Physical Activity and Depressive Mood in the Daily Life of Older Adults

Gruenenfelder-Steiger, Andrea E ; Katana, Marko ; Martin, Annika A ; Aschwanden, Damaris ; Koska, Julia L ; Kündig, Yvonne ; Pfister-Lipp, Eliane ; Allemand, Mathias

Abstract: Empirical evidence suggests that physical activity is related to less depressive moods. However, little is known about this association in the everyday life of older adults, limiting the ecological validity of prior findings. This study examined within-person associations between physical activity and depressive mood in older adults across 7 days. Moreover, the study tested the extent to which need-fulfillment can explain this association. The sample consisted of 68 adults aged 65 to 93 years. Physical activity was assessed objectively with accelerometers, whereas need-fulfillment and depressive mood were assessed at the end of each day using self-reports. Results from multilevel analysis suggest that daily physical activity was negatively related to daily depressive mood within persons. Although need-fulfillment did not explain the association between physical activity and depressive mood, it was a statistically significant predictor of daily depressive mood and even attenuated the effect of physical activity on depressive mood to nonsignificance.

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Suggested Reviewers:	
Opposed Reviewers:	
Response to Reviewers:	Dear Prof. Dr. Lang, Editor-in-Chief, We thank you very much for your feedback and the opportunity to revise the manuscript. Both Reviewers suggested helpful comments to improve the quality of our manuscript and we attended these constructive comments with great care. Please find our responses to the reviewers below. For the sake of convenience, we simply copied the reviewers' comments and answered them point by point.

In our revision, we highlighted all changes in response to these reviews and technical comments in red-colored letters as requested. Please let us know if you have any questions concerning our revision.

Sincerely,
Andrea Gruenenfelder-Steiger
Marko Katana
Annika Martin
Damaris Aschwanden (corresponding author concerning submission/revision)
Julia Koska
Yvonne Kündig
Eliane Pfister-Lipp
Mathias Allemand

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Responses to the Reviewers' Comments

Reviewer #4:

1. I would refrain from using the term intensive longitudinal design in this ms. If I calculated correctly, you have 49 items in 68 people. EMA may be more appropriate. In light of this criticism, the limitations could be stated more clearly (to be frank, I find that these are very few data points and believe that this hampers the interpretability of your moderator analyses).

Referring to the book "Intensive Longitudinal Methods" by Bolger and Laurenceau (2013), we would like to keep the term intensive longitudinal instead of EMA. In the introduction of this book it is stated: "Although specifying a minimum number of measurements is somewhat arbitrary, we chose five because with five observations it is possible to estimate within each subject a linear model with an intercept, a slope for time, a slope for a prior value of the outcome, and a slope for on putative causal antecedent" (p.2).

We agree that seven measurement points is still relatively small and refer to the discussion part to address the criticism raised by Reviewer #4:

"…. several limitations must be noted. First, the study period included seven consecutive days. Although we are convinced that one week of assessment gave us some idea about the associations between the examined processes, it cannot be excluded that seven days are not enough to get a more valid picture of everyday life of older people. Future studies should assess a higher number of participants and cover a longer assessment period that may provide more information about the unfolding processes and its associations over several weeks." (p.19)

2. The abstract needs 1-2 sentences on background and objective.

We added some sentences on background and objective to the abstract as proposed by Reviewer #4.

"Empirical evidence suggests that physical activity is related to less depressive mood. However, little is known about this association in everyday life of older adults, limiting the ecological validity of prior findings. The goal of this study was to examine the within-person association between physical activity and depressive mood in older adults across seven days."

3. The choice of depressivity items and their content needs discussion - clinically, these seem severe depression items that should show little within-person variance over time but they do in your study - Why?

We measured depressive mood with three items. The three items reflect typical characteristics of depressive mood such as hopelessness for the future, listlessness, and difficulty to start an activity and were obtained from the Beck Depression Inventory

	(BDI; Hautzinger, Bailer, Worall, & Keller, 1994). As reviewer #4 stated absolutely correctly, these items would reflect severe depression if constantly rated with “totally agree”, representing the high end of the scale. However, participants rated these items on a scale from 1 to 10. Hence, subtle changes on a day-to-day basis with regard to depressive mood could be assessed, as these tend to fluctuate and represent states of emotional reactivity, even in non-clinical samples. A multitude of empirical studies, based on clinical and non-clinical samples have evidenced that individuals experience different degrees of depressive mood (such as hopelessness for the future, listlessness, or difficulty to start an activity) across time and situations. For a review see Pemberton and Tyszkiewicz (2016). For a moment-to-moment micro-level-perspective on depressive mood in everyday life see Wichers (2014). Pemberton, R., & Tyszkiewicz, M. F. (2016). Factors contributing to depressive mood states in everyday life: A systematic review. Journal of Affective Disorders, 200103-110. doi:10.1016/j.jad.2016.04.023 Wichers, M. (2014). The dynamic nature of depression: A new micro-level perspective of mental disorder that meets current challenges. Psychological Medicine, 44, 1349-1360. doi:10.1017/S0033291713001979 4. Minor: P.9, 1st line should read Deci We thank Reviewer #4 for his/her comment and changed it accordingly. Reviewer #5: Technical Check We thank Reviewer #5 for the technical check. In this revision, we corrected all issues raised by Reviewer #5.

