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ECOLOGICAL MOMENTARY ASSESSMENT AND INTERVENTION IN PHYSICAL ACTIVITY AND WELL-BEING: AFFECTIVE REACTIONS, SOCIAL-COGNITIVE FACTORS, AND BEHAVIORS AS DETERMINANTS OF PHYSICAL ACTIVITY AND EXERCISE

Topic Editors
Wolfgang Schlicht, Ulrich W. Ebner-Priemer and Martina Kanning

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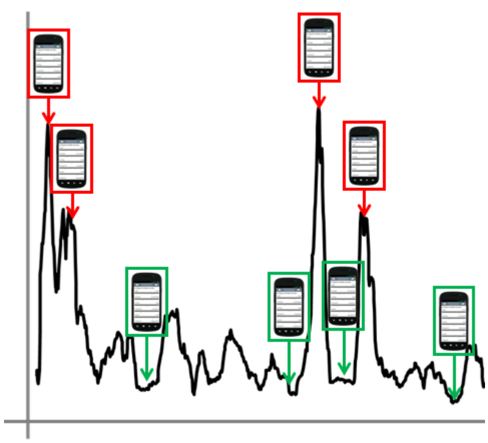

Ecological momentary assessment (EMA) allows potentially timely examination of relationships among variables such as affect, cognition, and physical activity or sedentary behavior in their natural environments. EMA or ambulatory assessment is achieved by use of step monitors, accelerometers, global positioning systems, smartphones, and other portable devices and has been utilized in a number of populations and behavior or health conditions. We invite submissions of studies (original articles, reviews, brief reports) using ecological momentary assessment to examine psychological (i.e., social-cognitive, emotional, or affective) antecendents, events, or reactions to physical activity/exercise or inactivity/sedentariness. Of particular interest are ecological studies that utilize EMA to investigate influences on physical activity or sedentariness. Emotional and perceptual responses and triggers (e.g., positive and negative affect, fatigue) are believed to play important causal or bidirectional roles in the support of physical activity and related habits. Social contexts and social-cognitive variables and psychological states (such as playing with friends, self-efficacy or outcome expectancies, depression) may trigger or reflect activity behavior. Invited as well are Ecological Momentary Intervention (EMI) studies that use ambulatory delivery via electronic or other devices to affect subsequent cognitions, affect, and physical activity behavior (Heron, K., and Smyth, J., 2010). Studies that examine whether ambulatory monitoring of physical activity enhances or undermines long-term exercise or physical activity would be of interest in this call.

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EDITORIAL
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Ecological momentary assessment and intervention in physical activity and well-being: affective reactions, social-cognitive factors, and behaviors as determinants of physical activity and exercise

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Keywords: ambulatory assessment, ambulatory monitoring, ecological momentary assessment, experience sampling method, computer-assisted diary, ecological validity, accelerometry

Psychological research uses multifarious assessment strategies to describe and to explain emotional and cognitive processes accompanying behavior in order to predict future behavior. However, laboratory assessments and questionnaire approaches dominate psychology, which has been criticized lately (Baumeister et al., 2007). In general, the appropriateness of a method or an instrument depends on the research questions. Observational methods are on the shortlist if behavior is the construct in focus. Questionnaires are appropriate where attitudes or personal traits should be described. Compared to traits, which are by definition stable in time and consistent across different situations, affective constructs like emotions, mood, and affective reactions tend to be highly volatile. Affective dynamics are caused by internal and external influences of high variance, e.g., by bad or good news, by hormonal variations, etc. (Schlicht et al., 2013). Questionnaires to investigate affective states presume too much regarding subjects' power of memory. As different authors point out, memory processes are open to biases and distortions (e.g., Kahneman et al., 2004).

This is the same if subjects are asked to remember their volume of physical activity. The time, which one has invested in a sports game, in a tennis match or walking in a group or in other similar types of structured physical activity is often easy to remember. Questionnaires might be appropriate instruments to get reliable data in these situations. This is not the case with exercise bouts and with low intense physical activity like non-exercise thermogenesis, activities of daily living or all kinds of activities done during the course of a normal day. Only accelerometers or other types of electronic monitors registering data (e.g., bio data such as heart rate) will deliver valid and reliable information.

Another methodological question is raised if research seeks to gain data out of subjects' real life. If the ecological validity should be convincing research has to go into everyday life using a suitable approach to get valid and reliable data. Ambulatory Assessment (AA) or ecological momentary assessment is an appropriate and promising approach for infield real time investigations. The *Society for Ambulatory Assessment—Understanding Behavior in Context* defines AA as any use of "...infield methods to assess ongoing behavior, physiology, experience, and environmental aspects of humans ... " (http://www.ambulatory-assessment.org; last access 03. October 2013).

Meanwhile, AA has gained increasing interest in psychology, has been used in countless studies and reviews, and several special issues have been published (e.g., in *European Psychologist edited by* Ebner-Priemer et al. (2009); in *Psychological Assessment* edited by Trull and Ebner-Priemer (2009); and in *Psychosomatice Medicine*, edited by Kubiak and Stone (2012). An internet search for AA delivers 11,100,000 entries and one article in Wikipedia. One can get the impression that those activities prove that AA is nowadays a common method in psychology, but it isn't. AA is still an approach needing special expertise. Real time data collection requires specialized hard- and software and that resulting longitudinal data needs sophisticated statistical analyses.

Devices for AA are computer-aided and allow for the collection of a huge variety of interesting parameters in daily life (for more details see Fahrenberg et al., 2002):

- self reported data (whereabouts, behaviors, settings);
- moods, affective reactions, symptoms like aches, commentaries;
- psychological tests infield;
- behaviors (e.g., physical activity; speech patterns);
- environmental conditions (e.g., noise, temperature);
- bio-markers (e.g., blood pressure, heart rate, skin response).

Although electronic diaries have gained increasing interest in psychology to assess variables of interest in real time, and although accelerometers are quite popular in sports and exercise science to objectively assess physical activity and movement pattern in everyday life, the combination of both methods is still alarmingly rare. To give researchers, in the context of physical activity and exercise psychology, guidance in the advantages and benefits of combining e-dairies with accelerometers, we invited experts to report their original studies. It resulted in a reader giving an impression of the fruitfulness of AA in this special field.

The reader starts with a position statement done by the editors themselves (Kanning et al., 2013), making suggestions "how to investigate within-subject associations."

This statement is followed by an article written by Bossmann et al. (2013) looking for the association between short periods of everyday activity and mood. The authors examined the influence of various everyday life activities on three dimensions of mood (valence, calmness, energetic arousal) in a predominantly inactive sample.

Bussmann (2013), the next author in the reader, provokes with his thesis that "One plus one equals three (or more...)." He is convinced that "the time is right to combine advanced methods of measuring movement behavior with advanced use of e-diaries/e-questionnaires" resulting not just in adding the values of both separate fields, but surpassing this sum.

The same author, together with his co-author (Bussmann and van den Berg-Emons, 2013), discusses what can be measured beyond the total amount of activity. Contrary to health sciences where the volume or amount of physical activity is the crucial variable for determining the effect of this behavior in reducing the incidence of non-communicable diseases, Bussmann and his colleagues make the point that, when focussing other research questions, it is worth looking closer to single components of this multi-dimensional construct and to answer the methodological challenging question of which parameters are most relevant, valid and responsive in a given setting.

An original research article done by Dunton et al. (2012) follows this *theory article*. They tested the feasibility and validity of an EMA self-report protocol using electronic surveys on mobile phones. It is feasible and data are valid, but the volume of physical activity is underestimated, especially for those persons underweight or normal weight.

Ebner-Priemer et al. (2013) highlight the problem that physical activity can be monitored continuously, whereas psychological variables can only be assessed at discrete intervals. The challenge is to link both types of variables. The authors propose an interactive multimodal ambulatory monitoring algorithm, which automatically increases the number of e-diary assessments during "active" episodes.

Kanning (2013) uses objective, real-time measures to investigate the effect of actual physical activity on affective states in everyday life. In her original research article she reports a study differentiating the contexts of working and leisure time in a sample with students. There is an interesting moderator effect identified by multilevel analyses: Active episodes of physical activity and the context influenced subsequent energetic arousal. Valence and calmness seemed to be independent of the context in which the activity occurs.

From work and leisure time the next text goes to pupils in elementary schools. Kühnhausen et al. (2013) asked if and how it is possible to collect valid and reliable data in this special group of very young participants. It is feasible to objectively measure children's activity using accelerometers for a period of several weeks. In this investigation an impact of physical activity on affect in children was not shown.

Murphy et al. (2012) original research focuses on another group of participants; those with chronic pain. They investigate the association between symptoms, pain coping strategies and physical activity among patients with symptomatic knee and hip osteoarthritis. The higher the body mass index, subjective feelings of fatigue, and using "guarding" as coping method, the lower the activity levels have been. "Asking for assistance," another coping method was related to higher activity levels.

Schwerdtfeger et al. (2012) report an ecological 108 momentary intervention study using a randomized experimental design. In the treatment group they used text messages to increase physical activity and to induce breaks of sedentary time in contrast to a group only having an educational standard intervention and an untreated control group. It is perhaps against our expectations, but short text messages reminding subjects of their action plans are not more effective than an intervention without text messages. However, it is comforting to see that there seems to be a beneficial effect on subject's self-efficacy and, as is known, this is a very strong predictor of behavior change.

Two articles in which von Haaren is a contributor (von Haaren et al., 2013; and Walter et al., 2013) close the series of articles. The second to last original research article done by von Haaren launches an interesting debate. Following their results, they state that analysing the physical activity and affect association of inactive people is difficult due to little variance and distribution of the assessed variables. In the last article in this reader Walter et al. found non-statistically significant increases in mood intensity immediately after acute endurance exercise episodes. Perhaps surprisingly, no medium term effects in mood states could be observed after a few weeks of endurance training, too.

Given the combination of texts the reader has a colorful bouquet of different inquiries in his hands and we hope this launches more studies in the natural environment assessing behavior in real settings.

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How to investigate within-subject associations between physical activity and momentary affective states in everyday life: a position statement based on a literature overview

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Several meta-analyses have investigated the association between physical activity and affective states and have found evidence suggesting that exercise exerts a positive effect on affective state. However, in this field of research, most studies have conducted between-subject analyses. Nonetheless, there is more and more interest in the within-subject associations between physical activity and momentary affective states in everyday life. This position statement pertains to this up-and-coming field of research and provides methodological recommendations for further studies. The paper is divided into three parts: first, we summarize and evaluate three methodological requirements necessary for the proper evaluation of within-subject associations between physical activity and momentary affective states in everyday life. We propose that the following issues should be considered: (a) to address the dynamic nature of such relationships, repeated assessments are necessary; (b) as activities performed in everyday life are mostly spontaneous and unconscious, an objective assessment of physical activity is useful; (c) given that recall of affective states is often affected by systematic distortions, real-time assessment is preferable. In sum, we suggest the use of ambulatory assessment techniques, and more specifically the combination of accelerometer-assessment of physical activity with an electronic diary assessment of the momentary affective state and additional context information. Second, we summarize 22 empirical studies published between 1980 and 2012 using ambulatory assessment to investigate within-subject associations between momentary affective states and physical activity in everyday life. Generally, the literature overview detects a positive association, which appears stronger among those studies that were of high methodological quality. Third, we propose the use of ambulatory assessment intervention (AAIs) strategies to change people's behavior and to enable people to be active as often as possible during the day (e.g., reducing sitting time, taking more steps per day).

Keywords: ambulatory assessment, physical activity, affective states, methodological requirements, ecological momentary assessment

INTRODUCTION

Several meta-analyses (e.g., Arent et al., 2000; Netz et al., 2005; Puetz et al., 2006; Reed and Ones, 2006; Netz, 2009; Reed and Buck, 2009) have consistently revealed a positive between-subjects relation between physical activity and affective states; that is, a range of people feel better after having been physically active. To clarify whether physical activity might be a useful strategy to enhance good feelings, it is necessary to additionally investigate the within-subject relation; that is, does an individual person feel better after having been physically active? Unfortunately, the within-subject relations between these parameters have not been studied intensively. However, technological progress in recent years, especially in the field of mobile technology and statistics, enables the investigation of this relation with much higher precision than ever before. Accordingly, the purpose of this paper is to instruct readers regarding this new and innovative field of research on assessing the within-subject associations between physical activity and momentary affective states in everyday life according to the highest methodological standards.

In this position statement, we will propose, after providing an introduction to the assessment of physical activity and affect in general, three methodological standards, namely, (a) the need to address the dynamic process of the association; (b) the objective assessment of physical activity; and (c) the importance of real-time assessment. We suggest that meeting these standards is important in future studies. Second, we will report and summarize studies investigating the within-subject association between physical activity and momentary affective states in everyday life and will discuss whether they meet the methodological requirements of objective assessment and real-time assessment. Results will be summarized and discussed. Third, we will discuss how intervention studies can make use of the new methods.

PHYSICAL ACTIVITY

Physical activity is an umbrella term. There are different categories that fit under this term, ranging from playing sports or engaging in exercise at high levels of intensity to ambulating, which falls at the other end of the intensity scale. The latter category includes non-exercise activity thermogenesis (NEAT; Levine et al., 2005) or – in the vocabulary of gerontology and geriatrics – the basic and instrumental activities of daily living (ADL).

Physical activities can also differ according to the context in which they occur. Specifically, they can be performed in the workplace, during leisure time, by commuting, or by keeping the house clean. Furthermore, a person can be physically active for several reasons and for different motives (e.g., to meet other people, to strengthen health, or to run errands).

The physical activities of everyday life include in addition to sports and exercise mainly activities, which are done to achieve an intended purpose. For instance, people walk to the railway station, do gardening, walk to the supermarket, bike for transport, or play badminton with their children. In contrast to structured and regular exercise, the majority of everyday life activities is often processed automatically and habitually or performed spontaneously. The physical activities of everyday life include both categories of activities, and we label these activities here as "actual physical activities" (aPA).

Although aPA includes spontaneous and regular physical activities, there are certain important ways in which these kinds of activities differ. Compared with spontaneous activities, regular exercise often has a planned structure, will be repeated at a certain time and primarily includes higher levels of energy consumption. In most cases, regular exercise lasts longer, and people are often active together with others. However, spontaneous or habitually performed activities in everyday life may be planned (e.g., walking with the dog every day), but they may not be as stringent regarding time, place, and duration, in contrast to regular exercise or participation in sports. These activities during everyday life can last for a long (e.g., a bicycle tour during the weekend) or a short (e.g., walking to the railway station) period, and a person may be physically active on his or her own or together with others. Thus, spontaneous or habitually performed activities are more flexible than regular exercise. The person can be physically active in a way he or she likes the most at the moment. Therewith, these activities may have a subtle influence on a person's affective state.

AFFECTIVE STATES

Definitions of emotion, mood, and affect are not universally accepted, and, as Smith and Lazarus (1990) proposed, these constructs make up an "inherently fuzzy set" (p. 611). Thus, it is imperative that researchers use theoretically grounded definitions of the affective constructs and adequate instruments to measure affective states of interest. Affective states could be measured as a general construct (on a trait level) or as a momentarily construct (on a state level). In this position statement, we refer to momentary affective states as an elementary, conscious accessible feeling that could be good or bad and of high or low arousal. Affective states are irreducible and similar to the term "core affect" of Russell (1980) and they are most general compared to mood and emotion.

Unfortunately, an intense discussion about differences in the theoretical constructs of mood, affect, and emotions is beyond the scope of this paper. For a deeper discussion, readers are referred to Cabanac, 2002; Frijda, 1994; Scherer, 2005, 2009; and Russell, 2003 or to Ekkekakis and Petruzello, 2000 for a detailed discussion about the differences between affective constructs in the domain of Sport and Exercise Psychology.

WITHIN-SUBJECT RELATIONS VERSUS BETWEEN-SUBJECT RELATIONS

Comparable to the spontaneous or habitually performed activities of everyday life, momentary affective states on a state level are a volatile phenomenon. Momentary affective states show labile-state characteristics, whose dynamic quality is of interest (Ong et al., 2007). Therefore, it would be worthwhile to investigate intra-individual changes in addition to inter-individual differences or general effects following exercise or sport participation. Analyses of within-subject relationships reveal more the subtle and immediate effects of momentary affective states on physical activity, and vice versa, than is possible through analyses of between-subjects relationships. To fully understand the difference between within and between-subjects relationships, it is important to keep in mind that one cannot draw within-subject conclusions from across-person associations (Shiffman et al., 2008; Hamaker, 2012). Moreover, results based on within-subject data may contradict findings from between-subjects studies. For example, one result from some meta-analyses referring to intervention studies (e.g., Netz et al., 2005; Reed and Ones, 2006) is that regular exercise (on a trait level) has positive and significant effects on general affective states (on a trait level). The researchers tried to examine whether people who engage in low volumes of physical activity differ from those people who engage in high volumes of physical activity in their affective states. These findings do not imply that a person feels positive after having been physically active or feels negative (both on a state level) after having been inactive. Researchers who are interested in how much people vary over time in affective states and to what extent this variation is affected by physical activities should assess individuals during everyday life repeatedly and over time (see **Figure 1**). This process is necessary because inferences about the experiences of an individual cannot be made without observing that individual when he or she is actually physically active or not (Hektner et al., 2006).

In summary, analyses of between-subjects relations yield knowledge of important structural, dispositional variables that distinguish persons from one another, whereas analyses of within-subject relations yield insights into the dynamic association between variables and their dependence on situational circumstances (Bolger et al., 2003). To address the dynamic process between affective states and daily physical activity, different participants should be assessed repeatedly over time, during everyday life (Ebner-Priemer and Trull, 2009).

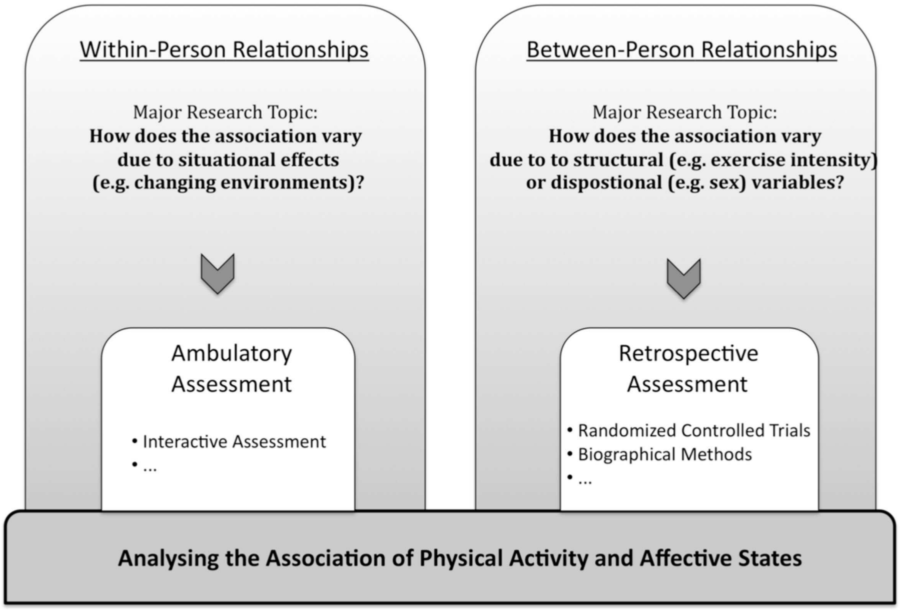

FIGURE 1 | Distinction between within-subject and between-subjects relationships in major research topics and assessment approaches.

