dynamic relationship between physical activity and affective states in depressed and non-depressed individuals. The associations found were not consistent across individuals, ranging from negative to positive, bidirectional or not, and with varying effect sizes. An exception was the direct association between physical activity and positive affect, which was positive in nearly all individuals, albeit with varying effect sizes.

A positive relationship between physical activity and positive affect has also been found in the majority of group-based EMA studies (for example see: Giacobbi, Hausenblas, & Frye, 2005 and Wichers et al., 2012). However, the delayed association between physical activity and positive affect was not consistently found in the current study; in some individuals it was positive, while in others it was negative. Furthermore, the strength of the relationship was small to negligible for most individuals. Thus, the results suggest that physical activity enhances positive affect directly while only in some individuals there is also a delayed effect.

The increase in positive affect following physical activity did not seem to differ between depressed and non-depressed individuals, although any potential differences between the two groups were not evaluated statistically due to the small sample size. A recent EMA study comparing patients with a depressive disorder and non-depressed controls (Mata et al., 2012) showed similar improvements in positive affect after physical activity in both groups. Hence, physical activity seems to (directly) improve positive affect in individuals regardless of their depression status.

While the direct association between physical activity and positive affect was quite consistent across individuals, this was not the case for negative affect. Both positive and negative associations between physical activity and negative affect were observed, though we found the strongest effect sizes for a negative association. A similar pattern emerged for the lagged association between physical activity and subsequent negative affect. So, in some individuals there seems to be a negative effect of physical activity on negative affect, but in most individuals this relationship is weak or non-existent. When aggregating data of individuals with opposing effects of physical activity on negative affect, the group-level effect will be small and inconsistent across different study samples. Hence, individual differences may explain inconsistent results in EMA studies regarding the relationship between physical activity and negative affect (Kanning et al., 2013).

Observational (between-subject) studies investigating the direction of the relationship between physical activity and depressive symptoms have found a reciprocal relationship between the two variables under investigation (Jerstad, Boutelle, Ness, & Stice, 2010;

Lindwall, Larsman, & Hagger, 2011; Stavrakakis, de Jonge, Ormel, & Oldehinkel, 2012). We extended these findings by showing that the reciprocal relationship differed between individuals. In some individuals increases in positive mood were followed by increases in their physical activity levels, while in others it was the other way around. Interestingly, in only a few individuals there appeared to be a noticeable bidirectional relationship. If these data were aggregated, we might have concluded that there was a bidirectional relationship at the group level, while in most individuals the relationship was unidirectional, albeit in different directions.

The effect sizes in the present study were generally small, but considering the non-experimental daily-life design and the short intervals between the measurements this could have been expected (Wichers et al., 2012). Nonetheless, small effects can accumulate over time and become larger, because of the way these changes are disseminated through the system and mutually enhanced through possible feedback loops. This can especially be true if physical activity becomes a daily habit, for instance through regular sport participation, which could result in systematic long-term improvements in positive mood. Future research using intensive time-series designs should explore this putative accumulating effect in more detail, in order to elucidate whether the short-term benefits of physical activity on mood can accumulate into larger benefits over time, and if so, in which individuals.

Clinical Relevance

Two findings from the current study might be of interest to clinicians. First, our results suggest that physical activity benefits positive affect in the short-term. A recent meta-analysis of randomized controlled studies showed evidence of a short-term benefit of physical activity on depression (Krogh et al., 2010). Our results support and extend this finding by showing that these short-term benefits might be acting through an elevation of positive mood rather than through a decrease in negative mood for the majority of individuals. The mechanisms behind this short-term benefit of physical activity on positive affect are currently not understood. Some hypotheses have been proposed implicating the endorphin system (Dishman & O'Connor, 2009; Thoren, Floras, Hoffmann, & Seals, 1990) and increases in self-efficacy (Bodin & Martinsen, 2004), but future research is needed to explore these in more depth.

Second, in some individuals high levels of positive or negative affect were associated with increases in physical activity in the current study. Feeling good might increase the level of physical activity engagement, but apparently also feeling bad might have such an effect in some individuals. This concurs with the suggestion that physical activity might be perceived as an efficient strategy to repair negative mood, i.e., 'walking off' negative affectivity (Clark & Isen, 1982). Our study cannot address this hypothesis properly, but suggests inter-individual differences in the way affect influences subsequent activity levels that need to be taken into account.

Strengths & Limitations

This study has several notable strengths. First, the time-series design allows the investigation of the associations at the individual level, thanks to the multiple repeated measurements over time, and also allows for the exploration of temporal patterns and the direction of the relationship. Second, although obtaining multiple repeated measurements can be troublesome, time-consuming, and demanding, especially for participants with depression, the compliance of the participants did not seem to deteriorate significantly in this study. There was no indication that the participants were unable or found it difficult to comply with the study protocol, and any systematic missing values were due to technical problems with the accelerometers. Even in these cases the number of obtained measurements per individual (>60) was still adequate to perform time-series analysis.

The results from this study should be interpreted with some caution due to several limitations. First, the generalizability of within-subject studies to the population at large is limited, and this is the trade-off that comes with the increased specificity of within-subjects time-series studies. Therefore, a combination of within- and between-subject approaches is warranted in order to improve our understanding of the complex relationship between physical activity and daily mood. Second, the models applied in this study assume that the relationship between physical activity and affect is linear. It is possible that the relationship between the two is curvilinear and a specific threshold (i.e., frequency, duration or intensity) of physical activity is needed to benefit individuals with regards to their affect, while exceeding this threshold might result in negative consequences. Another potential limitation is that the strength of an association depends on the degree of variability in the data. Therefore, it is possible that for some individuals the variability between the measures was not large enough to detect an association. Finally, we considered the temporal ordering of the contemporaneous associations to be from physical activity to affect, given the fact that physical activity covered each time period as a whole and affect was assessed at the end of each time period. However, it is possible that reverse effects (affect to physical activity) were acting here as well, which might have introduced bias in our interpretation. However, due to the design of the study we could not assess this eventuality further.

CONCLUSION

We explored inter-individual differences in the magnitude and direction of the relationship between physical activity and positive and negative affect using a within-subjects time-series design. Our findings provided evidence that the strength and direction of the relationship between physical activity and affect differs across individuals. Future research investigating this dynamic relationship could try to identify subgroups of individuals that might benefit most from physical activity. These findings could be informative for both research and clinical care intended to improve the mood of depressed individuals.

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