Physical Activity and Depressive Mood in Daily Life of Older Adults

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Abstract

Empirical evidence suggests that physical activity is related to less depressive mood. However, little is known about this association in everyday life of older adults, limiting the ecological validity of prior findings. The goal of this study was to examine within-person associations between physical activity and depressive mood in older adults across seven days. Moreover, the study tested the extent to which need-fulfillment can explain this association. The sample consisted of 68 adults aged 65 to 93 years. Physical activity was assessed objectively with accelerometers, whereas need-fulfillment and depressive mood were assessed at the end of each day using self-reports. Results from multilevel analysis suggest that daily physical activity was negatively related to daily depressive mood within-persons. Although need-fulfillment did not explain the association between physical activity and depressive mood, it was a statistically significant predictor of daily depressive mood and even attenuated the effect of physical activity on depressive mood to non-significance.

Keywords: physical activity, depressive mood, need-fulfillment, old age, multilevel models

Physical Activity and Depressive Mood in Daily Life of Older Adults

The growing group of older and very old people may be particularly vulnerable to depressive symptoms, as most of the risk factors such as low economic status, poor physical health, disability, and social isolation may apply for many of them (Bruce, 2002). Indeed, studies have shown that the prevalence of depressive symptoms tends to increase with age (cf. Kennedy, 1996). Therefore, identifying factors that prevent mental illness and promote health and well-being in old age is an important goal for the individual and aging research. Physical activity is one promising candidate, as it is often conceptualized as a resource for a healthy and satisfying lifestyle that serves as a valuable protective factor against mental illness (Warburton, Nicol, & Bredin, 2006). The present study examined the association between physical activity and depressive mood in daily life of older adults. Whereas clinical depression is a severe psychological disorder, non-clinical depressive mood refers to varying states of increased negative affect that fluctuate within individuals over shorter time periods (WHO, 2017). Depressive mood typically involves affective, cognitive and physiological symptoms (e.g., weakened activity, suspensions to be actively engaged in life, sadness) that can change from day to day, as people likely experience days with more and days with less depressive mood. In discussing previous research, we use the original terms (e.g., depressive mood, depressive symptoms, and depression) from the published work.

Definition and Assessment of Physical Activity

Physical activity is an umbrella term that combines different categories of body movements. Elements of physical activity are defined by Caspersen, Powell and Christenson (1985) and include bodily movement via skeletal muscles that results in energy expenditure and is positively correlated with physical fitness. Exercise, in contrast, involves planned, structured and repetitive bodily movements and has the objective to improve or maintain physical fitness (Caspersen et al., 1985). So far, most of the research focused on physical activity during leisure

time and exercising (Kanning & Schlicht, 2010). However, physical activity may not only involve playing sports or engaging in exercise at a high level of intensity but also covers low intensity level activities such as cleaning, gardening or walking from A to B (Kanning, Ebner-Priemer, & Schlicht, 2013). Indeed, common categorizations of physical activity show a distinction into sleeping, activities at work, and leisure activity, but other forms such as weekdays versus weekend activities have been used as well (Caspersen et al., 1985). For the present research, we were particularly interested in activities of daily living (ADL) that represent physical activity in everyday life (Kanning et al., 2013). High physical functioning in terms of ADL has been proposed as an important factor for well-being and satisfaction (Sato, Demura, Kobayashi, & Nagasawa, 2002). Physical activity in everyday life typically includes activities that are performed to achieve an intended purpose, such as walking to the supermarket or to the bus station, or doing gardening (Kanning et al., 2013).

Physical activity can be assessed with self-report measures including questionnaires, diaries/logs, surveys, and interviews. These measures are frequently used due to their practicality, low cost, low participant burden, and general acceptance. Although self-reports are useful for gaining insight into the levels of physical activity, they have the capacity to over- and underestimate true physical activity, energy expenditure, and rates of inactivity (Sallis & Saelens, 2000). Moreover, self-reports of physical activity suffer from issues of recall and response bias (e.g., inaccurate memory, social desirability) and the inability to capture the absolute level of physical activity. Alternatively, objective and direct measures of physical activity (e.g., accelerometer or step counts) are commonly used to increase precision and accuracy (Ward, Evenson, Vaughn, Rogers, & Troiano, 2005). Hence, physical activity might be best measured (a) continuously as part of one's everyday normal routine in order to catch one's unbiased level of daily general activity and body movements, and (b) by means of an objective and unobtrusive measure in order to avoid omitting important activity information.

Despite the benefits of objective and direct measures of physical activity, only a few studies have placed emphasis on real-life daily activities in old age (Cheung, Gray, & Karunanithi, 2011). For example, a study investigated how much time six older adults spent sitting (79%), standing (77%), lying (91%) and walking (98%) for a period of 2-3 months (Allan & Johnson, 2009). Another study examined active and passive movements in 47 older men (mean age 73.9 years) over 2 to 12 hours without being able to differentiate between standing and walking (Brown, Roth, & Allman, 2008). Thus, everyday activities across some days or even weeks might reflect an individual's physical activity level more realistically. So far, less is known about the protective effects of physical activity on depressive mood of older adults in daily life.