STUDIES AND META-ANALYSES ON THE ASSOCIATION BETWEEN PHYSICAL ACTIVITY AND AFFECTIVE STATES

Most studies investigating the effects of physical activity on affective reactions have focused on structured activities, such as exercising or sports that were engaged in during leisure time to strengthen health or simply for recreational purposes. Several meta-analyses have shown that physical activity is positively associated with affective states and well-being, although convincing theoretical models of the association between physical activity and affective states are missing so far (e.g., Raglin et al., 2007). Looking only at the last decade, a narrative review (Netz, 2009) and two systematic meta-analyses (Arent et al., 2000; Netz et al., 2005) assessed the link between regular exercise and subjective well-being and mood in older adults without clinical disorders. According to the reviewed results, older people reported higher values of well-being post-exercise compared to baseline (for the intervention groups). In addition, improved mood and sense of well-being are associated with regular exercise. A further meta-analysis performed by Puetz et al. (2006) found similar associations between regular exercise and feelings of energy and fatigue. Regular exercise refers to cumulative bouts of structured exercises intended to improve physical fitness. Approximately 80% of the effect sizes reported in their meta-analysis were based on patients' data (persons suffering from cancer or chronic fatigue, involved in cardiac rehabilitation, or suffering from psychic disorders, such as anxiety or depression). In addition, two meta-analyses investigated the effects of acute (Reed and Ones, 2006) and regular (Reed and Buck, 2009) exercise on positive affect. Both analyses showed that a person's odds of feeling better increase after engaging in activities of low-to-moderate intensity for at least 30 min all at once.

The aforementioned meta-analyses examined the effect of structured exercise interventions or the effect of precisely described physical activity on different constructs of mental health (on a trait level). In addition, they analyzed moderator effects related to exercise conditions, such as intensity and duration or related to the baseline values of affective states. These studies did not analyze, if individual's affective states vary due to physically active or inactive situations in every day life. Therefore, the findings did not show whether physical activity has a subtle influence on person's affective states in everyday life.

In addition, many studies have assessed affective states during everyday life with a set of items referring to positive affective states, such as "cheerful," "happy," and "joyful," or negative affective states, such as "sad," "angry," "stressed," and "depressed." The authors of these studies lacked a theoretical framework of affective states, and they did not specify what they intended to measure. With such a broad perspective, affective constructs such as mood, affect, feelings, and emotions were considered to be synonymous. However, the constructs designated by these terms differ along several dimensions, such as duration and origin, for instance. Furthermore, an important distinction between affective constructs is whether a relation between the subject and a particular object or event is involved (cf. Frijda, 1994).

METHODOLOGICAL REQUIREMENTS FOR INVESTIGATING WITHIN-SUBJECT ASSOCIATIONS

ASSESSMENTS SHOULD BE DONE REPEATEDLY IN REAL TIME

Repeated real-time assessments provide the opportunity to conduct context-sensitive analyses, whereas retrospective and cross-sectional reports, such as questionnaires or interviews, cannot precisely assess time-dependent processes and are limited in revealing context-sensitive information. Episodes of physical activity may be triggered by situational cues, whether external (e.g., a call from a friend, the local weather, or other environmental cues) or internal (e.g., cognitive cues or memories). Gaining a better understanding of episodes of physical activity, including their antecedents and consequences, is of theoretical and practical importance. *Do I feel better after running? Or do I exercise more when I'm feeling well and energized?* Such individual information supports understanding of the patterns that determine a person's physical activity and may be used for interventions to increase physical activity.

Experimental data, autobiographical studies, and investigations of daily life have all demonstrated that retrospective assessments are a highly dubious methodology (Stone et al., 2002; Fahrenberg et al., 2007), given that people's recall is vulnerable to multiple, systematic distortions and is often based on biased storage and recollection of memories (Fredrickson, 2000). Multiple memory heuristics have already been identified. For example, findings suggest that information associated with positive affect is more easily remembered than that associated with negative affect (i.e., the *affective valence effect*). However, the *mood-congruent memory effect*, the *peak end rule*, and *duration neglect* not only increase inaccuracy but also introduce systematic errors (Ebner-Priemer and Trull, 2009). The U.S. Food and Drug Administration fostered a discussion on heuristics, biases, and distortions by informing the pharmaceutical industry that real-time data are desirable because retrospective reports may be biased (U.S. Department of Health and Human Services Food and Drug Administration, 2009).

Real-life assessment is of special importance, given that multiple studies have shown that behavior (e.g., physical activity) that is manifested and measured under laboratory conditions is not representative of behavior performed in daily life outside of the laboratory. A relevant example of this distortion was reported by Horemans et al. (2005). The authors found that the heart rate of post-polio patients while walking at a self-paced speed was significantly lower in a laboratory compared to what it was in daily life; however, the same was not true for step rate. This difference is likely due to the more demanding environment of daily life (e.g., dual- or multi-tasking, uneven ground) and calls into question the generalizability of laboratory-based measurements. For a more detailed discussion of laboratory and real-world differences and the distinction between performance ("do do") and capacity ("can do"), please see Bussmann and Ebner-Priemer (2011).

PHYSICAL ACTIVITY SHOULD BE MEASURED OBJECTIVELY

In recent years, exercise and health sciences have experienced a tremendous increase in the use of objective methods to assess physical activity (see, for example, a special issue in Medicine and Science in Sports and Exercise, Volume 44, Supplement 1, January 2012). Multiple types of accelerative devices, especially accelerometers, are used all over the world to capture the amount of physical activity subjects are performing in everyday life. However, there are studies and papers that employ a methodological shortcut, namely, retrospective questionnaires, when assessing the unconscious activities of daily life (spontaneous or habitually performed). Instead of actually assessing the amount of physical activity performed, such studies allow participants to estimate their typical level of physical activity or the number of minutes of vigorous activity in which they engaged during the last 2 weeks. From a memory perspective, we would not assume a high level of precision in such estimations. Accordingly, several authors question whether self-assessments of physical activity can serve as a substitute for the collection of actual behavioral data in everyday life (Baumeister et al., 2007; Fahrenberg et al., 2007) and caution against studies relying solely on self-reported physical activity (Ward et al., 2005; de Vries et al., 2006; Rapport et al., 2006).

Two systematic reviews give empirical evidence that objective assessment and subjective ratings of physical activity are not closely related. Prince et al. (2008) analyzed 187 studies that assessed physical activity both objectively (directly measured, primarily through accelerometry) and subjectively (self-reports, e.g., questionnaires or diaries). Overall, the correlations were low-to-moderate, with a mean of 0.37, even though the same construct (physical activity) was measured by the two different assessment methods. Similarly, Adamo et al. (2008) found low-to-moderate associations (−0.56 to 0.89) when comparing 83 studies using self-reports versus direct measures in a systematic review of physical activity in children. In both reviews (Adamo et al., 2008; Prince et al., 2008), self-report measures of physical activity had generally higher results than objective measures, and self-reports overestimated physical activity to a greater extent in females than in males. Taken together, the findings show substantial discrepancies and only moderate correlations between self-reports and direct measures, suggesting that the measurement method does have a significant impact on the data that are revealed. Consequently, Adamo et al. (2008) and Prince et al. (2008) question the widespread justification of using more cost-effective methods by positing that there are meaningful correlations between indirect and direct measures.

However, objective measures also have their limitations and cannot be viewed uncritically as the gold standard. Whereas most activities are captured quite easily (e.g., whole body movement), other forms of activities are quite difficult. In particular, situations in which participants sit and perform a physical activity (e.g., cycling, certain forms of weightlifting exercise) are typically underestimated. However, new software algorithms help to accurately classify movement patterns (e.g., cycling, taking the bus) and, in so doing, enhance the precision of estimating energy consumption.

Therefore, we recommend our second methodological requirement, that unconscious activities (spontaneous or habitually performed) should be measured objectively.

AFFECTIVE STATES SHOULD BE MEASURED ELECTRONICALLY TO ENSURE COMPLIANCE

The third methodological requirement addresses the electronic assessment of affective states. Two methodological issues require further consideration. First, there is some evidence that the length of the recall interval determines the amount of report inaccuracy. Broderick et al. (2008) reported data showing that an increase in the recall period from 1 to 7 days was accompanied by a consistent increase in recalled reports of pain, although e-diary ratings did not increase over time. This finding implies that shorter recall intervals should facilitate the gathering of meaningful and reliable data. Second, an assessment can only be called real time if the procedures used can evaluate timely compliance to prompts, such as electronic diary devices that time-stamp responses. This aspect is important, as Stone et al. (2002) demonstrated in a paper-pencil diary study in which most participants reported themselves to be compliant 90% of the time. However, checking compliance by objective light sensors revealed that only a minimal number of reports were completed according to the time schedule set by the experimenters (11%). Therefore, we recommend electronic equipment for data acquisition to circumvent "back-filling," in which assessment points are completed en masse immediately prior to a visit to the researcher (for a detailed discussion of the pros and cons of electronic versus paper-pencil diaries, see Stone et al., 2002; Green et al., 2006; Tennen et al., 2006).

To summarize, we referred in this section to three methodological requirements to analyze within-subject associations between physical activity and affective states. Studies of high methodological quality (a) assess the variables repeatedly in real time in everyday life, (b) measure physical activities of everyday life objectively, and (c) measure affective states with self-reports electronically to capture the data with maximum accuracy.

Ambulatory assessment is a promising method for addressing these abovementioned methodological requirements.

Different terms have been used for methods that capture data repeatedly in real life and real time, including ambulatory assessment (Fahrenberg et al., 2007), experience sampling (Csikszentmihalyi and Larson, 1987), and ecological momentary assessment (Stone et al., 2007). To simplify matters, we will use the term ambulatory assessment, which is defined by the Society for Ambulatory Assessment as follows: "*Ambulatory Assessment* comprises the use of field methods to assess the ongoing behavior, physiology, experience, and environmental aspects of humans or non-human primates in naturalistic or unconstrained settings. Ambulatory Assessment designates an ecologically relevant assessment perspective that aims at understanding biopsychosocial processes as they naturally unfold in time and in context." (www.ambulatory-assessment.org).

STUDIES ON WITHIN-SUBJECT ASSOCIATIONS BETWEEN PHYSICAL ACTIVITY AND AFFECTIVE STATES IN EVERYDAY LIFE: AN LITERATURE OVERVIEW

LITERATURE SEARCH

To gain an overview of the proposed research field, we did a rough literature search strategy. We searched for studies analyzing within-subject associations between physical activity and momentary affective states assessed in real time in everyday life.

Our inclusion criteria were as follows:

1. To find studies assessing the aforementioned relation in everyday life, we included studies that used one of the following key terms: accelerometry, ambulatory assessment, ambulatory monitoring, computer-assisted diary, ecological momentary assessment, ecological momentary intervention, electronic diary, experience sampling method, hand-held computer.
2. To find studies that assessed physical activity, we included studies that used one of the following key terms: ADL, exercise, NEATs, physical activity, sedentariness, sport.
3. To find studies that assessed momentary affective states, we included studies that used one of the following key terms: affect, affective reactions, affective states, emotions, feelings, mood.
4. In addition, we included English-language studies that were published between 1980 and June 2012.

All four inclusion criteria had to be met for a study to be included. Reading the abstract, we checked if the relation between physical activity and affect was investigated as a within-subject relation (inclusion criteria five) and if the study was performed in everyday life (inclusion criteria six), i.e., not in a laboratory setting.

The exclusion criteria were as follows:

a) Studies that measured affect as a trait variable and not through multiple measurements in the individual's natural environment (e.g., the better aging project; Fox et al., 2007; Parfitt et al., 2009) were excluded.
b) Studies that did not assess momentary affective states or aPA in real time, but with global diary surveys that were completed daily, for instance, shortly before bedtime (e.g., Giacobbi et al., 2005; Hyde et al., 2011; Poole et al., 2011) were excluded. In these studies, affective states and aPA are represented by retrospective evaluations.

We conducted computer searches in several relevant scientific databases (PubMed, Psyndex, PsycInfo, and Google Scholar). *All in all*, we found 393 articles. Abstracts were read, and all potentially relevant full manuscripts were retrieved ($N = 24$). Due to the exclusion criteria mentioned above, we excluded five studies. Next, the reference lists of the retrieved articles were searched for additional pertinent studies. This search yielded three additional studies, totaling 22 publications.

DESCRIPTIVE REPORTS

In the 22 publications, within-subject associations between momentary affective states and aPA in daily life were investigated. Two publications referred to the same study (Schwerdtfeger et al., 2008, 2010). A total of 1799 individuals participated (1356 females, 418 males). The ages ranged from 10 to 85 years; thus, the studies assessed nearly all age groups, from adolescents (Axelson et al., 2003; Bohnert et al., 2009; Dunton et al., 2011) to young adults (Gauvin and Szabo, 1992; Vansteelandt et al., 2007; Hausenblas et al., 2008; LePage and Crowther, 2010; Kanning et al., 2012) to middle-aged and older people (the remaining 14 studies). In most cases, the sample was a healthy cohort; however, seven studies dealt with patient groups with conditions such as affective or eating disorders (Axelson et al., 2003; Vansteelandt et al., 2007), breast cancer (Grossman et al., 2008), joint replacement (Powell et al., 2009), knee osteoarthritis (Focht et al., 2004), or chronic pain (Vendrig and Lousberg, 1997). Two studies included overweight people (Carels et al., 2007; Rofey et al., 2010). Although all of the studies made assessments in real time, the number of time points of measurement per day ranged from 1 to 30. Likewise, the study periods ranged from 12 h to 70 days. All studies took place in the context of everyday life.

We used the second (physical activity should be measured objectively) and third (affective states should be measured electronically) methodological requirements to structure and evaluate the methodological quality of the 22 publications. First, in seven publications describing six studies, aPA was assessed objectively with accelerometers, and due to the use of electronic diaries or telephone calls, it was possible to determine the timing of the diary entries. In so doing, retrospective bias was minimized.

Second, in four studies, either aPA was assessed objectively, or the time points of the measurements were controllable. Third, in the remaining 11 studies, aPA was not assessed objectively, nor were the time points of measurements controllable by means such as electronic diaries.

aPA WAS ASSESSED OBJECTIVELY AND AFFECTIVE STATES WERE ASSESSED WITH ELECTRONIC DEVICES

The results of six articles (Grossman et al., 2008; Schwerdtfeger et al., 2008, 2010; Powell et al., 2009; Dunton et al., 2011; Kanning et al., 2012) showed that aPA and momentary affective states were significantly and positively associated. However, Axelson et al. (2003) arranged a feasibility study and did not report statistical analyses. Two studies (Grossman et al., 2008; Dunton et al., 2011) used a set of items to measure positive and negative affects, whereas the remaining studies assessed affective states with the Activation-Deactivation Adjective Checklist (AD-ACL; Thayer, 1989), a Mood Scale (Wilhelm and Schoebi, 2007), or the Positive and Negative Affect Schedule (PANAS; Watson and Telegen, 1988) (see **Table 1**).

EITHER aPA WAS ASSESSED OBJECTIVELY OR AFFECTIVE STATES WERE ASSESSED WITH ELECTRONIC DEVICES

Dunton et al. (2009) showed in their pilot study with 23 older adults that positive affects had significant positive impacts and negative affects had significant negative impacts on the total minutes of moderate-to-vigorous physical activity. However, participants self-reported their aPAs. Rofey et al. (2010) performed a feasibility study with 20 adolescents to analyze behaviors (e.g., aPA) and emotions during everyday life. To elicit ambulatory data, participants received telephone calls from trained staff members conducting a structured interview to evaluate current aPA and affective states. Thus, the time point of data entry was controllable, but aPA was assessed with self-reports. The authors did not report statistical analyses. McCormick et al. (2008) used accelerometry to assess aPA objectively, but they assessed psychological variables with a "paper-pencil" method using a pager to receive repeated self-reports during everyday life. The study of Vansteelandt et al. (2007) was the only one in this section that used a theoretically grounded definition of the affective constructs they used. Despite the methodological impairment, Dunton et al. (2009), McCormick et al. (2008), and Vansteelandt et al. (2007) showed that aPA and positive affect were significantly and positively associated (see **Table 2**).

aPA WAS NOT ASSESSED OBJECTIVELY, NOR WERE AFFECTIVE STATES ASSESSED WITH ELECTRONIC DEVICES

Most of the selected studies in this section used pagers and booklets to assess aPA and momentary affective states during everyday life, meaning that a pager rang several times a day at a stratified random schedule. The participants had to fill in a booklet as soon as they heard the acoustic signal. Thus, aPA was not assessed objectively, and it was not possible to determine the time point at which the participants actually filled in the questionnaires. Given that the exact time at which each assessment was completed cannot be verified using a paper diary, concerns regarding patient compliance with paper diaries remain.

This section includes 11 studies showing mixed support for the association of aPA and momentary affective states. Eight studies (Gauvin et al., 1996, 2000; Carels et al., 2007; Hausenblas et al., 2008; Bohnert et al., 2009; Kanning and Schlicht, 2010; LePage and Crowther, 2010; Wichers et al., 2011) indicated significant and positive effects of aPA on momentary affective states, whereas three studies (Gauvin and Szabo, 1992; Vendrig and Lousberg, 1997; Focht et al., 2004) did not find significant associations between momentary affective states and aPA. Most studies assessed affective states with validated instruments, such as the PANAS (see Watson and Telegen, 1988; LePage and Crowther, 2010; Wichers et al., 2011), the Exercise-Induced Feeling Inventory (EFI, see Gauvin and Rejeski, 1993; Focht et al., 2004; Hausenblas et al., 2008), the Multidimensional Mood Questionnaire (MDBF, see Steyer et al., 1997; Kanning and Schlicht, 2010), or the Feeling Scale (see Hardy and Rejeski, 1989; Carels et al., 2007).

Nevertheless, several studies analyzed interesting research questions concerning the association between physical activity and momentary affective states in daily life. Gauvin and Szabo (1992) examined the effect of 1-week exercise withdrawal on daily positive and negative affect. Their results showed that exercise withdrawal had no significant impacts on affect. However, the authors did not assess aPA during the study period; thus, they were not able to exclude the possibility that the participants were physically active during the days they were not supposed to be physically active (cf. Hausenblas et al., 2008). Another interesting issue relates to the duration of affect enhancement after being physically active. Wichers et al. (2011) examined changes in affective states before and after daily life increases in aPA. Female twins ($N = 504$, $M_{age} = 27$) were assessed on 5 days with a maximum of 10 measurements per day. The participants filled in a booklet with data regarding aPA (single item) and affect (PANAS) after receiving a beep from a watch. Participants showed higher scores of positive affect after having been physically active. The increase remained significant up to 180 min following the increase in aPA. The authors did not find significant associations with negative affect (see **Table 3**).

All in all, half of the studies (11 publications) were of low and the other half of the studies (4 + 7 publications) were of higher methodological quality according to our methodological requirements. Especially the publications of higher methodological quality reported consistently positive association between aPA and momentary affective states in every day life. Only the studies that did not assess aPA objectively and momentary affective states not with electronic devices reported mixed support for the association of affective states and aPA in every day life.

STUDIES ON WITHIN-SUBJECT ASSOCIATIONS BETWEEN PHYSICAL ACTIVITY AND AFFECTIVE STATES IN EVERYDAY LIFE: DISCUSSION, LIMITATIONS, AND OUTLOOK

As seen from this literature overview, there is strong research interest in within-subject associations assessing the dynamic interactions of momentary affective states and physical activity in everyday life. What is remarkable about the studies presented here is the consistency of their findings within the studies of higher methodological quality. All of these studies (11 out of 22 publications) showed consistently a positive association between aPA and positive affective states. The remaining 11 studies were of lower

Table 1 | aPA was assessed objectively and affective states were assessed electronically.