Physical Activity and Depressive Mood

A large body of epidemiological research shows a clear negative link between physical activity and depressive symptoms – besides a number of positive associations with people's health status (e.g., Harris, Cronkite & Moos, 2006; Strawbridge, Deleger, Roberts, & Kaplan, 2002). A systematic review of prospective studies examined the relationship between physical activity and the prevention of depression (see Mammen & Faulkner, 2013 for a review). Of the reviewed studies, 83% indicated that physical activity is associated with a lower risk for the onset of a depression. As an example, higher walking levels are associated with a decreased risk of depressive mood of up to nearly 60% (Mammen & Faulkner, 2013). The reviewed studies consisted of non-clinical community samples across all age groups from 11 to 100 years in North America and Europe. Only one of the reviewed studies, however, objectively measured physical activity by using ergometer cycling. Most studies measured physical activity by asking participants how many minutes per week or day they had been physically active. Furthermore, Bernaards et al. (2006) investigated the longitudinal relation between strenuous leisure time physical activity and psychological complaints in a Dutch working population in a 3-year

follow-up study. For workers with sedentary jobs, leisure time physical activity (1-2 times per week) was associated with a reduced risk of future depressive mood in workers aged 18 to 59 years. Leisure time physical activity was measured through self-report measures. Moreover, a longitudinal study of middle-aged women with three surveys across 5 years found a negative relationship between physical activity and depressive symptoms, independent of pre-existing physical and psychological health (Brown, Ford, Burton, Marshall, & Dobson, 2005). Self-report measures were used assess time spent in walking, moderate- and vigorous intensity physical activity and psychological health.

The negative association between physical activity and depressive symptoms were also evidenced in samples of older adults. For example, older adults ($N = 663$) aged 65+ participated in an eight-year study with two measurement occasions that examined changes in intensity of physical activity as predictors of depressive symptoms (Lampinen, Heikkinen, & Ruoppila, 2000). Results suggest that those participants with reduced intensity of physical activity during the eight years reported more depressive symptoms at the second measurement occasion. Older people who reduced the amount of walking had a 5.38 times higher risk of experiencing symptoms of depression. A meta-analysis investigated the association between physical activity and symptoms of depression in old age (Teychenne, Ball, & Salmon, 2008). A total amount of 27 observational and 40 intervention studies were included, and most of them showed a significant effect of physical activity on depression.

Despite the growing number of studies demonstrating associations between physical activity and depressive symptoms, less is known about whether and to what degree within-person variations in physical activity are related to within-person variations in depressive mood in everyday life. Previous work mostly relied on cross-sectional data, intervention data, prospective longitudinal data over longer time periods, and typically used self-reported measures of physical activity or focused on physical activity during leisure time and exercising (Kanning

& Schlicht, 2010; Mammen & Faulkner, 2013; Teychenne et al., 2008). Moreover, previous research typically focused on between-person analyses, suggesting that higher levels of physical activity are associated with a lower risk of developing depressive symptoms. However, people differ both in their level of activity and depressive mood across days, weeks and months. That is, people do not only differ between each other on how physically active they are *in general*, but people also differ *within* themselves, that is, their physical activity differs from day to day. For example, a person might be moderately active during a typical week (e.g., perform one hour of intensive cycling per week and casually uses the bike). It would be interesting to see whether that person's *variation* in activity influences her or his daily depressive mood. Is this person feeling less depressed on days during which she or he experienced more activity compared to days when she or he was inactive? This question is interesting independent of how active the person is compared to the general population. Therefore, it would be very important to know whether and to what degree physical activity is related to depressive mood within individuals. Such knowledge would be fruitful to identify how these constructs are linked to each other and provide us with valuable information for intervention strategies in everyday life. Instead of grouping people into more or less active groups, we aimed at relating within-person variations in physical activity to within-person variations in depressive mood.

So far, very few studies examined within-person associations between physical activity and depressive mood, or more broadly, affect in everyday life using intensive longitudinal designs, and these studies typically focused on samples of younger adults (e.g., Bossmann, Kanning, Koudela-Hamila, Hey, & Ebner-Priemer, 2013; Kanning & Schlicht, 2010; Langguth, Schmid, Gawrilow, & Stadler, 2016; Reichert et al., 2016; Schwerdtfeger, Eberhardt, Chmitorz, & Schaller, 2010). For example, a recent study investigated within-person associations between physical activity and affect in younger adults over 10 consecutive days (Haas, Schmid, Stadler, Reuter, & Gawrilow, 2017). Participants wore accelerometers to assess physical activity and

they reported their affect before going to sleep using online diaries. The results showed that on days when participants engaged in more activity than usual, they reported not only less depressed and angry evening affect but also more vigor and serenity in the evening. Moreover, a study investigated within-person associations between physical activity in everyday life with positive and negative affect in participants aged 18 to 73 years (Schwerdtfeger, Eberhardt, & Chmitorz, 2008). Physical activity was measured throughout one day (12 hours) with accelerometers, whereas positive and negative affect were assessed every hour using handheld computer. Results showed that physical activity was significantly and positively related to positive affect but not to negative affect.

The Role of Psychological Need-Fulfillment

Several mechanisms and processes have been suggested to explain the negative association between physical activity and depressive symptoms including increases in mastery, self-efficacy, and distraction (Craft, 2005; Craft & Perna, 2004; Paluska & Schwenk, 2000) or increases in endorphin levels and reductions in cortisol levels (Johnsgard, 1989; Nabkasorn et al., 2006). One potential mechanism is psychological need-fulfillment, as engaging in physical activities may meet psychological needs, which in turn, effect depressive mood. In this study, we therefore explored the role of psychological need-fulfillment. This factor might be particularly relevant because previous research evidenced positive associations between physical activity and need-fulfillment (McDavid, McDonough, Blankenship, & LeBreton, 2016), and negative associations between need-fulfillment and depression (Deci & Ryan, 1985). Further, need-fulfillment may vary as a function of changes in daily life circumstances (Patrick, Knee, Canevello, & Lonsbary, 2007). Research has shown that short-term variations in need-fulfillment and well-being were interrelated (Reis, Sheldon, Gable, Roscoe, & Ryan, 2000; Sheldon, Ryan & Reis, 1996).

Self-Determination Theory (SDT; Deci & Ryan, 2000) has identified three essential psychological needs for optimal well-being: Relatedness, autonomy and competence. According to SDT, fulfillment of these three needs results in life satisfaction, well-being, and optimal psychological functioning. From a functional perspective, physical activity in everyday life may play an important role for all three psychological needs. First, physical activity can meet the need for competence. This psychological need represents the experience of effectiveness in one's pursuits (Deci & Ryan, 1985; Vansteenkiste, Niemiec, & Soenens, 2010). In everyday life, this may be achieved by being able to show activities of daily living such as walking to the bus stop, hiking, or gardening. Second, physical activity in everyday life can meet the need for autonomy. This psychological need reflects the desire of individuals to be the origin or source of their own behavior (Deci & Ryan, 1985) and is experienced when individuals perceive their behavior as self-endorsed (Ryan & La Guardia, 2000). This need can be satisfied when a person is able to perform daily activities based on his or her own interest. In daily life, this can be achieved when walking wherever one wants to go, when deciding or planning an activity, or when experiencing freedom to organize the day according to one's preferred structure (e.g., eating when desired, choosing among a variety of activities, freedom to structure the day individually). Third, physical activity can meet the need for relatedness. This psychological need is defined as the experience of reciprocal care and concern to important others (Deci & Ryan, 1985; Vansteenkiste et al., 2010). In daily life, participating in a walking group or going on a hiking trip with friends may meet this need. For this study, we focused on daily need-fulfillment as a composite of the three psychological needs rather than differentiating between different needs, as the basic assumption of SDT is that all three needs need to be satisfied in an individual to maintain well-being (Deci & Ryan, 2000). Given the above-mentioned considerations, one would expect that need-fulfillment explains the link between physical activity and depressive mood in daily life.

The Present Study

This intensive longitudinal study focused on within-person associations between daily depressive mood and daily physical activity in older adults across seven days. We expected that physical activity and depressive mood show day-to-day variations within individuals and are negatively interrelated. Specifically, on days when older adults engaged in more physical activity than usual, they should report less depressive mood on that day. Besides examining the relationships between daily physical activity and daily depressive mood, we explored the role of daily need-fulfillment. On the one hand, we expected that on days when older adults engaged in more physical activity than usual, they should report higher need-fulfillment on that day. On the other hand, we expected that higher need-fulfillment on a given day is associated with lower depressive mood on that day. Finally, we tested the extent to which need-fulfillment can explain the association between daily physical activity and depressive mood by means of a within-person mediation.

Methods

Participants

Sixty-eight healthy older adults aged 65 to 93 years (M = 78.00, SD = 7.90; 73.5% female) participated in this study. Regarding the marital status, 16.2% of the participants were single, 44.1% were married, 14.7% were divorced and 25% were widowed. Participants were recruited at the Institute of Neumuenster in Switzerland. We designed our study across seven days to have enough intraindividual data to conduct the targeted within-person analyses. During a recruitment event, potential participants had the opportunity to ask questions concerning the study and to sign up for it. Requirements to participate in this study were that the older adults had to be mobile and cognitively able to pass the mini-mental state examination (MMSE; Folstein, Folstein, & McHugh, 1975). A further requirement was that participants did not need help with their daily activities from an outpatient service for home care. Regarding chronic

conditions, 99% of the participants reported to be physically mobile, 9% reported to need some sort of walking frame and only 2% reported to need help from close others when performing daily activities. At the end of the study, participants received a little gift and their personal physical activity profile that has emerged from the study.

Procedure

At the beginning of the study, participants filled out a questionnaire with demographic variables and scales that are not relevant for this study. As the sample consisted of healthy older adults, we did not extensively assess chronic conditions and somatic diseases. Research assistants visited all participants at their homes, or if desired, outside of their homes in a place at their convenience to familiarize them with the accelerometer (motion sensor) that collected daily physical activity. The intensive longitudinal part of the study took place over a period of seven consecutive days. During these days, participants carried an accelerometer to continuously record their physical activity in the form of step counts, and they reported their daily need-fulfillment and daily depressive mood and at the end of each day using a paper-and-pencil questionnaire. At the end of the study, participants were asked whether the week of data collection was a rather typical or an atypical week for them and rated this question on a scale from 1 to 10 (1 = *very atypical*, 10 = *very typical*; $M = 7.28$, $SD = 2.68$). Participants provided data on average with 6.90 measurement points of daily physical activity ($SD = 0.85$), 6.94 assessments ($SD = 0.38$) of daily need-fulfillment, and 6.93 repeated assessments ($SD = 0.40$) of daily depressive mood.