Reference	Aim of the study	Sample	Procedures	Measurements		Results
				Physical activity	Affective states	
Axelson et al. (2003)	Pilot study: testing feasibility to perform ambulatory assessment with symptomatic patients with pediatric disorders	16 Children with affective disorders (major depressive disorder, generalized anxiety disorder, bipolar disorders) + 5 healthy controls, 9 girls, 12 boys, 10–17 years ($M = 14.4$; SD = 1.6)	Five extended weekends, Pbn received telephone calls – 12 calls between 4:00 p.m. (Friday) and 10:00 p.m. (Monday)	Self-report + accelerometer: ActiGraph, on wrist, 60 s epoch	Subset of PANAS-C, four positive (happy, joyful, exited, energetic) and four negative items (sad, angry, nervous, upset)	Performing ambulatory assessment for real-time experience sampling is feasible in symptomatic patients with pediatric affective disorders. Statistical analyses were not performed
Dunton et al. (2011)	To determine whether leisure time physical activity levels and experiences differ across social and physical contexts among children	121 Children (62 male), 9–13 years	4 days (Friday 4:00 p.m. to Monday 8:30 p.m. – not during school hours) random time within seven pre-established intervals, mobile phone, electronic diary	Accelerometer: ActiGraph (7164 GT2M), right hip, 30 s epoch	Electronic diary; positive affect: happy + joyful, negative affect: sad, angry, stressed, anxious	Affect differed during physical activity across physical and social contexts: greater ratings of positive affect when physically active outdoors, greater ratings of negative affect when physically active alone and with family only
Grossman et al. (2008)	To compare activity and mood between post-treatment breast cancer patients and matched control females	33 Post-treatment breast cancer patients + 33 healthy controls, age: $M = 51.2$; SD = 10.2	One weekday, every 50 min during awake hours	Accelerometer: LifeShirt	Electronic diary; mood (happy, sad, angry, anxious)	Activity did not differ between groups. Cancer patients were less happy across the day than healthy controls. Averaged accelerometry activity was correlated with mean self-reported energy and happiness
Kanning et al. (2012)	To analyze the effect of actual physical activity, autonomous regulation mode, and their interaction on affective states	44 University students (21 female), age: $M = 26.2$; SD = 3.2	One weekday, every 45 min between 8:00 a.m. and 10:00 p.m.	Accelerometer: Varioport-e, right hip, 60 s epoch	Electronic diary; short scale; six bipolar adjectives measuring valence, energetic arousal, and calmness	Actual physical activity, autonomous regulation mode, and their interaction significantly influenced affective states

(Continued)

Table 1 | Continued

Reference	Aim of the study	Sample	Procedures	Measurements		Results
				Physical activity	Affective states	
Powell et al. (2009)	To explore the associations of negative and positive affect with activity levels using ecological momentary assessment	25 Individuals (36% female), 46–85 years old ($M = 71.4$) who had undergone total joint replacement of either knee or hip 12 months earlier	2-day study, diary sounded an alarm every 90–120 min from 9:00 a.m. until the participants went to bed	Self-report: computerized diary records, objective activity assessment: accelerometer: Vitaport 3, on trunk (lower part of sternum) and thighs	Electronic diary; positive affect; cheerful, negative affect; irritable, depressed, anxious, frustrated; PANAS on the following day	Walking time and dynamic activity was associated with lower negative affect. More activity was also associated with higher positive affect, however only the correlation of self-reported walking time with PANAS positive affect reached significance
Schwerdtfeger et al. (2008)	Is there a correlation between everyday life physical activity and psychological well-being?	124 Volunteers (64 females), 18–73 years old $M = 31.67$, SD = 12.56; BMI: $M = 23.23$; SD = 3.14	12 h Study on a typical workday, averaged bodily movement across four time windows (1, 1–5, 1–15, 1–30 min before assessment of affect)	Accelerometer: ActiGraph (GT1M), on left ankle	Electronic diary; adopted version (German version) of PANAS and AD-ACL to assess positive and negative affect	Daily physical activity episodes were associated with positive affective states not with negative affective states
Schwerdtfeger et al. (2010)	To examine whether momentarily assessed affect and bodily movement in everyday life are mutually associated	124 Volunteers (64 females), 18–73 years old $M = 31.67$, SD = 12.56; BMI: $M = 23.23$; SD = 3.14	12 h Study on a typical workday, averaged bodily movement across four time windows (1, 1–5, 1–15, 1–30 min before and after assessment of affect)	Accelerometer: ActiGraph (GT1M), on left ankle	Electronic diary; adopted version (German version) of PANAS and AD-ACL to assess positive and negative affect	Affective states and physical activity in every day life were mutually associated

Table 2 | Either aPA was assessed objectively or affective states were assessed electronically.

Reference	Aim of the study	Sample	Procedure	Measurements		Results
				Physical activity	Affective states	
Dunton et al. (2009)	To identify cognitive, social, affective, contextual, and physiological antecedents and correlates of physical activity episodes across the day among adults age 50+ years	23 Healthy, community-dwelling older adults (70% female) who did not engage in regular PA, age: $M = 60.6$; SD = 8.2; range = 50–76	Four times a day (fixed interval measurement schedule) across a 2-week period, electronic diaries	Self-report: Pbn were asked whether and how long they had performed each of 12 different types of moderate-to-vigorous activities (MVPA)	Electronic diary; eight different types of emotion (emotionally upset, stressed, lonely, annoyed, tense, sad, frustrated, happy) were assessed with a bipolar scale	Greater levels of positive affect ($t - 1$) predicted higher levels of MVPA and greater levels of negative affect ($t - 1$) predicted lower levels of MVPA
McCormick et al. (2008)	To identify if physical activity level is useful in predicting transitory mood in the everyday lives of people with severe mental illness (SMI)	Individuals with SMI suffer for more than 2 years from severe mental disorders (e.g., bipolar disorder, major depression, schizophrenia). 15 Serbians (age: $M = 38.9$; SD = 11.3) and 22 US citizens (age: $M = 38.8$; SD = 11.4)	Two communities, 7 days, seven times a day (9:00 a.m. to 9:00 p.m.), stratified random schedule	Accelerometer: MTI (7164), right hip, 60 s epoch	Self-report: pager and booklet; positive and negative mood were assessed via dichotomously scored (y/n) mood items: happy, secure, cheerful, bored anxious, angry	Physical activity remained significantly positively associated with mood after accounting for individual variation
Rofey et al. (2010)	Discussion about a pilot study, primarily regarding utilization of ambulatory assessment	20 English Speaking participants, 11–19 years old; BMI $M = 39$, 80% White, 15% African American	14 Cellular phone calls over three extended weekends, they were called twice on weekdays and four times on weekends	Self-report: Pbn reported their physical activity during phone calls Accelerometer; body media, sense wear, weight management system, showing steps taken and calories burned, wearing on upper arm	Structured interview to evaluate affect, via phone call	Technological devices that gather objective data have reasonably high compliance rates, and inform measurement of treatment outcomes in adolescents who are obese
Vansteelandt et al. (2007)	To assess if there is a positive association between patients' drive for thinness and their level of physical activity across time To assess the association between patients momentary negative/positive emotional states and their level of physical activity over time	32 Female inpatients with an eating disorder, 15–37 years old $M = 21.6$, SD = 6.7; BMI: $M = 19.4$; SD = 4.4; range = 13.5–32.02	1 Week, nine times a day, stratified random Schedule	Self-report: electronic diary, three items referring to type and intensity	Electronic diary; PANAS	Drive for thinness as well as positive emotional states are both, significantly related to patients physical activity. Negative emotional state was not significantly associated with physical activity

Table 3 | aPa was not assessed objectively, nor were affective states assessed electronically.

Reference	Aim of the study	Sample	Procedures	Measurements		Results
				Physical activity	Affective states	
Bohnert et al. (2009)	To assess if more involvement in active structured discretionary activities would be associated with fewer depressive symptoms and delinquency To assess if positive effect mediate these relationship	246 Urban African American adolescents, 107 boys, 139 girls, 10–15 years $M = 11.95$, SD = 1.23	1 Week/seven times a day	Self-report: pager and booklet; open-ended question "what were you doing?"	Booklet: how were you feeling? – bipolar scale with the following pairs of adjectives: happy – unhappy, weak – strong, angry – friendly, awake – tired, cheerful – grouchy/cranky	Contrary to the expectations, results suggest that involvement in structured discretionary time activities was not associated with less depressive symptoms and delinquency. But more time spent in these activities was positively associated with positive affect
Carels et al. (2007)	To assess the influence of morning mood on exercise, intensity, and duration To assess the effect of exercise intensity and duration on post-exercise mood enhancement	51 Adults (89% female), 31–65 years, $M = 49.3$, SD = 11.2; BMI: $M = 41.5$, SD = 7.3	During the first 4 and the final 4 weeks of a weight loss intervention program participants completed an exercise and mood diary. Participants reported morning, evening, pre- and post-exercise mood, as well as the type, intensity, and duration of exercise	Self-report, booklet: type, duration, intensity	Booklet: feeling scale (single item)	Morning mood was associated with an increased likelihood of exercising; morning mood was not a significant predictor of exercise intensity and duration. Mood ratings were higher following exercise of greater intensity and duration
Focht et al. (2004)	To examine feeling state fluctuations in older, obese adults with knee osteoarthritis throughout the day and in response to an acute bout of physical activity	32 Clinically obese, sedentary adults (25 female) over 60 years of age ($M = 69.1$; SD = 6.5) BMI: $M = 27.5$, with knee osteoarthritis	6 Days, 8:00 a.m. to 9:30 p.m., stratified random schedule; days were divided in three exercise and three non-exercise days	Exercise sessions (11:00 a.m. to 12:00 p.m.) for all participants, walking phase 50–70% of heart rate reserve	Pager and booklet; Exercise-Induced Feeling Inventory (EFI)	Affective states did not change with involvement in acute exercise

(Continued)

Table 3 | Continued

Reference	Aim of the study	Sample	Procedures	Measurements		Results
				Physical activity	Affective states	
Gauvin and Szabo (1992)	To examine the effects of 1-week exercise withdrawal on daily positive and negative affect	12 Experimental and 9 control subjects (14 male), age: $M = 23.6$; SD = 5.4, exercising on average for 7.5 (SD = 3.1) hours/week during the past 5 month	5Weeks, four times a day (fixed interval measurement schedule); experimental group: participants were asked to stop exercising on day 15 until day 21	Physical activity was not measured during experimental period	Pager and booklet; four positive and five negative affective states: happy, pleased, joyful, enjoyment, unhappy, depressed, blue, angry, frustrated, anxious; and two additional indicators: stressed, relaxed	Exercise withdrawal had no significant impact on positive and negative affect
Gauvin et al. (1996)	To describe changes in affect and feeling states in a community sample of physically active women after acute bouts of vigorous physical activity To explore the moderating role of average mood states, pre-activity scores, estimated aerobic capacity, and frequency of participation in physical activity in the outcome measures	108 Women attending fitness classes at local YMCAs; 86 participants (age: $M = 33$) provided sufficient data	6Weeks, four times a day, pager signal at random intervals between 8:00 a.m. and 10:00 p.m., additional before and after physical activity bouts lasting 20 min or longer	Self-report: pager and booklet; vigorous (e.g., fitness class or brisk walk) versus light (e.g., leisurely walk or yoga) physical activity	Booklet; affective states were measured with (1) positive affects: happy, pleased, joyful, experience of enjoyment-fun; negative affect: depressed-blue, worried-anxious, frustrated, unhappy, angry-hostile and (2) with Exercise-Induced Feeling Inventory (EFI)	Involvement in physical activity was associated with increases in tranquility, revitalization, and positive affect, and decreases in negative affect. Between-subjects variables did not systematically moderate pre-activity to post-activity changes in mood
Gauvin et al. (2000)	To examine diurnal patterns of feeling states in a community sample of physically active women on days that they were either active of inactive	84 Physically active women from local YMCAs, 19–57 years old $M = 33.1$; SD = 10.4	6Weeks, four times a day at random intervals between 8:00 a.m. and 10:00 p.m., additional experience sampling questionnaires before and after physical activity bouts lasting 20 min	Self-report: pager and booklet; participants wrote down what they were doing, when responding to the pager call, or before/after exercise	Booklet; Exercise-Induced Feeling Inventory (EFI)	Scores for positive engagement, revitalization, and tranquility assessed following exercise were significantly higher than values recorded at the same time on inactive days

(Continued)

Table 3 | Continued

Reference	Aim of the study	Sample	Procedures	Measurements		Results
				Physical activity	Affective states	
Hausenblas et al. (2008)	To determine if deprivation from exercise resulted in variations in feeling states	40 University students (26 female), age: $M = 20.5$; SD = 2.5, engaged in five weekly bouts of moderate/strenuous exercise	6-Day study, three exercise + three non-exercise days, three times a day (9:00 a.m. to 9:00 p.m.), in addition: immediately before and following exercise	Self-report: pager and booklet; Leisure Time Exercise Questionnaire (LTEQ)	Booklet; Exercise-Induced Feeling Inventory (EFI)	Acute exercise resulted in improved feeling states
Kanning and Schlicht (2010)	To analyze if physically active episodes are associated with more positive mood compared with episodes of inactivity	13 Participants 52–59 years old (9 female)	10-Week period, one to three self-selected episodes per day during their daily routine (defined as occurrences with a definite start/end)	Self-report: booklet; activity described by the participants (strolling around, reading etc.)	Booklet; German-language Multidimensional Mood Questionnaire (MDBF)	When activity increased, valence, energetic arousal, and calmness also increased
LePage and Crowther (2010)	To assess if low trait body dissatisfied individuals will exhibit less state body dissatisfaction and negative affect and more positive affect following exercise than at other times throughout the day	61 Female undergraduate university students, age: $M = 19.1$; SD = 2.88 BMI: $M = 23.23$; SD = 3.65	10 Days, four times throughout the day and following exercise	Self-report; pager and booklet, questions assessing type and amount of exercise	Booklet; ten items of the PANAS-X	Individuals reported less negative affect after exercising than at random assessments
Vendrig and Lousberg (1997)	An initial effort to examine within person relationships among pain intensity, mood, and activity level of chronic pain patients using experience sampling method	57 (31 Females) chronic pain patients, 21–65 years old $M = 42.3$, SD = 10	6 Days/eight times a day, between 8:30 a.m. and 10:30 p.m. (Tuesday–Sunday). one booklet per day	Self-report: pager and booklet; single item scoring activity intensity: 1 = rest, 2 = lying down, 3 = doing nothing to 7 = heavy physical work	Single item: seven point Likert scale, very negative mood to very positive mood	There was no significant relation between activity level and mood
Wichers et al. (2011)	To examine the subtle hour-to-hour fluctuations in affect in relation to increases in physical activity in the flow of daily life	504 Female twins, 18–46 years old; $M = 27$, SD = 7.6	Five consecutive days, ten times a day, between 7:30 and 22:30, stratified random schedule	Self-report: pager and booklet; single item scoring activity intensity from 1 (e.g., resting) to 7 (e.g., running)	Booklet; PANAS	Significant increase in positive affect following the moment of increase in physical activity was replicated across both samples up to 180 min after physical activity. There was no effect of physical activity on negative affect

methodological quality showing mixed support for this association. Because the findings did not show consistent associations between negative affective states and aPA in every day life, the findings did not support the hypothesis that aPA might be a useful strategy to influence person's affective states in everyday life.

All in all, the methodological quality of most of the studies could be improved. About 30% of the studies used an ambulatory assessment design, assessing physical activity objectively and momentary affective states with electronic devices. Furthermore, 55% of the studies used theoretically grounded definitions of affective constructs.

Three studies explicitly examined the dynamic nature of the aPA-affect relationship, but the results were inconsistent. Schwerdtfeger et al. (2010) and Powell et al. (2009) both reported significant effects on positive affective states, and they indicated that increased levels of affective states predicted increased activity levels, suggesting that momentary affective states and aPA have circular effects on each other. Carels et al. (2007) examined the dynamic process in a behavioral weight loss program for obese people. In this study, thirty-six overweight participants ($M_{\text{age}} = 49$, $M_{\text{BMI}} = 41.5$) completed an exercise and mood diary during the first 4 weeks and the last 4 weeks of the intervention program. The within-subject effects showed that greater reported exercise intensity and duration were related to greater mood enhancement. Conversely, positive morning mood was associated with an increased likelihood of exercising during the day, but negative morning mood was related to fewer exercises during the day. In contrast, Schwerdtfeger et al. (2010) and Powell et al. (2009) showed that participants with higher scores on negative affective states were more active over the following interval. Thus, participants with high levels of negative affect might have used aPA as a strategy to improve their mood, believing that being more active would diminish their negative affect.

However, the literature overview also revealed inconsistent findings about the impact of aPA on negative affect. Five studies (Vansteelandt et al., 2007; Schwerdtfeger et al., 2008, 2010; Powell et al., 2009; Wichers et al., 2011) did not find a significant effect of aPA on negative affect, whereas two studies (LePage and Crowther, 2010; Dunton et al., 2011) found significant associations.

All in all, the findings did not consistently show that aPA is a "mood repair" strategy that works satisfactorily. The dynamic process of the association between aPA and momentary affective states needs more consideration in further studies assessing whether individuals might use aPA as a means to improve their affective states and regulate their mood.

In addition, more studies are needed that address moderating factors like the dose of physical activity, the quality of affective states, or the timeframe of the association between physical activity and momentary affective states (within-subject analysis). We can show that physical activity may affect energetic arousal immediately but that there seems to be a timeframe for the effect on calmness (Kanning et al., 2012). With more studies of high methodological quality, it may be possible to conduct a meta-analysis of within-subject associations between aPA and affective states in the future.

Furthermore, we found some studies that focused on the effects of physical activity on affect for children and young adults, while others focused on different patient groups. Future studies are needed in these areas, and it would be interesting to discover whether the effect of physical activity on affective states is the same in different age groups or for different types of persons (e.g., patents versus non-patients – a between-subjects analysis).

The findings of our literature overview are inconsistent concerning the dynamic process and the impact of activity on negative affect. Inconsistent findings may be due to the low numbers of studied episodes with high levels of physical activity. McCormick et al. (2008) discuss this problem in their study, which challenges most researchers analyzing the association of affective states and physical activity in everyday life. The authors mentioned an "extreme skewness in the PA variable, with its high proportion of low activity level" (p. 533). Similarly, Dunton et al. (2011, p. S107) determined that they were not able to capture all bouts of physical activity due to the signal-contingent sampling protocol they used. This lack of information is due to the modern condition that the majority of individuals in contemporary societies fail to achieve the recommended minimum level of physical activity (World Health Organization, 2002). Epidemiological research has resulted in a recommendation to be physically active at a moderate intensity for at least 150 min per week (Haskell et al., 2007). Despite these recommendations, the volume of physical activity actually performed by adults and even in children and youth is insufficient, connoting that people are physically active for approximately 3% of their waking hours. It is difficult and improbable to capture these few episodes of physical activity with a time-based or signal-contingent sampling protocol.

To solve this problem, researchers may assess affective states not with a time-based protocol but as a function of predefined intensities of physical activity. Thus, the intensity of the activity triggers the entry of the electronic diary (i.e., interactive ambulatory assessment). Interactive ambulatory assessment is typically employed to maximize variance by physiology- or context-triggered sampling (Intille, 2007). The best-known representative of interactive assessment is Myrtek (2004), who used and validated this method in a series of studies based on many different samples and approximately 1,300 participants. In short, these studies monitored heart rate and physical activity in daily life and separated out in real time heart rate increases caused by physical activity. Any remaining additional heart rate increase was assumed to indicate momentary emotional activation. A recorder/analyzer was programed to trigger a hand-held PC, which in turn signaled the participant to self-report on their current activity, the situation, and their emotions. This phenomenon occurred when the heart rate increase exceeded a certain threshold. With this approach, e-diary prompts were not delivered randomly but during the episodes of interest, therefore maximizing the variance in physiological episodes during e-diary prompts. For an example of how interactive ambulatory assessment can improve the assessment of the relationship between physical activity and momentary affective states, please see Ebner-Priemer et al. (2013).

Despite the methodological benefits, ambulatory assessment has its limitations. Because the strength of an ambulatory assessment approach is its high external validity, experimental control of confounding variables is almost impossible. However, statistical control using self-reports of contextual information and assessment of various confounding effects, such as temperature, physical activity, and breathing patterns, have been successfully employed in ambulatory assessment. We believe that developments in sensor and telecommunication technology will create even more opportunities and applications for research in the near future (Intille, 2007). Data analysis in ambulatory assessment is not trivial, as the data mostly show a hierarchical structure in which multiple assessment points are nested within subjects (Wilhelm, 2001; Bolger et al., 2003; Schwartz and Stone, 2007; Nezlek, 2012). However, there are increasing numbers of published papers on specific aspects of ambulatory assessment analyses (Kubiak and Jonas, 2007; Jahng et al., 2008; Ebner-Priemer and Bussmann, 2011), as well as approaches to calculate the reliability, validity, and sensitivity of change for multilevel data (Wilhelm and Schoebi, 2007). There are also several papers on design issues, which will help novices in this field (Fahrenberg and Myrtek, 2001; Fahrenberg et al., 2007; Piasecki et al., 2007; Shiffman, 2007; Conner and Lehman, 2012), and overviews on hard- and software solutions for ambulatory assessment (Ebner-Priemer and Kubiak, 2007).

FUTURE PROSPECTS FOR INTERVENTION STUDIES

Capturing data in real time could also provide a basis for intervening effectively and efficiently in the often sedentary and inactive lives of most people in modern societies. Such intervention would help to reduce health risks and to promote mental health. For example, Wen et al. (2011) conducted a prospective cohort study with a sample of more than 400,000 individuals and a follow-up period of 8 years. The authors showed that individuals who were physically active for 15 min per day had a 14% reduction in the risk of all-cause mortality. A person can be physically active for 15 min if he or she exercises or regularly participates in a sport. However, it is also possible to perform daily physical activities that are spontaneous or habitually performed, such as taking a stroll, transporting oneself to work, or doing chores. These aPA should be classified as significant preventative health behaviors.

Ambulatory Assessment Interventions (AAIs) with individually tailored, moment-specific feedback have the potential to influence and support the individual when the unhealthy behavior (e.g., inactivity, sedentariness, unhealthy food intake) actually occurs. Individually tailored, moment-specific feedback added to an ambulatory assessment clearly leaves pure assessment behind and is used as a treatment component. Such online feedback can urge participants to perform physical activity or to disrupt episodes of sedentariness. From a learning perspective, this method should be superior to traditional interventions in which the advantages of regular physical activity are explained in a single session. In a standard intervention, the challenge is to generalize behavior that was learned in a certain setting to everyday life. In an AAI with individually tailored, moment-specific feedback, components are delivered in daily life directly in the situations in which participants should change their behavior. For instance, a person enters information about how, when, and where he would like to be physically active into a smartphone. The smartphone reminds the person of his or her activity goals and may provide alternative activity programs or information about the opening hours of a fitness center nearby. For a more detailed description of such an intervention, please see Schwerdtfeger et al. (2012).

Heron and Smyth (2010) listed in their review 27 studies using an AAI targeting a variety of psychological and physical symptoms and health/disease behaviors (e.g., smoking cessation, weight loss, diabetes management, alcohol use, healthy eating, physical activity). The review provided a more stringent test of the efficacy of AAI compared to previously validated interventions (e.g., psychoeducation). The review also showed that an AAI intervention is not effective only for younger people. Younger people are mostly familiar with hand-held computers and smartphones; thus, an intervention using this technology may fit better within their lifestyle, potentially making AAI more readily accepted and improving the chances of lasting behavioral changes. However, the review listed three intervention studies with people older than 55 years showing that the intervention is effectively implemented and accepted by these older people.

Implementing interventions in everyday life presents particular challenges with respect to intervention development, planning, and compliance, but AAI offers the chance to support the individual exactly at the moment when he or she requires help.

CONCLUSION

Analyzing within-subject associations with less methodological impairment will provide a deeper understanding of the dynamic linkage between momentary affective states and physical activity in everyday life. We recommended three methodological requirements for future studies: first, assessments should be done repeatedly in real time. Second, physical activity should be measured objectively. Third, momentary affective states should be measured electronically.

To analyze the contribution of physical activity in everyday life to the variability of affective states would broaden our knowledge of the mental health benefits of such activity. This knowledge would help establish appropriate physical activity guidelines and support ambulatory assessment treatment as a proactive intervention in a person's life.

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The association between short periods of everyday life activities and affective states: a replication study using ambulatory assessment

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Regularly conducted exercise programs effectively influence affective states. Studies suggest that this is also true for short bouts of physical activity (PA) of 10 min or less. Accordingly, everyday life activities of short duration might be used to regulate affective states. However, this association has rarely been studied in reference to unstructured activities in ongoing real-life situations. The current study examined the influence of various everyday life activities on three dimensions of mood (valence, calmness, energetic arousal) in a predominantly inactive sample. Ambulatory Assessment (AA) was used to investigate the association between actual PA and affective states during the course of 1 day. Seventy-seven students ages 19–30 participated in the study. PA was assessed with accelerometers, and affective state assessments were conducted hourly using an e-diary with a six-item mood scale that was specially designed for AA. Multilevel analyses indicated that the mood dimensions energetic arousal ($p = 0.001$) and valence ($p = 0.005$) were positively influenced by the intensity of the activity carried out in the 10-min prior to the assessment. As their activity increased, the participants' positive feelings and energetic arousal increased. However, the students' calmness was not affected by their activity levels. The findings highlight the importance of integrating short activity intervals of 10 min or less into everyday life routines to improve affective states.

Keywords: ambulatory assessment, affective states, mood regulation, physical activity, well-being

INTRODUCTION

The association between physical activity (PA) and affective states has been of interest for several decades (Arent et al., 2000; Netz et al., 2005). In the field of exercise and psychological adaptations, it is widely acknowledged that structured and organized sports activities have positive effects on subjective well-being (LaFontaine et al., 1992; Reed and Ones, 2006). A meta-analysis carried out by Reed and Ones (2006) verifies this positive effect on various mood parameters (affective states) for low to moderate intensity forms of PA. The meta-analysis found that the effects lasted for at least 30 min and influenced both valence (positive/negative) and energetic arousal (positive activated affect). Greater enhancements were documented when the baseline mood level was lower.

This positive effect on affective states has been shown in several age and patient groups. For example, some studies, focusing especially on young adults (20–30 years old), showed that acute exercise resulted in improved positive affect and less negative affect (Gauvin et al., 1996; Hausenblas et al., 2008; LePage and Crowther, 2010; Kanning et al., 2012). In addition, numerous studies with older and depressive participants have demonstrated the immediate short-term improvements in depressive symptoms and the lasting improvements in affective states that can occur due to various types of PA (Folkins, 1976; LaFontaine et al., 1992; Fox, 1999; Bartholomew et al., 2005; Blake, 2009). Anxious and sedentary people seem to profit most from PA (Folkins, 1976; LaFontaine et al., 1992). Non-depressive persons often exhibit no or minimal effects due to high baseline values of positive affect (LaFontaine et al., 1992). Other studies support the assumption that PA has a more general protective effect on psychological health (Thayer, 1987; Otto and Stemmann, 1991; Gauvin and Spence, 1996; Ekkekakis et al., 2000).

In addition, current research suggests that even short interruptions of sedentary behavior might positively influence health and affective states (Hamilton et al., 2007; Biddle et al., 2010). For example, Thayer (1987) demonstrated that 10 min of brisk walking raised energy levels and reduced tension in adults. The immediate changes lasted for 2 h. Furthermore, Ekkekakis et al. (2000) found that short walking bouts had a positive effect on affective states.

Consequently, it seems that everyday life activities such as walking can be used to improve people's subjective well-being and psychological health. The likelihood that such forms of PA will be continuously integrated into the everyday life routines of individuals seems higher than the likelihood that individuals will routinely participate in structured, organized physical activities that require more time and effort (Ekkekakis et al., 2000; Schwerdtfeger et al., 2008).

Only few studies have focused on everyday life activities and their effects on affective states (Axelson et al., 2003; Motl et al., 2004; Grossman et al., 2008; Schwerdtfeger et al., 2008; Ebner-Priemer et al., 2008; Powell et al., 2009; Kanning and Schlicht, 2010; Dunton et al., 2011; Kanning et al., 2012). A majority of studies on PA and mood have been conducted in controlled settings such as sports classes or training sessions (for a discussion of this aspect of the research, see Schwerdtfeger et al., 2008; Kanning et al., 2013). In addition, many of these studies have used retrospective questionnaires to assess affective states. Retrospective reports have been criticized as biased due to systematic recall errors (Trull and Ebner-Priemer, 2013).

Unfortunately, definitions of mood, affect, and emotions are quite diverse, and a serious discussion of the differences between these theoretical constructs lies beyond the scope of this paper (for a deeper discussion, see Frijda, 1994; Cabanac, 2002; Scherer, 2009). In the current paper we assume that affective states are volatile and dynamic phenomena (Kuppens et al., 2010). As introduced by several authors (Matthews et al., 1990; Steyer et al., 1997; Schimmack and Grob, 2000), we will base our research on a three-dimensional scale model including *valence* (unwell vs. well), *calmness* (relaxed vs. tense), and *energetic arousal* (tired vs. awake).

Innovative methods are needed to document continuous individual changes in affective states. Unlike research in traditional laboratory settings, such methods assess affective states and PA in real-life situations. Ambulatory assessment (AA) allows the repeated assessment of individual changes in PA levels and affective states over time in everyday life (Bussmann and Ebner-Priemer, 2011; Trull and Ebner-Priemer, 2013). The natural setting and non-invasive procedure provides a less biased assessment of the participants' affective states. AA has often been called the gold standard in everyday life because it allows (a) the repeated real-time assessment of subjective experiences over long periods of time without retrospective distortions, (b) the real-life assessment of daily activities, and (c) the objective assessment of behavior using accelerometers (Bussmann et al., 2009; Bussmann and Ebner-Priemer, 2011; Trull and Ebner-Priemer, 2013). According to the Society for Ambulatory Assessment (SAA), "*Ambulatory assessment comprises the use of field methods to assess the ongoing behavior, physiology, experience, and environmental aspects of humans or non-human primates in naturalistic or unconstrained settings. Ambulatory assessment designates an ecologically relevant assessment perspective that aims at understanding biopsychosocial processes as they naturally unfold in time and in context.*"[1]

There are still few studies that use AA to investigate the association between unstructured activities and affective states in real time, in real life, and repeatedly over a period of time (see Kanning et al., 2013 for an overview). To our knowledge, only three such studies have been conducted with healthy subjects. Schwerdtfeger et al. (2008) recorded the PA of 124 individuals using accelerometers and assessed mood hourly via handheld computers. They confirmed that there is a significant positive association between PA and energetic arousal and positive activated affect. Significantly, PA is typically a global score that includes intensity and duration of PA. Accordingly, higher intensity and/or duration accompany higher energetic arousal and more positive affect in Schwerdtfeger et al.'s (2008) study. Kanning et al. (2012) investigated the interaction between affective changes, PA, and autonomous regulation in 44 university students using 24-h accelerometry and electronic diaries. Like Schwerdtfeger et al. (2008), the authors reported a positive association between PA and energetic arousal. However, contrary to Schwerdtfeger et al. (2008), they found no significant effect on valence and a significant negative effect on calmness.

Dunton et al. (2011) assessed PA and mood in 121 children using e-diaries and activity monitors but did not report on the relationship between the two variables, as they were interested in context-specific (physical location, social context) interactions. In addition, several studies have assessed the relationship between psychological variables and PA using AA in patients with pediatric affective disorders (Axelson et al., 2003), borderline personality disorder (Ebner-Priemer et al., 2008), and breast cancer (Grossman et al., 2008), as well as those who have just had joint replacement surgery (Powell et al., 2009).

As demonstrated in the above discussion, studies that assess the relationship between everyday life PA and affect on the highest methodological level are rare, and their findings are contradictory. Therefore, the current study aims to clarify the association between PA in everyday life situations and affective states in the course of 1 day. Unlike previous researchers, we examined a sample of students during their exam period; thus, these students are relatively young, fit, and healthy but were inactive at the time of the study. AAs were conducted using electronic diaries and accelerometers to generate objective activity data and avoid retrospective distortions of the affect assessment. Based on recent findings, we hypothesized that the more active people are within the 10-min prior to the affect assessment, the better they feel (valence), the more activated and energetic they feel (energetic arousal), and the less calm they feel (calmness). As Gauvin and Rejeski (2000) indicated that changes in affective states at least partly follow diurnal patterns, we controlled for time of day.

MATERIALS AND METHODS

PARTICIPANTS

The current sample originates from a larger study on workload and stress in students. The original study comprised 149 participants, but PA was assessed in a subsample of 77 students only. We had missing data in 15 subjects, resulting in a final data set with 62 subjects. The participants were between 19 and 30 years old ($M = 21.4$; $SD = 1.8$); 53 participants were male, and 9 participants were female. The participants' body mass index varied between 18 and 29 ($M = 22.1$; $SD = 2.0$). The participants

[1]www.ambulatory-assessment.org

were recruited via a lecture on time management. Accordingly, the sample was entirely composed of students from the Karlsruhe Institute of Technology (KIT, Germany). The study was performed during the exam period at the end of the semester. We assumed that during this period, students spend nearly all of every day at their writing desks preparing for their upcoming exams. Therefore, we expected them to show low PA but felt that this would not indicate that the group is generally inactive. All participants provided informed consent prior to the assessment. The subjects received no monetary compensation for their participation.

AMBULATORY ASSESSMENT PROCEDURE

The study was conducted over the course of 1 week. PA was measured continuously for 24 h using an accelerometer. Electronic diary items were completed via smartphones. The students activated their electronic diaries after waking up, and the measurements were repeated each full hour thereafter. An acoustic signal prompted the participants to complete the electronic diary entries. If a participant could not use the smartphone at a particular assessment point, no later entries were assigned.

Before the study began, all of the participants were fully informed about the content of the study and the handling of the smartphones. After they had received all of the necessary equipment, the participants were able to pursue their daily activities.

MEASURES OF ACTUAL PHYSICAL ACTIVITY

Movement and activity patterns were recorded using an accelerometer (Move I)[2]. Move I consists of a triaxial acceleration sensor with a range of ±8 g, a resolution of 12 bit and a sampling frequency of 32 Hz. Each participant wore an accelerometer on a belt around his or her chest. The recorded raw data were saved in Unisens format and transferred via a USB 2.0 interface to a computer for further analysis. The acceleration sensor can assess both movement and posture (static acceleration due to gravity). The AC (dynamic) and the DC (static) parts of the acceleration were separated by subtracting the mean value of the signal every 4 s. The AC parts of the acceleration were then used to estimate the vector magnitude of the acceleration, and the mean value of every 1 min interval was calculated. PA was quantified using the unit "milli-g." To relate PA to the e-diary data, we computed 10-min segments of PA for the 10-min before each e-diary entry. We used 10-min segments to maintain comparability across our studies (Kanning et al., 2012; Ebner-Priemer et al., 2013). The original decision to use a 10-min segment (more details in Ebner-Priemer et al., 2013) was based on the findings of Schwerdtfeger et al. (2008), which showed promising relationships for two time frames (5, 15 min), and was based on the information that PA for a minimum of 10 min yields health benefits (Haskell et al., 2007).

AFFECTIVE STATES

To assess momentary affective states, we used a short scale with six items based on the Multidimensional Mood Questionnaire (MDMQ; Steyer et al., 1997), which has been explicitly developed and evaluated for use in AA (Wilhelm and Schoebi, 2007). The scale contains six items that measure the basic affective states of *valence* (unwell vs. well), *calmness* (relaxed vs. tense), and *energetic arousal* (tired vs. awake) using two bipolar items for each subscale. Homogeneity was assessed at the between-person level and the within-person level. The level-specific reliability coefficient for the between-person level was 0.92 for *valence* and 0.90 for *energetic arousal* and *calmness*. The reliability coefficient for the within-person level was 0.70 for *valence* and *calmness* and 0.77 for *energetic arousal*, resulting in satisfactory internal consistency (see Wilhelm and Schoebi, 2007 for the procedure used). The subjects indicated the extent to which they were experiencing specific affective states on a six-point scale. Answers were provided by moving a slider from the left ("0," i.e., "discontent") to the right ("5," i.e., "content") end of the bipolar scale. The scores for each subscale were obtained by summing the item scores, in which generated a range from "0" (low value) to "10" (high value). The electronic diary was provided on HTC Touch 2 smartphones that were programmed using the experience sampling software *MyExperience movisens Edition version 594* (movisens GmbH, Karlsruhe, Germany). For data management on the smartphones, the *MyExperience IDE* program *version 1.3.594* (movisens GmbH, Karlsruhe, Germany) was used.

We controlled for time of day. First, we centered the time variables. Then, we added the variables "time" and "time-square" into the analyses to control for the linear and squared effects of time.

ANALYSES

The AA approach produced repeated measurements of PA and affective states (level-1) that were nested within persons (level-2). To assure chronological comparability, the accelerometers and smartphones were synchronized. We conducted separate multilevel analyses for each affect subscale using the statistical program HLM 6.0 (Raudenbush et al., 2004). We used restricted maximum likelihood estimations for the multilevel analyses. The α-level of the tests was set to $p < 0.05$.

First, we estimated the intra-class coefficient of the three subscales with unconditional models where "y" is not modeled as a function of another variable at level-1 or level-2. Second, we consecutively entered the predictor variables PA and time-square into each model (see Eq. 1). We analyzed the linear effect but did not find any differences between these results and the ones that we obtained when we controlled for time-square only. Thus, we deleted the linear effect. Third, we analyzed whether affective state and the last 10 min of PA before each e-diary entry (level-1) significantly varied as a function of three level-2 predictors, gender (sex), the average level of the affective state (mean_affst), and the average level of PA (mean_PA). These three level-2 predictors were inserted into each model. Thus, for each subscale, we examined the relationship between the level-1 intercept and the level-2 predictors (see Eq. 2) as well as the cross-level interaction between the level-1 slopes and level-2 predictors (see Eqs 3 and 4).

$$\text{Level-1: } Y_{ti} = \beta_{0i} + \beta_{1i}\,(\text{PA})_{ti} + \beta_{2i}\,(\text{time - square})_{ti} + r_{ti} \quad (1)$$

$$\text{Level-2: } b_{0i} = \gamma_{00} + \gamma_{01}\,(\text{sex}) + \gamma_{02}\,(\text{mean\_affst}) + \gamma_{03}\,(\text{mean\_PA}) + \mu_{0i} \quad (2)$$

[2]www.movisens.com

$$\text{Level-2: } b_{1i} = \gamma_{10} + \gamma_{11} \ (\text{sex}) + \gamma_{12} \ (\text{mean\_affst}) + \gamma_{13} \ (\text{mean\_PA}) + \mu_{1i} \quad (3)$$

$$\text{Level-2: } b_{2i} = \gamma_{20} + \gamma_{21} \ (\text{sex}) + \gamma_{22} \ (\text{mean\_affst}) + \gamma_{23} \ (\text{mean\_PA}) + \mu_{2i} \quad (4)$$

Level-1 represents the participants' responses (subscript i) on one of the basic affect subscales (Y_{ti}) in any given diary entry (subscript t). Y_{ti} is defined as the average intercept of the corresponding affect subscale across all participants (β_{0i}) and the two level-1 predictors PA (β_{1i} PA_{ti}) and time-square (β_{2i} time-square). These predictors are group mean-centered, with the group referring to a person (level-2). The intercepts and slopes are conceived as varying randomly. The random effect of the level-1 model is given by r_{ti}. It is assumed to be normally distributed with a mean of "0" and a variance of σ^2. Level-2 expresses between-subject effects. It includes the fixed effects, γ, as the average intercepts and slopes across all persons, the predictors *gender, mean_affst* and *mean_PA*, and the random effects μ_{0i}, μ_{1i}, μ_{2i}, and μ_{3i}. The random effects are assumed to be multivariate and normally distributed, both with expected values of "0."