Daily physical activity. An accelerometer (movisens3; movisens GmbH, 2016) was used to measure physical activity objectively. This motion sensor records raw data on three-axis: Acceleration, barometric altitude and temperature (cf. Shammas et al., 2014) with a frequency of 64 Hz. The activity output parameters in terms of daily steps were calculated using the analysis software *DataAnalyzer* from *movisens* (see www.movisens.com/en/products/dataanalyzer/). For

this study, the raw data captured by the accelerometer was used to calculate the daily amount of steps as the key parameter for daily physical activity. We coded physical data with less than 1,200 steps per day as outliers to control for extreme low values of step counts (cf. Tudor-Locke et al., 2011), which resulted in 30 outliers (6.3%) out of 476 measurement points (68 participants x 7 assessments). After removing the outliers, participants provided on average 6.46 complete measurement points of daily physical activity (*SD* = 1.44). From the 476 potential measurements of daily physical activity, there were 439 measurement points (92.2 %) collected. The mean of the daily amount of steps was around 7,000 steps per day (*M* = 7,028.05, *SD* = 3,287.12) with a range from 1,468 to 15,609 steps. For reasons of comparability with the self-reports, we standardized the amount of step counts to a 1 to 10 metric for the multilevel analyses.

Daily depressive mood. Three items reflecting typical depressive mood such as hopelessness for the future, listlessness, and difficulty to start an activity from the Beck Depression Inventory (BDI; Hautzinger, Bailer, Worall, & Keller, 1994) were used to measure depressive mood. The three items are, "I feel the future is hopeless and that things cannot improve", "I was tired and listless" and "I have to force myself to any activity". The items were rated on a scale ranging from 1 (*disagree*) to 10 (*agree*). The Cronbach's α reliability estimate ranged from .68 to .78 across the seven days. Cronbach's α is a between-person measure of internal consistency. Following the recommendations of Bolger and Laurenceau (2013), we also tested for the within-person reliability. The within-person reliability estimate R_C was .70.

Daily need-fulfillment. Need-fulfillment was measured with three items from the General Causality Orientations Scale (Deci & Ryan, 1985). For reasons of parsimony, we only used one item for each need-fulfillment dimension (i.e., relatedness, competence and autonomy). The items are "Today I felt close and connected to the people I care about" (relatedness), "I felt efficient and competent in what I was doing" (competence), and "Today my actions were based on my values and interests" (autonomy). We used the average of these three items as our daily

need-fulfillment score. The items were rated on a scale ranging from 1 (*disagree*) to 10 (*agree*). The Cronbach's α reliability ranged from .74 to .89 across the measurement period. The within-person reliability estimate R_C was .80.

Statistical Analysis

In this study, we investigated within-person associations between daily physical activity and daily depressive mood. In contrast to conventional longitudinal models, this intensive longitudinal study design provided multiple measurements of self-reported observations to capture within-person processes. In such designs, it is important to consider that error terms of repeated measurements within one person are non-independent. Multilevel modeling allows the analysis of such data structure appropriately, where multiple measurements are nested within a person. Therefore, we used multilevel analysis to investigate our research questions (Bolger & Laurenceau, 2013; Kreft & DeLeeuw, 1998; Raudenbush & Bryk, 2002). With multilevel modeling, it is possible to estimate within-person processes between variables for each individual, taking into account the potentially different intercepts and slopes of each participant due to environmental and individual influences. Moreover, multilevel modeling enables researchers to differentiate within-person and between-person processes and to disentangle how variables wax and wane together within a person over multiple measurement points.

Regarding our analytical procedure, we first examined the nested structure of the data by computing intraclass correlation coefficients (ICCs) and compared how much of the total variance lied within-person. Second, we compared whether a random-intercept or a random-intercept and random-slope structure of the time-varying independent variables (daily physical activity, daily need-fulfilment, and time) best describes the data by choosing models with better goodness of fit indices (-2log likelihood) and by comparing the χ^2-difference between two models. Third, we examined the associations between daily physical activity and daily depressive mood while controlling for the person-mean of physical activity, age, gender, and

time (Model 1). Equations for the basic model examining the association between daily depressive mood and daily physical activity are depicted in the Appendix. Next, we added daily need-fulfillment to the previous model (Model 2). Finally, in Model 3 we investigated the extent to which need-fulfillment explained the association between daily physical activity and daily depressive mood using within-person mediation analysis following the procedures suggested by Bolger and Laurenceau (2013, chap. 9). The within-person mediation analysis was conducted with bootstrapping, containing 1,000 iterations and a confidence interval of 95%.

Following Bolger and Laurenceau (2013), we included a between-person version and a within-person version of the same variable to control for the between-person effects and to truly examine the within-person variation. The between-person version of our independent time-varying predictors were the person-means. The within-person version of our independent time-varying predictors were computed by subtracting the person-mean from the grand-mean centered variables. Age and gender (male = 0, female = 1) were grand-mean centered for the analysis. The variable time reflected the ordinal time point (day) of the daily assessments (0 to 6). We did not expect systematic mean-level changes in physical activity, need-fulfilment, and depressive mood across seven days, as this study was not an intervention study. However, we might expect reactivity effects and individual differences over time. Therefore, we controlled for time in all our models (cf. Bolger & Laurenceau, 2013).