To clarify the magnitude of the effect, we standardized the effects of PA and time on the three mood subscales (see Eq. 5). The standard deviation was taken from the mean of the sample of the last 10 min of PA before each diary entry and from the sample mean for the affective states.

$$\text{Standardized effect} \quad \beta_{1i} * \text{SD} \ (\text{activity or time - square}) \ / \ \text{SD} \ (\text{correspondent affective state}) \quad (5)$$

RESULTS

The 77 participants provided 807 data points, yielding an average of 10.5 e-diary entries per subject. The overall average level of PA across the 10-min periods prior to the measurements of the affective states was 62.0 mg/min (SD = 64.9) with a range from 12.8 to 765.2 mg/min. For the sake of comparison, note that jogging episodes equal approximately 1000 mg/min, walking episodes approximately 350 mg/min, and pure sitting episodes approximately 10 mg/min. The average levels of *valence*, *energetic arousal*, and *calmness* were 8.2, 7.0, and 8.5, respectively, representing medium to high affective states. The results for the intra-class coefficient were $\rho_I = 0.50$ for valence, $\rho_I = 0.40$ for energetic arousal, and $\rho_I = 0.46$ for calmness. This indicates that 50, 60, and 54%, respectively, of the affect subscales' variance was caused by intra-individual variation. The distribution of PA, the time-square variable, and the three affect subscales allowed for multilevel analyses.

The random error terms of the PA slopes were not significant in the models. They were fixed because the random and fixed variability of the slopes could not be separated reliably. Nevertheless, the slopes of the last 10 min of PA before each diary entry varied between the persons but did not vary randomly as a function of the level-2 predictors gender and the average levels of the affective state and PA. The fixed and random effects on each affective state are shown in **Table 1**.

WITHIN-PERSON EFFECTS

Valence was significantly predicted by the last 10 min of PA before each diary entry ($p = 0.005$) but not by time-square ($p = 0.419$). The more our subjects were physically active during the preceding 10 min, the better and more satisfied they felt. The standardized effects were 0.07 for PA. Thus, if PA increased by 1 SD, the valence increased by 0.07 SD.

Energetic arousal was positively affected by the last 10 min of PA before each diary entry ($p = 0.001$) and negatively affected by time-square ($p < 0.001$). As PA during the preceding 10 min increased, the students' sense that they were awake and energized increased. The analyses also revealed that the later it was during the day, the more tired and weak the participants felt. According to the standardized effects, when the PA or time-square figure increased by 1 SD, energetic arousal increased by 0.1 SD, and decreased by 0.3 SD, respectively.

C*almness* was not significantly predicted by the 10-min of PA preceding each diary entry ($p = 0.079$; SD = 0.04) but was predicted by time-square ($p = 0.018$; SD = 0.65). The later it was in the day, the more relaxed and calm the participants felt.

BETWEEN-PERSON EFFECTS

We used the level-2 predictors to investigate gender differences. In addition, we controlled for the within-person effect of PA on affective states in determining the mean level of the selected affective state and the mean level of PA. As shown in **Table 1**, neither the average level of the selected affective states nor the mean level of PA were significantly related to the within-person effect of PA. We found significant gender differences ($p = 0.047$) for the subscale *valence*. Women felt significantly better and more satisfied than men after they increased their activity levels.

DISCUSSION

To investigate the association between PA and affect in everyday life and to clarify the contradictory results of previous studies (Schwerdtfeger et al., 2008 vs. Kanning et al., 2012), we used state-of-the-art methodology: namely, AA with real-time, real-life, repeated, objective assessment. In general, the current findings support the hypothesis that there is a positive association between PA and affective states.

We documented the significant influence of PA on energetic arousal. This result confirms previously published findings that have been obtained using AA (Schwerdtfeger et al., 2008; Kanning et al., 2012).

In addition, the data revealed a significant association between PA and positive affect (*valence*). This finding is consistent with the findings of Schwerdtfeger et al. (2008) but contrary to the findings of Kanning et al. (2012).

Unlike the findings of Kanning et al. (2012), the current data analysis did not reveal a negative association between activity and *calmness*.

To explain the findings regarding the three dimensions of affect, we speculate that physiological adaptations due to short bursts of increased PA, may cause the participants to perceive themselves as having enhanced energy levels. In some studies, increased energy levels were associated with a sense of reduced calmness; however, this relationship might not necessarily hold. We speculate

Table 1 | Fixed and random effects and variance components for valence (model 1), energetic arousal (model 2), and calmness (model 3) on actual physical activity (aPA).

Outcome	Fixed				Random					
Predictor	**Coefficient**	**SE**	***t*-Value (*df*)**	***p*-Value**	**Variance estimate**	**SD**	***X* (*df*)**	***p*-Value**	**95-Predictive interval[a]**	**Slope > 0[b]**
MODEL 1: VALENCE										
Intercept	8.199	0.123	66.41 (58)	<0.001	0.65	0.81	194.98 (57)	<0.001		
Sex	−0.297	0.350	−0.85 (58)	0.399						
VA-mean	1.094	0.076	14.42 (58)	<0.001						
aPA_mean	0.006	0.009	0.70 (58)	0.484						
aPA	0.003	0.001	2.83 (798)	0.005					−0.002; 0.007	90%
Sex	−0.007	0.003	−1.93 (798)	0.047						
V_mean	0.001	0.001	1.07 (798)	0.286						
aPA-mean	0.001	0.001	0.05 (798)	0.964						
Time	−0.002	0.002	−0.81 (61)	0.419	0.001	0.012	103.18 (60)	0.001	−0.026; 0.022	43%
MODEL 2: ENERGETIC AROUSAL										
Intercept	7.061	0.142	49.71 (58)	<0.001	0.875	0.935	196.38 (57)	<0.001		
Sex	−0.253	0.406	−0.62 (58)	0.536						
EA-mean	1.045	0.087	12.04 (58)	<0.001						
aPA_mean	0.012	0.010	1.14 (58)	0.261						
aPA	0.005	0.001	3.49 (798)	<0.001					0.002; 0.007	99%
Sex	−0.005	0.004	−1.21 (798)	0.229						
EA_mean	0.001	0.001	0.12 (798)	0.905						
aPA-mean	0.001	0.001	0.18 (798)	0.858						
Time	−0.024	0.003	−7.15 (61)	<0.001	0.001	0.018	127.75 (60)	<0.001	−0.059; 0.011	99%
MODEL 3: CALMNESS										
Intercept	8.457	0.121	69.86 (58)	<0.001	0.647	0.805	214.16 (57)	<0.001		
Sex	0.243	0.354	0.69 (58)	0.495						
C-mean	0.886	0.076	11.88 (58)	<0.001						
aPA_mean	−0.012	0.008	−1.31 (58)	0.197						
aPA	0.002	0.001	1.76 (798)	0.079					−0.0011; 0.0043	87%
Sex	−0.002	0.003	−0.47 (798)	0.641						
C_mean	−0.001	0.001	−0.66 (798)	0.512						
aPA-mean	−0.001	0.001	−1.03 (798)	0.303						
Time	0.007	0.003	2.45 (61)	0.018	0.001	0.012	142.51 (60)	<0.001	−0.0255; 0.0399	67%

[a] *Based on the assumption of normally distributed regression coefficients, the 95% predictive interval indicates the range of values between which 95% of the regression coefficients are estimated to lie (Hox, 2010). The intervals were calculated based on a model without level-2 predictors.*

[b] *Based on the assumption of normally distributed regression coefficients, this value indicates true percentage of regression coefficients that are positive (Hox, 2010). The percentages were calculated based on a model without level-2 predictors.*

that individual activity thresholds (for duration and/or intensity) must be exceeded for positive affect to develop. The dimension *valence*, however, might be positively affected by even short bouts of PA.

This study communicates an important health message, especially for people who sit at work for more than 8 h per day and/or lead an inactive life. The results suggest that short and low-intensity PA, which may be conducted as brief breaks from sedentary time even in such working environments, has the potential to enhance people's energy levels and make them feel better instantly. Accordingly, jogging intervals of half an hour are not necessary to induce such changes. It might even be speculated that everyday life activities such as stair climbing, taking a short walk around the block or doing jumping jacks may be sufficient to positively change a person's affective state. Our use of a sample that was rather inactive at the time of the study (students during their exam period) further supports this point. However, as our participants were not chronically inactive, but rather currently inactive (because of their exams), generalization of our findings is limited regarding chronically inactive participants. We might speculate that our only currently inactive sample does profit more from small activity episodes, because of learned connections between PA and affect, compared to chronically inactive samples.

Previous findings indicated that the effects of PA were stronger when initial mood levels were low (Folkins, 1976; LaFontaine et al., 1992). However, the current study did not confirm the existence of these ceiling effects. The strength of the association between

PA and *valence/energetic arousal* was not affected by the students' average mood level. Therefore, even people who are already experiencing positive feelings could profit from carrying out short bursts of low-intensity activity. This finding is consistent with those of studies that have supported the assumption of a more general protective effect of PA on psychological health (Thayer, 1987; Otto and Stemmann, 1991; Gauvin and Spence, 1996; Ekkekakis et al., 2000).

Several limitations of the present study must be taken into account. First, the measurement time points were fixed. This can be problematic, if the levels of activity prior to the assessments show too little variation, decreasing the power of the assessment approach. However, despite this disadvantage, we showed significant associations between activity and two of the three affective dimensions. To overcome the limited variation in the PA conducted directly before the e-diary assessments, interactive AA has been recommended (Ebner-Priemer et al., 2013). In interactive AA, e-dairy entries are triggered not by time but by the variables of interest, such as activity. Second, only university students were questioned, leaving out less educated or older people with a lower socio-economic status. Third, the assessment period covered only 1 day. Fourth, we primarily focused on the association between PA and affective states. Future studies should further analyze the association between PA and the degree of a subsequent change in affective states over a longer period of time. This search for an effective "*intensity threshold*" could aid in the development of more precise recommendations regarding activities that could interrupt sedentary behavior.

The key message of the current study is that repeated short periods of everyday life activities have the potential to positively influence affective states and subjective well-being and, in the long term, support a healthy lifestyle.

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One plus one equals three (or more . . .): combining the assessment of movement behavior and subjective states in everyday life

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Movement behavior, i.e., the overt permanence of postures and motions in daily life, is of crucial importance in human functioning. Movement behavior contributes to participating in daily life, and improves quality of life (Buffart et al., 2009). In addition, movement behavior—mostly described in terms of levels of physical activity, active lifestyle, and/or sedentary lifestyle—has shown to be related to health outcomes, such as incidence of and mortality due to diseases such as cancer, diabetes, and cardiovascular disease (United States Department of Health and Human Services, 2000; Pedersen and Saltin, 2006).

Another important aspect of movement behavior is its relationship with mood, affective states, and mental functioning. However, this relationship is quite complex and surely not unidirectional. It is generally accepted that being physically active contributes to a better mood, while affective states will influence movement behavior, in both quantitative (e.g., amount of walking) and qualitative (e.g., walking pattern) outcomes. Therefore, it seems quite obvious that much research focusing on understanding movement behavior includes mental states, while much research on understanding mental states includes movement behavior. Surprisingly, this it not the case.

Despite the important mutual relationship, linking movement behavior and mental states has not been common in the past. One of the reasons might be the separated areas of expertise—people working in the field of mental states not familiar with measurement of movement behavior and vice versa. An expression of this is the existence of two separate meetings: the International Conference of Physical Activity and Movement (ICAMPAM; next conference in Amherst, June 17–19, 2013) that is mainly attended by the "activity" researchers, and the Society of Ambulatory Assessment conference (SAA, next conference in Amsterdam, June 20–22, 2013), mainly visited by "electronic diary" researchers.

Developments in this field of research is strongly driven by technological progress. For example, within the field of activity monitoring it has resulted in several devices that measure physical activity for a prolonged period, without significant load for the participant, and quite low-cost (Bassett, 2012). Parallel to this, accelerometers and GPS nowadays are regular components of smartphones that, supported by many apps, provide data on some aspects of movement behavior. In the area of mood and mental states research considerable technological progress has been made too. Started with paper diaries, measurement of mood and mental states evoluted to e-diaries on Personal Digital Assistant (PDA)-based devices such as the Palm. Although sometimes a link was made with movement behavior, measurement of both concepts was not integrated. Also in the area of e-diaries and e-questionnaires significant progress was made with the development and more regular use of smartphones.

The use of e-diaries/questionnaires is not only relevant from the perspective of combining movement behavior and mental states or mood. The technique of e-diaries and questionnaires can also be used to get "context" information, including the situational (e.g., work, leisure time, study), social (presence of friends, colleagues, family), or geographical (the location in which the subject is) context. E-diaries and questionnaires can also be used to assess—especially in patient groups—symptoms such as pain and fatigue. Here again, a complex and mostly unsolved relationship exists between movement behavior on the one hand, and these symptoms on the other. Similar to the research are of mental states, simultaneous measurement of these constructs will contribute to a better understanding of these relationships, and to a better diagnosis and treatment of many patients.

An important future challenge in the area of combining activity monitoring with ambulatory assessment of mood and other mental states will be the application of feedback, provided directly or later on. For example, in research specific characteristics of movement behavior (or characteristics related to it, such as heart rate) can automatically initiate an assessment of mental state (interactive ambulatory assessment). Feedback can also be used in interventions and therapy: ambulatory assessment interventions. In the field of movement behavior feedback on the e.g., the number of steps has shown to be effective in improving levels of physical activity. Similarly, tailored feedback on level of physical activity can be used in therapies aimed at improving mental health.

The current research topic "Ecological Momentary Assessment and Intervention in physical activity and well-being: Affective reactions, social-cognitive factors, and behaviors as determinants of physical activity and exercise (edited by W. Schlicht, U. Ebner-Priemer, and Martina Kanning)" published in Frontiers in

Movement Science and Sport Psychology nicely represent the issues discussed above and give insight in the current advances (Kanning et al., 2013). Several papers focus on measuring movement behavior (e.g., in terms of physical activity and sedentary lifestyle) and affective states, and on their mutual relationships (Dunton et al., 2012; Bossmann et al., 2013; Kanning, 2013; Von Haaren et al., 2013). But also some other areas—interactive ambulatory assessment (Ebner-Priemer et al., 2013), assessment of clinical symptoms (Murphy et al., 2012), and ways to optimize movement behavior (Schwerdtfeger et al., 2012)—are well-covered.

It can be concluded that the time is right to combine advanced methods of measuring movement behavior with advanced use of e-diaries/e-questionnaires. The effect of this will not just be the result of adding the values of both separate fields, but will surpass this sum. Although the idea of combining them is not new, technological progress has resulted in products and possibilities that allow a significant next step. That next step surely includes the application of e-diaries/questionnaires focusing on mood and mental states, but is also relevant for constructs such as context, and symptoms as pain and fatigue. Combining methods will contribute to new knowledge, relevant from a fundamental scientific perspective, but also from a more clinical and treatment-based perspective. Although the first next steps will be made within research, the moment of application in individual people with individual problems or questions has moved into the foreseeable future.

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To total amount of activity..... and beyond: perspectives on measuring physical behavior

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The aim of this paper is to describe and discuss some perspectives on definitions, constructs, and outcome parameters of physical behavior. The paper focuses on the following constructs: Physical activity and active lifestyle vs. sedentary behavior and sedentary lifestyle; Amount of physical activity vs. amount of walking; Detailed body posture and movement data vs. overall physical activity data; Behavioral context of activities; Quantity vs. quality; Physical behavior vs. physiological response. Subsequently, the following outcome parameters provided by data reduction procedures are discussed: Distribution of length of bouts; Variability in bout length; Time window; Intensity and intensity threshold. The overview indicates that physical behavior is a multi-dimensional construct, and it stresses the importance and relevance of constructs and parameters other than total amount of physical activity. It is concluded that the challenge for the future will be to determine which parameters are most relevant, valid and responsive. This is a matter for physical behavior researchers to consider, that is critical to multi-disciplinary collaboration.

Keywords: physical activity, measurement, validity, ambulatory monitoring, physical behavior

INTRODUCTION

Over the last few decades, the methods used to objectively assess a person's behavior in terms of body postures (e.g., sitting, standing), body movements (e.g., walking, cycling), and/or daily activities (e.g., sports, gardening) in a daily life setting have improved considerably. Devices have become smaller, power consumption requirements have decreased, data storage capacity has increased, and innovative, integrated sensors have been developed. From the beginning, outcome variables related to this type of behavior mainly focused on amount and volume parameters, such as number of steps, volume of physical activity as expressed by total number of counts, and total energy expenditure. These developments and outcome variables have contributed to a better understanding of daily behavior and a more accepted role of it in research and clinical practice.

However, at the same time, the development of knowledge within this area is threatened by some theoretical and methodological issues. Firstly, vagueness and variability exist in terminology, concepts and definition of behavior related to body postures, movements and daily activities. An example of this is the term *physical activity*. This term is most common in literature, and mostly defined as any bodily movement produced by skeletal muscles that requires energy expenditure (Caspersen et al., 1985). However, physical activity as defined in this way does not cover all aspects of behavior that can be relevant (e.g., body postures as sitting and standing), and therefore cannot be used as umbrella term.

At the same time, the term is defined and used in ways that significantly differs from the definition stated above, as stated by Pettee Gabriel et al. (2012). Therefore, we will use and propose in this paper the term *physical behavior* as umbrella term, which includes the behavior of a person in terms of body postures, movements, and/or daily activities in his/her own environment.

Secondly, the importance of well-selected outcome measures is not always fully recognized. For example, physical behavior is not only characterized by amount or volume, but also by other aspects, as illustrated below with an example from research we were involved in. In 2004 Garssen et al. performed a study on effects of training in severely fatigued patients with Guillain Barre Syndrome (Garssen et al., 2004). It was assumed by doctors and therapists that this group had a low level of physical fitness, that they were hypoactive and that they had a lot of problems with functioning and participation in daily life. These assumptions were indeed confirmed, with the exception of the assumption on hypoactivity. No significant difference in amount of being physically active (i.e., time spent in walking, cycling, running, etc.) was found with healthy controls, and no significant effects of an exercise program on this parameter were observed. In the discussion section it was concluded: "In contrast with most physiologic and subjective variables, objectively measured daily physical activity using the Rotterdam Activity Monitor did not show any significant increase in activity. This may suggest that changing the level of daily physical activity is not an important adaptation strategy in these fatigued patients." Although it is uncertain that this conclusion is false, it is justified to put some question marks behind it. Did we really focus on the right aspect of physical behavior?

Most overview or review papers so far have focused on characteristics of, and differences between, techniques, and devices. The aim of this paper is to describe and discuss some perspectives on measuring physical behavior, with a distinction between different constructs of physical behavior, and different outcome variables resulting from data reduction procedures. The paper does not pretend to give a complete overview of literature, but aims to demonstrate by examples that physical behavior is more than total amount of activity.

CONSTRUCTS OF PHYSICAL BEHAVIOR

PHYSICAL ACTIVITY AND ACTIVE LIFESTYLE vs. SEDENTARY BEHAVIOR AND SEDENTARY LIFESTYLE

As already stated, physical activity can be defined as any bodily movement produced by skeletal muscles that requires energy expenditure (Caspersen et al., 1985). The volume of physical activity is mostly expressed by the number of activity counts per time period, which depends on the amount and intensity of movement. From these counts, energy expenditure can be estimated. When the type, amount and/or intensity of physical activity or energy expenditure over longer periods (e.g., a week) exceeds defined guidelines, this behavioral pattern can be characterized as an "active lifestyle." So far, most studies that aimed at (improving) health have focused on measuring the volume of physical activity or energy expenditure from this perspective. However, recent studies showed the relevance of sedentary behavior. The term sedentary is related to the Latin word "sedere" (to sit) and defined as "any waking sitting or lying behavior with low energy expenditure" (Wilmot et al., 2012). However, also other definitions exist, such as "sitting without being otherwise active" (Owen et al., 2011), or "a distinct class of activities that require low levels of energy expenditure and involve sitting during commuting, in the workplace and the domestic environment, and during leisure" (Thorp et al., 2011). These definitions broadly fit with—but are not similar to—the commonly used criterion of 1–1.5 metabolic equivalent units (MET's; multiples of basal metabolic rate) (Wilmot et al., 2012).

Sedentary behavior is not just the counterpart of physical activity (Lord et al., 2011; Owen et al., 2011; Wilmot et al., 2012). For example, a person cannot be "active" and "sedentary" at the same moment, but he/she can have an "active lifestyle" from the perspective of physical activity or energy expenditure, and simultaneously be characterized by having a sedentary lifestyle because of long periods of sitting or reclining with low levels of energy expenditure. That sedentary behavior patterns are different from just low levels of physical activity is supported by several studies, that show the active lifestyle-independent relationship between sedentary behavior and disease, health markers, and mortality (Proper et al., 2011; Thorp et al., 2011; Wilmot et al., 2012). Thus, the literature indicates that health-related research must not only focus on physical activity and its guidelines, but also on sedentary behavior.

AMOUNT OF PHYSICAL ACTIVITY vs. AMOUNT OF WALKING

So far, many studies have specifically focused on amount aspects of walking, including number of steps, distance walked, and walking time. Step counting was one of the first, widespread applications of activity monitoring. The underlying idea of step counting is that walking is the most important modality of physical activity and that it is a major contributor to activity-related energy expenditure (Bravata et al., 2007). This point of view is also reflected in studies including public health recommendations in terms of steps/day (Tudor-Locke and Bassett, 2004). Walking parameters like the number of steps can be relevant from certain perspectives, but besides methodological problems [e.g., in low walking speeds (Feito et al., 2012) or distorted walking (Mudge et al., 2007)], the extrapolation to total level of daily physical activity has to be done with care. That being physically active is not similar to walking is also shown by data of our department from a large data set of healthy, Dutch control subjects who were measured with the Vitaport Activity Monitor (TEMEC Instruments, Kerkrade, The Netherlands) (Bussmann et al., 2001), a device that allows detailed body posture and movement detection. These data showed that overall in this population walking duration only contributes for 75% to the duration of being active and, besides that, there is a large inter-individual range (43–98%) (unpublished observation). Therefore, it can be concluded that number of steps or walking duration is a questionable-valid estimator of time being active, and that a considerable underestimation may occur.

DETAILED BODY POSTURE AND MOVEMENT DATA vs. OVERALL PHYSICAL ACTIVITY DATA

Most accelerometer-based wearable monitors are based on the principle of movement counts from a single sensor, with the number of counts depending on the amount and intensity of movements. A limitation of this approach is that no distinction can be (easily) made between different postures, movements and daily activities. As described in the preceding paragraph, sedentary behavior, can be approached from the perspective of energy expenditure and from the perspective of body postures as sitting. The first perspective needs techniques that validly measure energy expenditure/MET's, the second one requires body posture detection. The ActivePAL device (PAL technologies, Glasgow, UK) is currently considered a reference method for discriminating sitting, standing, and ambulation. The potential relevance of detailed body posture and movement data has been shown by Hamilton et al. (2007), who have provided evidence (based on electromyography and lipoprotein lipase activity) that sitting and standing are physiologically different. Detailed posture and movement data can also be used to improve the estimation of energy expenditure in daily life (Bonomi et al., 2009). An example from another perspective is a study by Cumming et al. (2011), who reported favorable effects of early mobilization, with lying in bed being considerably different from a mobilization point of view than sitting out of bed. These examples express some potential benefits of data on specific postures and movements.

BEHAVIORAL CONTEXT OF ACTIVITIES

Most studies and devices focus on physical behavior over the whole day, for example the number of steps per day. It might be, however, that not the total quantity (amount or volume) is of interest, but the quantity performed within a specific behavioral context of activities (Giles-Corti et al., 2005). Thus, the target (Giles-Corti et al., 2005) or domain (Healy et al., 2011a) of that activity (e.g., shopping, watching television) as well as the setting or physical environment (e.g., walking indoors, outdoors) should then be considered. This issue is well described in a paper of Giles-Corti et al. (2005), and an example is a study of Duncan et al. (2009) which studied the relationship between built environment and walking outdoors (defined as transport-related physical activity and recreational walking). In such a study, not all walking periods are of interest, but mainly the periods of walking performed outdoors. The behavioral context is mostly assessed by observation or diaries and questionnaires, but future technological developments will also allow registration in other ways, such as GPS (Duncan et al., 2009) and miniature camera systems. Examples and discussion of combining the assessment of physical behavior and context variables using e-dairies in everyday life can be found in literature (Bussmann, 2013; Ebner-Priemer et al., 2013; Kanning, 2013).

QUANTITY vs. QUALITY

Physical behavior not only concerns amount and volume (quantity), it's also about the way activities are performed (or quality). It might be that diseases or interventions do not affect quantity, but do affect quality. Every posture, movement, or physical activity has its own quality aspects. For example, in walking symmetry, stability, spatio-temporal parameters, and walking speed are examples of quality parameters. A good example of this quantity-quality issue are recent studies by de Groot et al. and Vissers et al. on the effects of osteoartrosis and total hip artroplasty on physical behavior (de Groot et al., 2008; Vissers et al., 2011). When quantity parameters were analysed—such as time spent walking and number of sit-to-stand transitions—no differences were found pre-surgery between patients and healthy controls, and no effects were found from pre- to post-surgery. When quality data were analysed—such as walking speed and speed of rising from a chair—significant differences and effects of treatment were found. So apparently, diseases and surgery did influence physical behavior, but not quantitative aspects of physical behavior.

PHYSICAL BEHAVIOR vs. PHYSIOLOGICAL RESPONSE

Many accelerometers aim to estimate energy expenditure, which results from, but is no part of physical behavior. With the focus on energy expenditure, movement counts are converted to kilocalories, mostly with gender, weight, height, and age taken into account. However, movement efficiency (the ratio of external work performed compared to the internal energy expended to do the work) is generally not considered and, especially in disabled people, movement efficiency might considerably differ between persons and groups. As a result, the relationship between e.g., movement counts and energy expenditure will strongly vary.

For example, persons walking with a lower limb prosthesis have been shown to have a similar activity count as healthy controls when walking at a fixed speed, but the physiological response (expressed by heart rate and oxygen uptake) was significantly higher in amputees (Bussmann et al., 2004b). In such cases, accelerometry will underestimate the actual energy expenditure. From another perspective, this phenomenon was also found in another study by our group (Bussmann et al., 2004a, 2008): compared with healthy controls, people with an amputation were shown to walk less and at a lower walking speed, but the heart rate during walking was not significantly different, demonstrating the conceptual difference between physical behavior parameters and its physiological responses. It can be concluded that—especially in persons or groups that differ in movement efficiency—physical activity and the associated physiological response are different constructs, but both are important to assess.

PHYSICAL BEHAVIOR OUTCOME VARIABLES RESULTING FROM DATA REDUCTION PROCEDURES

The previous paragraph focused on different conceptual constructs of physical behavior. However, the same construct can be operationalized in different ways, and different constructs similarly. Actually, it is an issue of data processing. In the literature, amount, and volume of physical behavior outcome variables are usually presented in terms of duration and frequency, such as the mean count per minute, the total number of steps, and the number of sit-to-stand transitions. It can be questioned whether these overall outcome variables are sufficiently relevant, valid, and responsive in all conditions. In this paragraph we will discuss some additional methods of data processing, aiming at bout length and frequency, variability in bout length, the time window, and intensity and thresholds.

BOUT LENGTH AND FREQUENCY

The same amount and volume of body postures and movements and daily activities can be achieved by many short bouts interspersed throughout the day or from few long bouts (**Figure 1**; bars A,B). For example, 60 min of walking during a regular day can be composed of 30 walking bouts of 2 min, or two walking bouts of 30 min. The importance of bout length is described in literature. For example, a study of Healy et al. (2011b) suggests that besides reducing sedentary time, breaking up sedentary time may be beneficial for cardiovascular disease risk. Another example is provided by Chastin et al. (2010) who showed that persons with Parkinson Disease (PD) did not differ from healthy subjects in the total amount of sedentary time, but did significantly differ in distribution parameters: subjects with PD had longer continuous periods of sedentary behavior than their healthy comparison subjects. In a study of our group (Keijzer-Oster et al., unpublished data) we explored the physical behavior of computer workers with and without Repetitive Strain Injury (RSI). Data showed that the two subgroups did not differ in overall amount of sitting, but that there was a significant difference in number of breaks in sitting, expressed by the number of sit-to-stand transitions (see **Figure 2**).

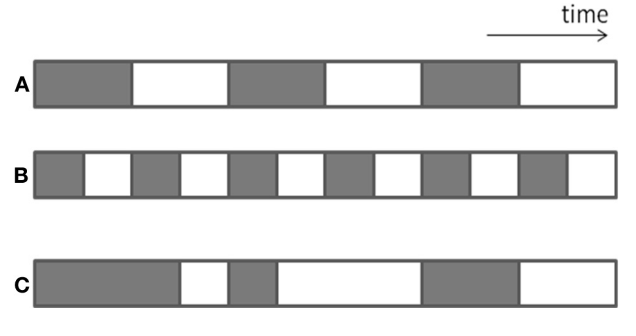

FIGURE 1 | Graphical representation of differences in distribution of length of bouts and variability in bout length. The gray bars indicate sedentary behavior (sitting).

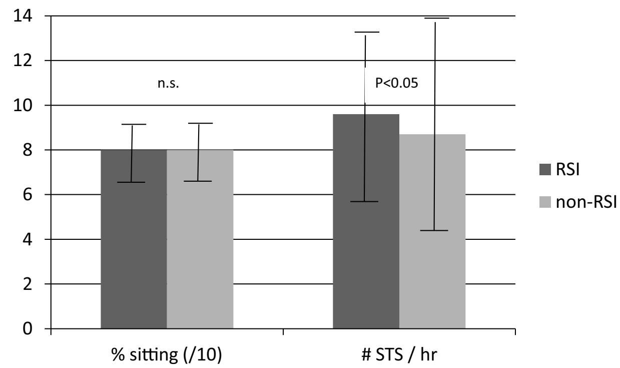

FIGURE 2 | Mean and SD of percentage sitting (for graphical reasons divided by 10) and number of sit-to-stand transitions per hour during working hours in computer workers with and without RSI.

In contrast to the expectations, subjects with RSI had a larger number of STS transitions. Generally, these results indicate that in some cases no effect is found on amount or volume measures, whereas these are found in the area of distribution.

VARIABILITY IN BOUT LENGTH

The same total amount can be built up from similar-length bouts (i.e., of the same duration, **Figure 1**; bar B), or from bouts with variable length (**Figure 1**; bar C). There are many physiological processes in human functioning in which variability is considered to be important, for example as a measure of capability to adapt to different circumstances. For example, Madeleine et al. (2008) showed that workers with pain and workers with less work experience had less variable movement patterns than those without pain or with more experience. On the other hand, too much variability may be disadvantageous; e.g., patients with PD are not able to walk with a consistent gait pattern, and this increased variability is associated with PD symptoms and fall risk (Weiss et al., 2011). To date, studies have rarely focused on variability analysis of activities of interest, but it can be hypothesized that variability in bout length for specific activities also represents the ability to adapt and/or consequences of diseases on physical behavior. Similarly, variability in other aspects of physical behavior (e.g., walking speed, daily activity counts) and in the physiological responses resulting from it (such as heart rate) might express the capacity to adapt.

TIME WINDOW

In studies of physical behavior, data are generally averaged over the whole measurement period. By such analyses it might be that effects are averaged out. An example of this phenomenon is a study by Rochester et al. (2006). They compared volume measures such as amount of time walking, amount of time standing, and number of walk periods in subjects with PD vs. healthy control subjects. Whole-day analyses showed no significant differences between these groups. When data were expressed on an hourly basis, however, different patterns were found. This means that the relevance of the outcome variables depends on the time window of analyses. Similarly, this might be the case between weekend and work days, with possibly no differences on a weekly basis, but significant differences when a distinction is made between work and weekend days. Therefore, the time window of analyses should be carefully chosen before starting a study.

INTENSITY AND INTENSITY THRESHOLD

In many cases the overall activity count or energy expenditure is assessed. However, the same overall activity count can result from long periods of low-intensity physical activity or a short period of vigorous physical activity. From a health perspective, the physiological effect of these two examples will be considerably different. Therefore, in many studies and instruments, the data are not only presented as, for example, mean MET score, but also as minutes in different intensity or MET categories (e.g., light, moderate, vigorous; e.g., Ekelund et al., 2011).

One example is a study of Janz et al. (2006), which showed that the number of minutes above a certain intensity level is related to femoral neck bone strength in children. In the same line of reasoning, Duvivier et al. (2013) concluded that given constant energy expenditure, reducing inactivity by increasing the time spent walking/standing is more effective than one hour of physical exercise, from the perspective of insulin sensitivity and plasma lipids.

DISCUSSION

In this overview the umbrella term “physical behavior” was purposely used. Although we realize that physical activity is a more familiar construct, we also feel that the term is confusing and that it does not logically and semantically cover all its underlying constructs. Others already attempted to create a conceptual framework of physical activity, e.g., Pettee Gabriel et al. (2012). They also recognize the umbrella concept of (physical) behavior. However, their model is strongly based on the distinction between two types of behavior (physical activity and sedentary), whereas we feel that physical behavior has much more relevant descriptors and components. In agreement with Pettee Gabriel et al., we feel that (physical) behavior does not include the physiological responses resulting from it, although they will be strongly related to each other.

As stated in the introduction section, the issues and cases described and discussed in this paper are examples to illustrate the central message that physical behavior is more than amount and volume, and that failure to find an effect or differences does not mean that there are no effects on physical behavior. We realize that in this paper literature is not extensively and systematically discussed, and that the given examples are arbitrary. A next step might be a systematic and in-depth review on some of the topics that are discussed in the current paper.

From our perspective we feel that the challenge for the future will be to determine which parameters are clinically relevant, valid, and responsive. There will be no general answer on this question: the parameter of interest will necessarily depend on the purpose of measurement. As formulated by Terwee et al. (2011): “…for measuring physical activity as a risk factor for developing osteoarthritis an instrument should measure the mechanical load [on the joints].... for measuring physical activity as a protective factor against functional decline, an instrument should measure frequency and duration of recreational activities such as walking and cycling." We feel that in several cases a device is used and data are presented just because that device was available and has a specific parameter as main outcome variable. We therefore strongly recommend a clear analysis of the aim of the study and measurement and the component of physical behavior of interest, in line with the reasoning of e.g., Warren et al. (2010) and Clanchy et al. (2011).

If possible, that aim must be hypothesis-driven and embedded in current state of knowledge; random "data fishing" must be avoided as much as possible. As a result, we also strongly recommend that studies focus on underlying mechanisms. Of course, RCT's focusing on physical behavior and/or including measurement of physical behavior will be important, but understanding the role of physical behavior in the problem of interest and its determinants are at least equally important.

Stating that defining relevant, responsive and valid outcome variables must be based on a good question is a somewhat simplified way of reasoning. Many factors and people play a role in defining the question and outcome variables produced by data reduction procedures. First of all, people with practical knowledge and experience, such as doctors and therapists, are essential. Technicians and data analysts are needed for developing usable hardware and software that have relevant outcome variables as output. Researchers are necessary for e.g., methodologically testing outcome variables produced by data reduction procedures and for integrating research projects in current scientific knowledge. Together with other disciplines they can introduce and test new theories and models, possibly originating from other areas and disciplines. From our point of view it's a choice between "following the status quo," and hoping to hit the target with luck, or a coordinated, focused and multi-disciplinary action.

RECOMMENDATIONS

To improve the research on physical behavior, we recommend for new studies:

(1) To be aware of the "state of the art" of physical behavior measurement and outcome parameters;
(2) To make a clear link between (clinical) problem and (relevant) behavior parameters;
(3) To specify in the research question the aspects of physical behavior at interest;
(4) To describe and discuss the selection of parameters in the paper;
(5) To describe in detail the measurement settings and applied data reduction procedures;
(6) To select devices meeting the research question and selected outcomes, not vice versa;
(7) To use outcomes that are tested in focused and sound validation studies;
(8) To consider the added value of (simultaneous) acquisition of other data, such as physiological and psychological parameters, and context;
(9) To be eager to be innovative and inventive;

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Momentary assessment of adults' physical activity and sedentary behavior: feasibility and validity

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Introduction: Mobile phones are ubiquitous and easy to use, and thus have the capacity to collect real-time data from large numbers of people. Research tested the feasibility and validity of an Ecological Momentary Assessment (EMA) self-report protocol using electronic surveys on mobile phones to assess adults' physical activity and sedentary behaviors. **Methods:** Adults ($N = 110$; 73% female, 30% Hispanic, 62% overweight/obese) completed a 4-day signal-contingent EMA protocol (Saturday–Tuesday) with eight surveys randomly spaced throughout each day. EMA items assessed current activity (e.g., Watching TV/Movies, Reading/Computer, Physical Activity/Exercise). EMA responses were time-matched to minutes of moderate-to-vigorous physical activity (MVPA) and sedentary activity (SA) measured by accelerometer immediately before and after each EMA prompt. **Results:** Unanswered EMA prompts had greater MVPA (±15 min) than answered EMA prompts ($p = 0.029$) for under/normal weight participants, indicating that activity level might influence the likelihood of responding. The 15-min. intervals before versus after the EMA-reported physical activity ($n = 296$ occasions) did not differ in MVPA ($p > 0.05$), suggesting that prompting did not disrupt physical activity. SA decreased after EMA-reported sedentary behavior ($n = 904$ occasions; $p < 0.05$) for overweight and obese participants. As compared with other activities, EMA-reported physical activity and sedentary behavior had significantly greater MVPA and SA, respectively, in the ±15 min of the EMA prompt ($ps < 0.001$), providing evidence for criterion validity. **Conclusion:** Findings generally support the acceptability and validity of a 4-day signal-contingent EMA protocol using mobile phones to measure physical activity and sedentary behavior in adults. However, some MVPA may be missed among underweight and normal weight individuals.

Keywords: physical activity, sedentary behavior, ecological momentary assessment, validity, adults, accelerometers

INTRODUCTION

Participating in regular physical activity has been shown to significantly reduce the risk of cancer, diabetes, and heart disease (Physical Activity Guidelines Advisory Committee, 2008). However, recent estimates suggest that only 10% of U.S. adults meet the Physical Activity Guidelines for Americans of at least 150 min of moderate-to-vigorous intensity physical activity per week (Tucker et al., 2011). Also, rates of physical activity decline across adulthood for men and women regardless of racial/ethnic group (Hawkins et al., 2009). Studies examining physical activity determinants, health consequences, and promotion strategies rely upon accurate and unbiased physical activity measures (Haskell, 2012; Troiano et al., 2012). Recall-based self-report methods of assessing physical activity can be prone to errors and biases (Merom et al., 2009; Loney et al., 2011; Nicaise et al., 2011). Objective physical activity measures such as accelerometers and pedometers are unable to provide information about specific activity types (e.g., watching TV versus computer use), suffer from substantial missing data due to non-wear (Troiano et al., 2008; Colley et al., 2010) and are unable to measure mood during or the context of physical activity, which may be important factors that influence behavior. Technology-enabled real-time self-report assessment strategies can overcome many of these limitations.