We analyzed the described models using the "lme4" package (Bates, Maechler, Bolker, & Walker, 2017) in R Version 3.4.0 (R Development Core Team, 2017). As an indicator of effect size, the model fit was evaluated using within-person pseudo-R^2 because the exact size of R^2 cannot be computed in these types of analyses. These values represent the percentage of how much of the variance was explained by the added independent variables. As an indicator of goodness of fit we compared which models reported a lower value of the Akaike Information

Criterion (AIC) and the Bayesian Information Criterion (BIC) (Kreft & DeLeeuw, 1998; Nezlek, 2001).

Results

Table 1 displays the within-person descriptive statistics and correlations among the variables of interest. Results showed that daily depressive mood was negatively correlated with the daily measures of physical activity and need-fulfillment, whereas daily physical activity and daily need-fulfillment were positively interrelated. Associations with age suggest that the older participants tended to report lower levels of daily physical activity and daily need-fulfillment, and higher levels of daily depressive mood.

For the intensive longitudinal analysis, we tested whether the daily assessments of physical activity, need-fulfillment, and depressive mood were each non-independent within-person by computing intraclass correlations (ICCs). The ICC(1) describes the amount of between-person variance in regard to the total variance. The ICC(2) describes how homogenous the ratings were throughout the seven assessments within an individual (cf. Meyer, Shemla, Li, & Wegge, 2015). The amount of daily physical activity was non-independent within individuals (ICC(1) = 0.51, $F(65,373) = 7.84$, $p < .001$). This indicates that 51% of the total variance lied between-persons and 49% lied within-persons. Individuals were distinguishable in regard to their mean level of daily physical activity (ICC(2) = 0.87). The same was true for the rating of daily depressive mood, findings showed non-independence within individuals (ICC(1) = 0.48, $F(67,403) = 7.51$, $p < .001$), and individuals were distinguishable in regard to their mean level of daily depressive mood (ICC(2) = 0.87). Also the ratings of daily need-fulfillment were non-independent within individuals (ICC(1) = 0.58, $F(67,404) = 10.42$, $p < .001$), and individuals were distinguishable in regard to their mean daily depressive mood (ICC(2) = 0.90). Therefore, we decided to analyze the data by multilevel modeling.

In examining the best structure for the time-varying predictor variables (the within-person variables of physical activity, need-fulfillment and time), we found the following results: The random-intercept model fitted the data better than the random-intercept and random-slope model for physical activity ($\Delta\chi^2 = 0.87$, $p > .05$) and time ($\Delta\chi^2 = 0.21$, $p > .05$). The random-intercept and random-slope model fitted the data better than the random-intercept model for need-fulfillment ($\Delta\chi^2 = 20.38$, $p < .001$). Following Bolger and Laurenceau (2013), we specified all time-varying predictor variables as random effects to account for additional variations.

Next, we tested Model 1 that consisted of the outcome variable daily depressive mood, the focal predictor within-person daily physical activity and the control variables person-mean of daily physical activity, age, gender, and time (Model 1, Table 2). The findings showed that daily depressive mood was negatively associated with within-person daily physical activity, meaning that an increase of one unit in physical activity was associated with a decrease of -0.14 in daily depressive mood within-person. Moreover, the results of the random effects showed that participants significantly differed in their intercepts.

In Model 2, we added the within-person variable of daily need-fulfillment and the person-mean of daily need-fulfillment to the previous model (Model 2, Table 2). The results showed that daily depressive mood was negatively associated with daily need-fulfillment, both on the within-person and the between-person level (person-mean of daily need-fulfillment). This implies that participants differed from each other but also that participants differed from themselves across the measurement occasions. In comparison to Model 1, the within-person association between daily physical activity and daily depressive mood was not statistically significant anymore. Adding daily need-fulfillment to the model attenuated the effect of daily physical activity to non-significance. The results of the random effects showed a significant variance in the within-person association between daily need-fulfillment and daily depressive mood. This implies that participants differed in the size of this association. Moreover, compared

to Model 1, both AIC and BIC showed lower scores and thus indicated a better fit for Model 2. The within-person pseudo-R^2 estimate indicates more explained variance in Model 2.

Finally, in Model 3 we tested the extent to which daily need-fulfillment explained the association between daily physical activity and daily depressive mood. The results suggested that there was no significant indirect (b = -0.03, p > .05, 95% CI [-0.07, 0.00]) effect, however, the direct effect (b = -0.11, p < .05, 95% CI [-0.22, -0.01]) and total effect (b = -0.14, p > .01, 95% CI [-0.25, -0.04]) were significant. This implies that the direct association between daily physical activity and daily depressive mood was significant but not the indirect way through daily need-fulfillment.

Discussion

This intensive longitudinal study is one of the first examining within-person associations between physical activity, psychological need-fulfillment, and depressive mood and in daily life of healthy older adults. Summarizing the results, we found a significant negative association between daily physical activity and daily depressive mood within-persons. That is, on days when participants engaged in more physical activity than usual, they reported less depressive mood on that day. We also found that on a given day with higher need-fulfillment, participants reported less depressive mood on that day. However, in models containing both physical activity and need-fulfillment as predictor of depressive mood, the effect of physical activity was attenuated to non-significance. The within-person finding that daily need-fulfillment was negatively related to daily depressive mood is in line with theory and previous research (Reis et al., 2000; Sheldon et al., 1996). Generally speaking, on the one hand the present results support the claim that engaging in physical activity may be associated with reductions in depressive mood. On the other hand, the results also show clear boundary conditions of the small effect of physical activity, because daily need-fulfillment attenuated the size of physical activity to non-significance. It is possible that share method variance with respect to the assessment of need-

fulfillment and depressive mood by means of self-reports was responsible, in part, for the attenuation of the effect of physical activity that was measured with a different method.

In contrast to our expectations, daily psychological need-fulfillment did not mediate the association between daily physical activity and daily depressive mood in older adults. Although the indirect effect through need-fulfillment was not significant, the direct and total effects of daily physical activity were significant. Future research should systematically test for other potential mechanisms underlying the within-person associations between physical activity and daily depressive mood in daily life. Candidates are biological factors (e.g., serotonin metabolism; Hamer, Molloy, de Oliveira, & Demakakos, 2009) or psychological factors (e.g., mastery and self-efficacy; Paluska & Schwenk, 2000). Even though psychological need-fulfillment did not function as a mechanism, a small but significant positive within-person association between physical activity and need-fulfillment was evidenced. Hence, it may be interesting to elaborate on intervention studies which address individual's need-fulfillment profile to satisfy one's individual needs through physical activity. Such daily activities could be walking groups for older adults, organized shopping trips to the mall via bikes or cooking events in the senior residence where everyone is welcome to participate for those individuals who report a high need to stay related to others in old age. Activities can address different needs and motivate to stay active due to different goals in later life. Finding an activity that is attuned to the individual need profile is likely to produce a long-term active lifestyle.

Some practical recommendations might derive from our results. First, as shown in our unobtrusive objective measurement of physical activity in daily life, lower depressive mood was related to higher physical activity, even though physical activity was not of high intensity (i.e., walking). Accordingly, activities of high intensity are not coercively necessary to induce a better mood (cf. Bossmann et al., 2013) what might be especially important in old age, as some older adults cannot or do not want to engage in highly intensive activities such as aerobic or strength

workouts. Therefore, older individuals may increase or maintain their daily number of steps to influence their mood (i.e., decrease depressive mood). Scientists and practitioners unanimously suggest that being physically active reduces negative affect and/or is positively related to positive affect, so that older adults should attempt to *walk on the bright side* (cf. Marselle, Irvine & Warber, 2014; Robertson, Robertson, Jepson, & Maxwell, 2012; Rosenberg et al., 2012). The daily amount of physical activity might be increased by walking more often or longer distances (i.e., increasing the daily amounts of steps), performing everyday movements or simply getting up more often, or activities such as dancing, gardening, hiking, swimming, cycling, or household chores (cf. WHO, 2017).

Strengths, Limitations and Future Research

The present study made several noteworthy contributions. First, we applied a real-life research design to assess within-person variations in physical activity, need-fulfillment, and depressive mood in contrast to earlier research with a main focus on between-person associations. Second, we used an objective measure to study the amount of physical activity, thus having a more realistic representation of how active a person in his or her everyday life is (rather than subjectively asking them how active they think they are). Furthermore, we preferred to capture physical activity as it occurs in daily life compared to artificially forming groups that may not adequately represent how active individuals are in their everyday life.

Despite these strengths, several limitations must be noted. First, the study period included seven consecutive days. Although we are convinced that one week of assessment gave us some idea about the associations between the examined processes, it cannot be excluded that seven days are not enough to get a more valid picture of everyday life of older people. Future studies should assess a higher number of participants and cover a longer assessment period that may provide more information about the unfolding processes and its associations over several weeks. Second, participants responded to self-report questions only at the end of each day. Higher

frequency of assessments per day (e.g., morning and evening or even more often) would have given a more fine-grained picture of how these associations unfold in everyday life. For instance, it would be interesting to investigate whether physical activity and depressive mood, respectively, in the morning are associated with depressive mood and physical activity, respectively, in the evening. Future research should investigate potential time lagged effects and circadian patters. Moreover, not only time triggered assessments should be applied, but also activity triggered assessments. This means that participants would report on their mood if a certain activity threshold is reached. Third, we did only use three items to assess need-fulfillment. Future studies may want to use more items to capture the needs of autonomy, competence and relatedness in greater detail. It would be interesting to determine how these subscales are differentially related to daily depressive mood.

Finally, in our multilevel models we have only looked at one direction, that is, from physical activity to depressive mood. However, it is also possible, that lower depressive mood might lead to higher physical activity. Future studies with more measurement occasions and a higher number of participants might disentangle the bidirectional relationship of physical activity and depressive mood. We assume that both vicious and positive circles within individuals can unfold bi-directionally for physical activity and depressive mood. These circles are likely to be strongly reinforcing in one's normal everyday life. For example, by starting to be more physically active, people possibly become less depressed and feel motivated and encouraged to being physically active in the future. By going out and experience small but effective results from their physical activity on the social, on the physical, and on the psychological level, these benefits might change the negative mindset and reduce depressive symptoms on an active day. The lowered depressive mood of that day, in turn, can reduce burdens to start being active again (e.g., motivation to start, self-confidence to go out, general energy level, more positive thinking patterns). On the other hand, by reducing physical activity and increasingly staying at home,

people might be stuck in a vicious circle of lower energy, more depressive mood, lower self-confidence, and less courage to go out and be active that further reduces their motivation to engage in physical activity.

Conclusions

There are two main conclusions to this study. First, the results provide support for negative within-person associations between objectively assessed daily physical activity and daily self-reported depressive mood in older adults. Second, the results also demonstrate the limits of daily physical activity for daily depressive mood in old age, and emphasize the role of daily need-fulfillment as an important resource for healthy functioning. Future studies are needed to better understand how, when, and why different types of physical activities (not only the amount of daily steps) prevent or reduce depressive mood. Overall, this study adds additional evidence to the associations between physical activities and depressive mood on the within-person level in daily life of older adults.