Recent advances in mobile phone technology have created opportunities for Ecological Momentary Assessment (EMA) of physical activity and sedentary behaviors in naturalistic settings (Patrick et al., 2008; Dunton and Atienza, 2009). Mobile phones have become affordable, easy to use, and quite ubiquitous. An estimated 68% of adults worldwide own a mobile phone[1], and they have been widely adopted across socioeconomic groups and in developing countries (Kaplan, 2006; Kosaraju et al., 2010). Software applications can be loaded onto basic mobile phones or smartphones to trigger electronic EMA surveys in real time. Some preliminary evidence for the utility of EMA to measure physical activity is available (Rofey et al., 2010; Dunton et al., 2011; Thomas et al., 2011). EMA can be used to measure physical activity and

[1] http://www.itu.int/ITU d/ict/publications/idi/2010/Material/MIS_2010_Summary_E.pdf

sedentary behaviors alone or in combination with accelerometers, Global Positioning Systems (GPS), and heart-rate and respiration monitors. An added benefit of EMA is the capability to simultaneously measure contextual, social, or psychological factors that may influence physical activity such as environmental perceptions, social companionship, mood, and stress (e.g., Dunton et al., 2009; Kanning and Schlicht, 2010; Conroy et al., 2011).

The goals of this study were to test the feasibility, acceptability, and validity of a real-time EMA protocol using self-report electronic surveys on mobile phones to measure adults' physical activity and sedentary behaviors in naturalistic settings. The first objective sought to describe the rates of mobile phone damage and loss, technical problems, and EMA survey response. The second objective was to determine whether participants engaged in higher levels of moderate-to-vigorous physical activity (MVPA) during unanswered EMA survey prompts, which would indicate that participants either do not carry the mobile phone or do not answer the EMA survey prompts during physical activity. The third objective was to determine whether the act of completing the EMA survey interrupted physical activity or sedentary behavior (i.e., activity levels differed before and after completing the survey). The fourth objective was to evaluate the criterion validity of the EMA self-reports of physical activity and sedentary behavior by comparing with time-matched data collected through an accelerometer. All objectives were initially stratified by the weight status because there is some evidence to suggest that overweight and obese individuals perform different types of physical activity than normal weight individuals (Spees et al., 2012). The overall purpose of the EMA protocol was not to provide a measure of total physical activity and sedentary behavior during the monitoring period. Instead, the goal was to sample the occurrence of specific behaviors that can be linked to other time-intensive EMA measures such as mood and context.

MATERIALS AND METHODS

PARTICIPANTS AND RECRUITMENT

Participants included healthy adults living in and around Chino, California (about 30 miles east of downtown Los Angeles). The current study analyzed baseline data from a longitudinal study called Project Measuring Our Behaviors in Living Environments (MOBILE), which is investigating the effects of environmental and intrapersonal factors on health behavior decision-making processes. Recruitment occurred through a number of channels including posters placed at community locations, letters sent to places of residence, and references from other research studies. Inclusion criteria consisted of the following: (a) age of 28 years or older, (b) living in Chino, CA, or a surrounding community, and (c) able to answer electronic EMA surveys while at work. Participants were excluded who (a) did not speak and read fluently in English (b) had an annual household income greater than $210,000, (c) regularly performed less than 150 min per week of exercise or physical activity, and (d) had physical limitations making them unable to exercise. Individuals who met the eligibility criteria were scheduled for a data collection appointment at a local community site or their home. This research was reviewed and approved by the Institutional Review Board at the University of Southern California.

ECOLOGICAL MOMENTARY ASSESSMENT

This study used electronic EMA to measure participants' current type of activity at any given moment. Other EMA items assessed social and physical context, mood and stress, but those variables were not the focus of the current paper. Data were collected using an HTC Shadow mobile phone (T-Mobile USA, Inc.) with a custom version of the MyExperience software installed[2] (Froehlich et al., 2007). The mobile phone calling, texting, and internet capabilities were disabled. The software was programmed to display electronic question sequences and response choices on mobile phone screen (see **Figure 1**).

Participants used the up and down arrows on the phone key pad to select a response choice from the options provided. Data were stored on the phone in an electronic file until downloaded by researchers. Verbal and written instructions were provided on how to use the device. Prior to starting the study, participants completed a practice assessment in the presence of a research staff member and were given the opportunity to ask questions.

Participants were monitored across 4 days (Saturday–Tuesday) between 6:30 am and 10:00 pm. Eight EMA surveys were prompted per day. Each EMA survey was prompted at a random time within eight pre-programmed windows in order to ensure adequate spacing across the day (see **Figure 2**). Participants were asked to carry the mobile phone while at work and answer surveys when prompted. EMA surveys were prompted using an auditory signal. Phones could be set to vibrate mode in order to avoid disrupting activities. Upon receiving a phone signal, participants were instructed to stop their current activity and complete a short electronic EMA question sequence. This process required 2–3 min. If a signal occurred during an incompatible activity (e.g., sleeping or bathing), participants were instructed to ignore it. If no entry was made, the phone emitted up to three reminder signals at 5 min intervals. After this point, the electronic EMA survey became inaccessible until the next recording opportunity. During the monitoring period, participants received one phone call and one to two SMS messages from researchers to inquire about any technical problems and remind them to recharge the phone each night. A study hotline was also available to participants to report technical issues and request a replacement phone if necessary. Participants were compensated up to $50 for participating in the study: $18 plus an additional $1 for each completed EMA survey entry (32 total) over the 4-days.

MEASURES

EMA items

Each EMA question sequence measured participants' current activity type ["What were you DOING right before the beep went off (Choose your main activity)?"; see **Figure 1**]. Two automatic branching question sequences were programmed according to the response of this initial question. For the first branching sequence, if "Physical Activity/Exercise" was selected in response to the original question, the participant received the follow-up question, "what type of PHYSICAL ACTIVITY/EXERCISE?" In the second

[2]http://myexperience.sourceforge.net/

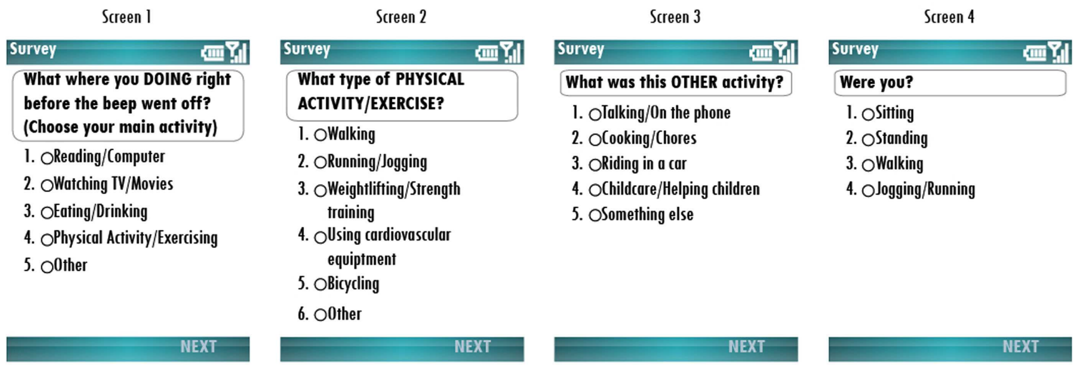

FIGURE 1 | Ecological momentary assessment (EMA) screen shots. Images display how Ecological Momentary Assessment (EMA) items and response choices appeared on the display screen of the mobile phone. Respondents used the key pad to toggle up/down and select their response. Only one response choice could be selected per screen. If a respondent selected "Physical Activity/Exercising" on Screen 1, he/she was automatically directed to Screen 2. If a respondent selected "Other" on Screen 1, he/she was automatically directed to Screen 3. If a respondent selected "Something else" on Screen 3, he/she was automatically directed to Screen 4.

Day	6:30am	8am-10am	10am-12pm	12pm-2pm	2pm-4pm	4pm-6pm	6pm-8pm	8pm-10pm
Saturday	X	X	X	X	X	X	X	X
Sunday	X	X	X	X	X	X	X	X
Monday	X	X	X	X	X	X	X	X
Tuesday	X	X	X	X	X	X	X	X

FIGURE 2 | Ecological momentary assessment (EMA) procedure. Each X represents an EMA survey that was prompted at a random time with the specified time interval.

branching sequence, if a participant responded "Other," he/she received the follow-up question, "what was this OTHER activity?" Subsequently, if he/she indicated, "Something else," the question "were you (Sitting, Standing, Walking, Jogging/Running)?" was shown. For data analyses testing the first through third study objectives, responses indicating "Physical Activity/Exercise" and "Jogging/Running" were coded as *physical activity* and those indicating "Reading/Computer," "Watching TV/Movies," and "Sitting" were coded as *sedentary behavior.* All activities were examined separately for analyses testing the fourth study objective. The EMA items were administered in English.

Physical activity

The Actigraph, Inc., GT2M model activity monitor (firmware v06.02.00) provided an objective measure of physical activity. The device was worn on the right hip attached to an adjustable belt. Participants were asked to wear the accelerometers across seven continuous days (encompassing the 4-days of EMA monitoring). The devices were not worn when sleeping, bathing, or swimming. The cut-point for MVPA was consistent with studies of national surveillance data (Troiano et al., 2008; Belcher et al., 2010). The MVPA threshold was 2020 counts per minute (equivalent to three METs). Sedentary activity (SA) was defined as less than 100 counts per minute (Healy et al., 2008). All accelerometer recordings were time-stamped in order to be linked with EMA data captured on the mobile phone. The internal clocks of the mobile phone and accelerometer were both synchronized to the same computer. A time window was created around each EMA survey, which comprised the 15-min before and the 15-min after the survey prompt. EMA entries with a total of zero activity counts in the 15-min before and 15 min after the survey prompt were considered accelerometer non-wear and excluded from analyses.

Height and weight

Height and weight were measured in duplicate using an electronically calibrated digital scale (Tanita WB-110A) and professional stadiometer (PE-AIM-101) to the nearest 0.1 kg and 0.1 cm, respectively. Body Mass index (BMI) was calculated (kg/m^2). Weight status was classified as follows: under and normal weight (BMI < 25), overweight (BMI greater than or equal to 25 and less than 30), and obese (BMI ≥ 30).

Demographic and time variables

Participants' age, sex, ethnicity, and annual household income were assessed through a self-report paper-and-pencil survey. Annual household income was coded into quartiles (less than $40,000, $40,000–$70,000, $70,001–$90,000, above $90,000). Each EMA survey was also coded for the time of day that it occurred [i.e., morning (6:30 am to 11:59 am), afternoon (12:00 pm to 5:59 pm), or evening (6:00 pm to 10:00 pm)].

DATA ANALYSES

Multilevel analyses were conducted using SUDAAN 10.0. To examine EMA survey compliance patterns (objective #1), multilevel logistic regression analyses tested whether the likelihood of survey non-response (unanswered versus answered) varied as a function of day of the week, time of day, sex, age, race/ethnicity, annual household income, and weight status. To examine accelerometer non-wear patterns, multilevel logistic regression analyses tested whether the likelihood of accelerometer non-wear (versus wear) during the matched EMA prompt varied as a function of day of the week, time of day, sex, age, race/ethnicity, annual household income, and weight status. Multilevel linear regression investigated whether EMA survey non-response was related to concurrent MVPA and SA (measured by accelerometer; objective #2). Multilevel repeated measures models conducted in SAS PROC MIXED compared MVPA and SA (in minutes measured by accelerometer) during the 15-min interval before and 15 min interval after each EMA survey response, stratified by EMA-reported (1) physical activity, and (2) sedentary behavior, respectively (objective #3). The construct validity of EMA survey reports of physical activity and sedentary behavior (objective #4) was tested through multilevel linear regression analyses with the EMA-reported main activity type (nine-level categorical variable) as the independent variable and concurrent MVPA and SA (measured by accelerometer) as the dependent variables. For the model testing differences in SA, focused pairwise contrasts were examined between the three EMA-reported sedentary behaviors (reading/computer, watching TV/movies, sitting) and two slightly higher intensity EMA-reported activities (cooking/chores, childcare/helping with children).

All models were initially stratified by weight status (underweight/normal weight versus overweight/obese). When no group differences were found, results are presented for the entire sample with the groups combined and weight status included as covariate. All models also controlled for sex, age, annual household income, and race/ethnicity (Hispanic versus non-Hispanic; at level two). Adjusted Wald F statistics and associated P values were used to determine the statistical significance of each factor in the regression analyses. Predicted marginal means (i.e., adjusting for all of the other model covariates) were generated from the linear regressions (Korn and Graubard, 1999).

RESULTS

DATA AVAILABILITY

A flow chart displaying data availability and sources of missing data is shown in **Figure 3**. No mobile phones were lost, stolen, or damaged. EMA data for three participants was mistakenly deleted prior to being downloaded. Eleven participants had insufficient data (<50% available) due to major technical problems with the phone ($n = 6$), a lack of understanding of the mobile phone instructions ($n = 2$), a job where responding to the surveys was not tolerated ($n = 1$), an unusually busy schedule during the weekend monitored ($n = 1$), and disinterest ($n = 1$). Eight of these individuals agreed to participate in a retrial. For these individuals, data from the retrial (not the original trial) are shown in **Figure 3** and used in the analyses. The six participants with insufficient data due to a major technical problem with the phone did not differ from the rest of the sample in terms of any demographic factors or weight status.

Of the 3,648 programmed EMA surveys (32 surveys each across 114 participants), 135 (3.7%) EMA surveys were not prompted due to the phone being powered off or battery drain, and 22 (0.6%) were not prompted due to unknown technical problems. Two accelerometers were lost prior to data download ($n = 1$ lost by a participant and $n = 1$ lost by the researchers). Accelerometer data were unavailable for two participants due to problems downloading the devices. Also, accelerometers were not worn (as determined by 0 total activity counts during the ±15 min of the EMA survey prompts) during 685 of the EMA survey prompts. The likelihood of accelerometer non-wear did not vary as a function of day of the week, sex, age, race/ethnicity, and annual household income. However, accelerometer non-wear was more likely to occur during the morning (6:30 am to 12:00 pm; 37%) than afternoon (12:00 pm to 6:00 pm; 8%) or evening (6:00 pm to 10:00 pm; 16%; Adj. Wald $F = 41.17$, df = 2, $p < 0.001$). Accelerometer non-wear was also higher among obese participants (27%) than underweight/normal weight (17%) and overweight (19%) participants (Adj. Wald $F = 4.29$, df = 2, $p = 0.016$). Of the 2,681 EMA survey prompts that were matched with data from a worn accelerometer, a total of 403 prompts were unanswered, resulting in an analytic sample size of 2,278 answered EMA surveys across 110 participants.

DESCRIPTIVE STATISTICS

Demographic characteristics for the analytic sample ($N = 110$) are shown in **Table 1**. Participants were mainly female (72.5%), married (66.1%), and overweight/obese (61.82%). Individuals ranged in age from 27 to 73 years with an average age of 40.4 years (SD = 9.74). The sample was racially/ethnically diverse with 30.3% Hispanic/Latino. Twenty-four percent had an annual household income less than $40,000. Of the EMA surveys answered while wearing an accelerometer, physical activity was reported to be the main activity in 8.6% of EMA surveys, which comprised of Walking (4.4%), Running/Jogging (0.5%), Weight lifting/Strength training (0.4%), Using Cardiovascular Equipment (0.4%), Bicycling (0.3%), Other (2.6%). Sedentary behavior was reported as the main activity in 39.6% of EMA surveys, which was comprised of Reading/Computer (17.0%), Watching TV/Movies (14.3%), and Something else-Sitting (8.3%). Other main activity types indicated were as follows: Eating/Drinking (12.5%), Talking on the phone (6.7%), Cooking/Chores (8.0%), Riding in a car (11.1%), Childcare/Helping children (4.9%), and Something else-Standing (5.0%), and Something else-Walking (3.3%).

UNANSWERED EMA PROMPTS

On average, participants answered 82% (range 25–100%) of EMA prompts. The average EMA survey answer rate for prompts while wearing an accelerometer was 85%. The likelihood of EMA survey non-response did not vary as a function of day of the week, time of day, sex, age, race/ethnicity, annual household income, or weight status. When examining the ±15 min of each EMA survey prompt, SA did not differ between answered (pred. marginal mean = 19.46, SE = 0.25 min) and unanswered (pred. marginal mean = 20.02, SE = 0.25 min) prompts. For MVPA, the results differed by weight status group. Unanswered EMA prompts had greater MVPA (± 15 min; pred. marginal mean = 1.35, SE = 0.34 min)

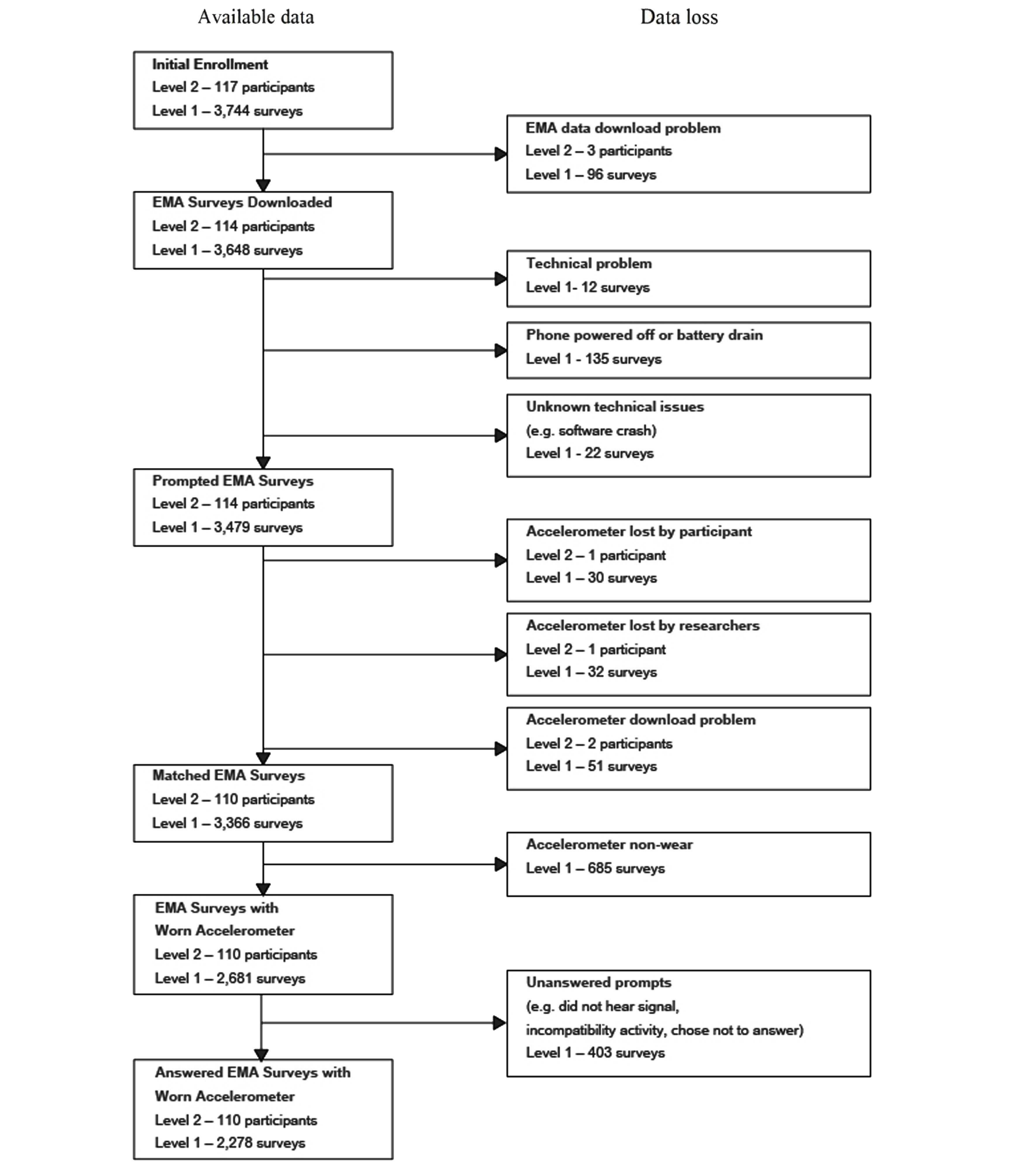

FIGURE 3 | Flow chart of data availability. Level 1 represents the number of electronic Ecological Momentary Assessment (EMA) surveys, and Level 2 represents the number of participants. EMA Surveys Downloaded = the number of EMA surveys successfully downloaded from the mobile phone. Prompted EMA Surveys = the number of EMA surveys with a time and date record of being prompted. Matched EMA Surveys = the number of prompted EMA surveys that could be time-matched to available accelerometer data. EMA Surveys with Worn Accelerometer = the number of prompted EMA surveys that could be time-matched to data indicating accelerometer wear during that period. Accelerometer wear was defined as greater than zero activity counts in the ±15 min window of each electronic EMA survey prompt. Answered EMA Surveys with Worn Accelerometer = the number of answered EMA surveys that could be time-matched to data indicating accelerometer wear during that period.