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Appendix

The Basic Multilevel Statistical Model

The statistical model for the association between physical activity and depressive mood is represented in the following equations. The first equation is a *within-person* equation:

$$Y_{ij} = \beta_{0j} + \beta_{1j}PAwp_{ij} + \beta_{2j}T_{ij} + \varepsilon_{ij}$$

Y_{ij} represents daily depressive mood for each person j on day i. β_{0j} represents the intercept of daily depressive mood for each person j, β_{1j} denotes the within-person slope between daily depressive mood and the within-person variable of daily physical activity for each person j, β_{2j} denotes the within-person slope between daily depressive mood and the control variable time for each person j, and r_{ij} represents the residual with-person variance. The second equation is a *between-person* equation:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}(PApm_j) + \gamma_{02}(age_j) + \gamma_{03}(gender_j) + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}(PApm_j) + \gamma_{12}(age_j) + \gamma_{13}(gender_j) + u_{1j}$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21}(PApm_j) + \gamma_{22}(age_j) + \gamma_{23}(gender_j) + u_{2j}$$

Any person's intercept of daily depressive symptoms β_{0j} is determined by a common intercept for the population, γ_{00}, a common fixed effect of the person-mean variable of physical activity for the population γ_{01}, a common fixed effect of the variable age for the population γ_{02}, a common fixed effect of the variable gender for the population γ_{03} and a person specific deviation of the intercept, u_{0j}. Any persons' slopes β_{1j}, and β_{2j} are determined by a fixed common slope effect γ_{10}, γ_{20}, a fixed common effect of the person-mean variable of physical activity on γ_{11}, γ_{21}, a fixed common effect of age on γ_{12}, γ_{22}, a fixed common effect of gender on γ_{13}, γ_{23} and a person specific deviation, u_{1j}, u_{2j}. Combining these two within-person and between-person equations, we receive this single equation:

$$Y_{ij} = \gamma_{00} + \gamma_{01}(PApm_j) + \gamma_{02}(age_j) + \gamma_{03}(gender_j) +$$

$$\gamma_{10} + \gamma_{11}\,(\mathrm{PApm}_j)\,\mathrm{PAwp}_{ij} + \gamma_{12}\,(\mathrm{age}_j)\,\mathrm{PAwp}_{ij} + \gamma_{13}\,(\mathrm{gender}_j)\,\mathrm{PAwp}_{ij} +$$

$$\gamma_{20} + \gamma_{21}\,(\mathrm{PApm}_j)\,T_{ij} + \gamma_{22}\,(\mathrm{age}_j)\,T_{ij} + \gamma_{23}\,(\mathrm{gender}_j)\,T_{ij} +$$

$$u_{0j} + u_{1j}\,\mathrm{PAwp}_j + u_{2j}\,T_{ij} + \varepsilon_{ij}$$

Table 1

Within-Person Descriptive Statistics and Correlations among the Main Variables

Variable	*M*	*SD*	1	2	3	4
1. Daily depressive mood	2.39	1.83				
2. Daily physical activity	3.39	1.70	-.20*			
3. Daily need-fulfillment	8.15	1.63	-.47*	.15*		
4. Age	78.00	7.85	.15*	-.39*	-.15*	
5. Gender	0.26	0.44	-.02	-.02	-.06	.09

Note. N = 437 to 471. The potential scale scores for physical activity (see method section), daily need-fulfillment, and daily depressive mood ranged from 1 to 10. Female gender was coded as 0 and male gender was coded as 1.
*$p < .001$.

Table 2

Intensive Longitudinal Association Between Daily Depressive Mood and Daily Physical Activity

	Daily depressive mood			
	Model 1		Model 2	
	Estimate	*SE*	Estimate	*SE*
Fixed Effects				
Intercept	2.52***	0.57	3.45***	0.98
Daily physical activity	-0.14*	0.06	-0.07	0.06
Daily need-fulfillment	NA	NA	-0.50***	0.08
Person-mean daily physical activity	-0.20	0.14	-0.11	0.11
Person-mean daily need-fulfillment	NA	NA	-0.62***	0.09
Age	0.01	0.02	< 0.01	0.02
Gender	0.01	0.37	-0.07	0.27
Time	< 0.01	0.03	-0.01	0.03
Random Effects				
Intercept	1.62**		1.98	
Daily physical activity	0.03		0.03	
Daily need-fulfillment	NA		0.09*	
Time	0.01		0.01	
Residuals	1.59		1.34	
AIC	1621.30		1555.35	
BIC	1674.34		1632.87	
Within-person pseudo-R^2	0.08		0.23	

Note. Number of observations = 437. Coefficients shown are unstandardized coefficients. *SE* represents the standard error of the unstandardized regression coefficients. Male gender was coded as 0, female gender as 1. Model 1 represents the model examining the association between daily physical activity and daily depressive mood. Model 2 represents the model examining the association between daily physical activity, daily need-fulfillment, and daily depressive mood. The random effect estimates were represented by random effect variances. AIC = Akaike Information Criterion. BIC = Bayesian Information Criterion.

* $p < .05$. ** $p < .01$. *** $p < .001$.