Table 1 | Participant characteristics.

	n (%)
SEX[a]	
Male	30 (27.5)
Female	79 (72.5)
MARITAL STATUS[b]	
Never married	21 (19.3)
Married	72 (66.1)
Separated/divorced/widowed	16 (14.7)
ANNUAL HOUSEHOLD INCOME[c]	
Less $40,000	25 (23.6)
$40,000–$70,000	24 (22.6)
$70,001–$90,000	27 (25.5)
Above $90,000	30 (28.3)
RACE[d]	
African–American	8 (7.8)
Asian	28 (27.2)
White/Caucasian	48 (46.6)
Biracial/Mixed	9 (8.7)
Other	10 (9.7)
ETHNICITY	
Hispanic/Latino	33 (30.3)
Non-Hispanic/Latino	77 (69.7)
WEIGHT STATUS	
Underweight/Normal Weight	42 (38.2)
Overweight	34 (30.9)
Obese	34 (30.9)

[a] Sex data missing for one participant; [b] Marital status data missing for one participant; [c] Annual household income missing for four participants; [d] Race data missing for seven participants.

than answered EMA prompts (pred. marginal mean = 0.60, SE = 0.11 min; Adj. Wald $F = 4.91$, df = 1, $p = 0.029$) for underweight and normal weight participants, indicating that activity level might influence likelihood of responding. However, for overweight/obese participants, MVPA did not differ between answered (pred. marginal mean = 0.91, SE = 0.11 min) as compared with unanswered (pred. marginal mean = 0.85, SE = 0.16 min) EMA survey prompts.

EXTENT TO WHICH EMA SURVEYS DISRUPTED PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR

To determine whether the act of answering an EMA survey disrupted a participant's ongoing activity, we compared MVPA and SA (measured by accelerometer) in the 15-min before versus the 15-min after each answered EMA survey. When physical activity was the main activity reported by EMA, results showed MVPA minutes did not differ during the 15-min interval before ($M = 1.38$, SD = 3.20 min) as compared to the 15-min interval after ($M = 1.28$, SD = 2.98 min) the answered survey prompt. For sedentary behavior, the results differed by weight status. Overweight and obese participants engaged in less SA during the 15-min before the prompt ($M = 11.04$, SD = 3.34 min) as compared with the 15-min after the prompt ($M = 11.44$, SD = 3.11 min; $\beta = -0.3579$, $p = 0.035$) when sedentary behavior was the main activity reported by EMA. For underweight and normal weight individuals, SA did not differ during the 15-min interval before ($M = 11.37$, SD = 3.09 min) as compared to the 15-min interval after ($M = 11.68$, SD = 2.95 min) the answered EMA survey prompt reporting sedentary behavior as the main activity.

VALIDITY OF EMA ACTIVITY RESPONSES

The construct validity of EMA activity responses was tested by examining differences in the time-matched MVPA and SA (measured by accelerometer in the ±15 min) by EMA-reported main activity categories. MVPA significantly differed across EMA-reported activities (Adj. Wald $F = 5.63$, df = 8, $p < 0.001$). MVPA was higher for EMA surveys reporting physical activity than any other type of activity ($ps < 0.001$; see **Figure 4**). SA also differed across EMA-reported activities (Adj. Wald $F = 28.75$, df = 8, $p < 0.001$). SA was higher for EMA surveys reporting computer/reading versus cooking/chores (Adj. Wald $F = 83.37$, df = 1, $p < 0.001$), computer/reading versus childcare/helping with children (Adj. Wald $F = 38.26$, df = 1, $p < 0.001$), watching TV/movies versus cooking/chores (Adj. Wald $F = 87.22$, df = 1, $p < 0.001$), watching TV/movies versus childcare/helping with children (Adj. Wald $F = 35.68$, df = 1, $p < 0.001$), sitting versus cooking/chores (Adj. Wald $F = 98.05$, df = 1, $p < 0.001$), and sitting versus childcare/helping with children (Adj. Wald $F = 36.46$, df = 1, $p < 0.001$; see **Figure 5**).

DISCUSSION

Ecological Momentary Assessment of physical activity and sedentary behavior using real-time electronic surveys displayed on mobile phones can reduce recall biases, improve ecological validity, and provide information about specific activity types. Results from the current study support the feasibility and acceptability of 4-day signal-contingent EMA protocol consisting of eight randomly prompted electronic surveys per day. Although EMA has the potential to introduce participant burden, participants answered approximately 82% of the electronic EMA surveys that were prompted. No mobile phones were lost, stolen, or damaged. Rates of missing accelerometer data due to device loss, downloading complications, and non-wear were greater than rates of missing EMA data.

Although some EMA data were lost due to mobile phone software and hardware problems, these instances occurred at random, and the data could be recovered through retrial. All participants who experienced a major technical problem resulting in greater than 50% data loss agreed to participate in a retrial, through which sufficient data was obtained. It is expected that data loss through major technical problems will be reduced in the future as the memory and processing capabilities on mobile phones will be improved through enhanced technology. Data loss due to the phone being powered off, on the other hand, may not occur at random. Future research should seek to identify strategies to collect workday EMA data from these individuals through auto-initiated surveys with short-term recall during work breaks and immediately after work shifts are completed. Data loss due to the phone being powered off may also be more common among individuals with unusual sleep and wake schedules. Future studies may remedy this problem by tailoring the EMA prompting period to individual sleep cycles.

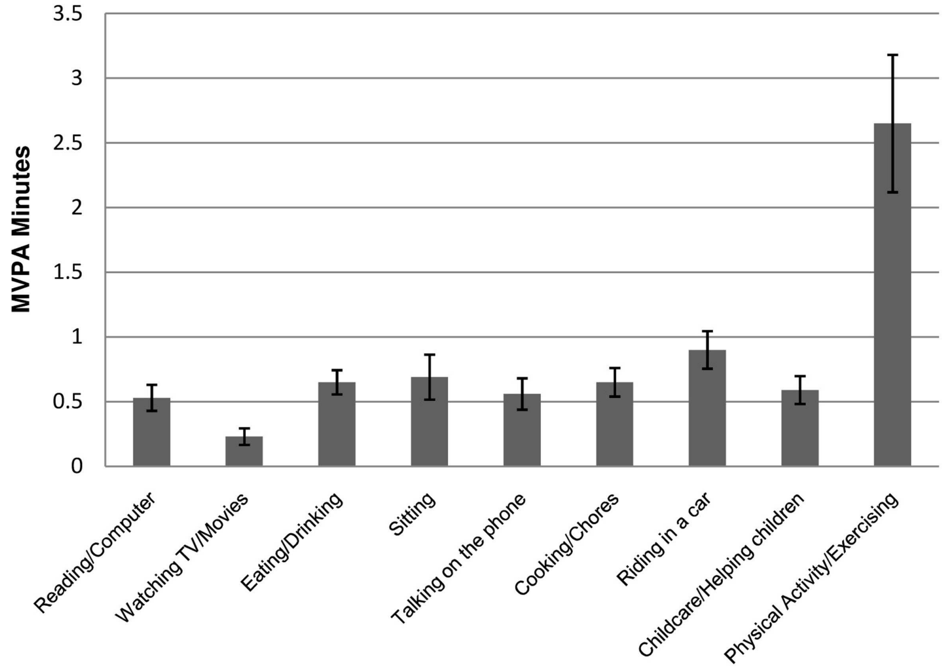

FIGURE 4 | Mean moderate-to-vigorous physical activity (MVPA) minutes by activity categories self-reported through ecological momentary assessment (EMA). MVPA was recorded by accelerometer in the ±15 min window of each answered EMA survey prompt. Values represent the predicted marginal means generated through multilevel linear regressions, which adjusted for sex, age, race/ethnicity, annual household income, and weight status. Standard error (SE) bars are shown. Non-overlapping SE bars indicate a statistically significant difference between means at $p < 0.05$.

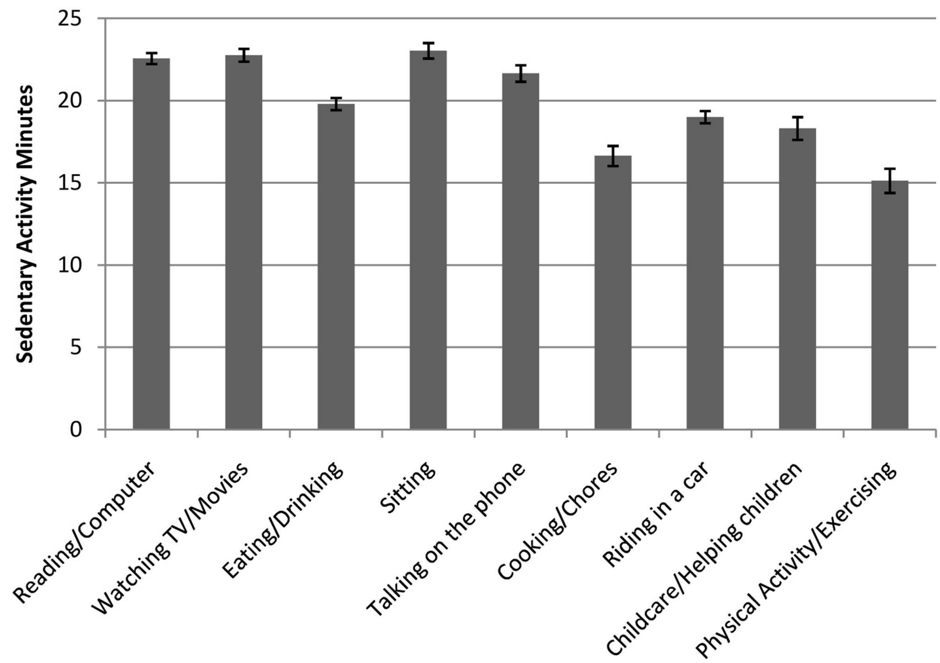

FIGURE 5 | Mean sedentary activity (SA) minutes by activity categories self-reported through ecological momentary assessment (EMA). SA was recorded by accelerometer in the ±15 min window of each answered EMA survey prompt. Values represent the predicted marginal means generated through multilevel linear regressions, which adjusted for sex, age, race/ethnicity, annual household income, and weight status. Standard error (SE) bars are shown. Non-overlapping SE bars indicate a statistically significant difference between means at $p < 0.05$.

Ecological momentary assessment survey response rates were consistent across sociodemographic and economic groups and comparable to other EMA studies (Hufford et al., 2002; Rofey et al., 2010). However, there was some evidence suggesting that underweight and normal weight individuals (40% of the sample) were less inclined to answer EMA survey prompts while engaging in higher levels of physical activity. From these data, it is unclear whether underweight and normal weight individuals were less likely to carry the phone with them while exercising or carried the phone while exercising but were less likely to answer the prompted surveys at those times. Interestingly, concurrent activity levels did not differ between answered and unanswered surveys for overweight and obese individuals (60% of the sample) when reporting physical activity. It is possible that underweight and normal weight individuals are more likely to engage in types of physical activities (e.g., road bicycling, team sports) where responding to an EMA survey would be difficult. Overweight and obese individuals perform more physical activity through brisk walking (Spees et al., 2012), which may be more compatible to EMA survey response. To promote EMA of higher intensity activities, a context-sensitive approach may be taken (Intille et al., 2012), which utilizes information from built-in or external motion sensors, to automatically prompt EMA surveys during natural activity breaks or immediately after the activity concludes.

Results indicated that the act of responding to the EMA survey did not disrupt physical activity. MVPA levels did not differ before and after the moment of the completed EMA survey, suggesting that individuals resumed their prior level of physical activity. However, overweight and obese individuals performed higher levels of SA after completing EMA surveys where they reported a sedentary behavior as their main activity. It is possible that the mere act of asking overweight and obese participants to self-report their current level of activity may compel them to persist at that behavior as has been suggested in previous work (Godin et al., 2008).

Another objective of this study was to test the criterion validity of participants' real-time self-reports of activity type. Results indicated that time-matched objective activity data (measured by accelerometer) corresponded with EMA self-reports of current activity levels. MVPA and SA in the ±15 min window surrounding each EMA prompt were greater for surveys reporting physical activity and sedentary behavior, respectively, than those reporting other types of behavior. These findings alleviate concerns that participants regularly provide untruthful, socially desirable responses; report activities that they have recently performed (instead of their current activity); or answer surveys haphazardly out of haste. Overall, these results provide evidence for the validity of real-time data capture techniques to measure physical activity and sedentary behaviors through self-report.

This study had a few limitations. First, the EMA protocol only monitored behavior on two weekend days and two weekdays (Monday and Tuesday). It is possible that the weekend selected or those particular weekdays are not representative of participants' usual daily lives. A longer monitoring period would be preferred but might introduce greater participant burden. Second, activity thresholds for sedentary behavior are not consistently defined in the literature. Different sedentary activity thresholds may yield different results. Third, the current main activity item did not distinguish between computer use performed for productive (i.e., related to paid work or household management) and leisure (e.g., social networking, Internet surfing, videos) purposes, which may be differentially targeted for intervention. Fourth, these EMA data do not indicate duration of activities. Also, not all physical activity and sedentary behavior was captured due to the random signal-contingent sampling procedure. The overall purpose of the EMA protocol was not to provide a measure of total physical activity and sedentary behavior during the monitoring period. Instead, the goal was to sample the occurrence of specific behaviors that can be linked to other time-intensive EMA measures such as mood and context. Lastly, the results may not be applicable to highly physically active individuals or those from high income households, or non-English speakers as they were excluded from the study.

Findings generally support the acceptability and validity of a 4-day signal-contingent EMA protocol using mobile phones to measure physical activity and sedentary behavior in adults. However, some MVPA may be missed among underweight and normal weight individuals.

ACKNOWLEDGMENTS

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Interactive multimodal ambulatory monitoring to investigate the association between physical activity and affect

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Although there is a wealth of evidence that physical activity has positive effects on psychological health, a large proportion of people are inactive. Data regarding counts, steps, and movement patterns are limited in their ability to explain why people remain inactive. We propose that multimodal ambulatory monitoring, which combines the assessment of physical activity with the assessment of psychological variables, helps to elucidate real world physical activity. Whereas physical activity can be monitored continuously, psychological variables can only be assessed at discrete intervals, such as every hour. Moreover, the assessment of psychological variables must be linked to the activity of interest. For example, if an *inactive and overweight person* is physically active once a week, psychological variables should be assessed during this episode. Linking the assessment of psychological variables to episodes of an activity of interest can be achieved with interactive monitoring. The primary aim of our interactive multimodal ambulatory monitoring approach was to intentionally increase the number of e-diary assessments during "active" episodes. We developed and tested an interactive monitoring algorithm that continuously monitors physical activity in everyday life. When predefined thresholds are surpassed, the algorithm triggers a signal for participants to answer questions in their electronic diary. Using data from 70 participants wearing an accelerative device for 24 h each, we found that our algorithm quadrupled the frequency of e-diary assessments during the activity episodes of interest compared to random sampling. Multimodal interactive ambulatory monitoring appears to be a promising approach to enhancing our understanding of real world physical activity and movement.

Keywords: ambulatory monitoring, e-diary, interactive assessment, physical activity

INTRODUCTION

Despite the positive effects of physical activity on health that have been demonstrated in the scientific literature (Healy et al., 2008; Physical Activity Guidelines Committee, 2008; Mead et al., 2009; Shiroma and Lee, 2010; Poole et al., 2011; Wichers et al., 2012) and despite that these positive effects are known to the community, a large number of people remain inactive compared to current guidelines (Haskell et al., 2007; Troiano et al., 2008). Unfortunately, data regarding counts, steps, and movement patterns have a limited ability to explain why people are inactive. To explain "inactive behavior," additional parameters must be taken into account such as motivational processes, habits, and/or affective states. Interestingly, a positive association between physical activity and affective states has been claimed for a long time (Schlicht, 1994; Arent et al., 2000; Netz et al., 2005). However, the methodological quality of these studies is mixed.

In the following, we will report on methodological considerations how to assess the relation between physical activity and affective states, emphasizing (a) objective assessment of physical activity, (b) assessment in real life, and (c) problems of different time courses when using multimodal assessment. All these considerations sum up in our recommendation to use interactive multimodal ambulatory assessment. After this introduction, we will report (a) how we developed the interactive assessment approach and (b) how it was validated. Specifically, we will report how we tested our primary aim of the interactive multimodal ambulatory monitoring approach, namely to intentionally increase the number of e-diary assessments during rare "active" episodes. We will conclude the paper with limitations and future prospects.

SELF-REPORTS VS. OBJECTIVE ASSESSMENTS

Multiple studies, investigating the effects of physical activity on physiological and psychological health, have been criticized for using self-reports to measure physical activity. For example, Shiroma and Lee (2010) summarizing 34 prospective studies with approximately 500,000 subjects in a review article state in their limitation section that most available data comes from observational studies with self-reported physical activity. This method might be limited in precision, and they further highlight that motion sensors (e.g., accelerometers) allow for physical activity and sedentary behavior in free-living populations to be assessed with greater accuracy and precision. Similar arguments have been made by Haskell et al. (2007), Schwerdtfeger et al. (2008), Poole et al. (2011), Wichers et al. (2012).

This methodological concern has been confirmed by two systematic reviews (Prince et al., 2008; Adamo et al., 2009) showing substantial discrepancies and only moderate correlations between objective assessments of physical activity and subjective reports of physical activity. Prince et al. (2008) compared subjectively (self-reported; e.g., questionnaire, diary) and objectively (directly measured; mostly accelerometry) assessed physical activity in adults. An analysis of 187 studies revealed only low-to-moderate correlations between self-reported and direct measures, with a mean of 0.37 (SD = 0.25; range −0.71 to 0.98). Similarly, in a systematic review on physical activity in children (83 studies), Adamo et al. (2009) found low-to-moderate associations (−0.56 to 0.89) between indirect and direct measures. Consequently, Adamo et al. (2009) and Prince et al. (2008) question the widespread approach of justifying the use of the more cost-effective self-report methods through correlations between indirect and direct measures.

In addition, there is considerable variability in study findings regarding the fulfillment of physical activity guidelines, especially when using different assessment methods (Reilly et al., 2008). Whereas national surveillance of pediatric physical activity in the UK showed that public health exercise-related targets were being exceeded by over 75% (e.g., in the Scottish Health Survey 2003) using subjective (parental) reports of physical activity, comparable UK studies using accelerometry as a measure of physical activity revealed that less than 5% of children and adolescents were meeting the target of 60 min of moderate-to-vigorous physical activity per day (Reilly et al., 2008). Using objective data obtained with accelerometers from a representative sample of the U.S. population (6329 participants), Troiano et al. (2008) reported that only 8% of adolescents achieved the recommended 60 min/day of physical activity, whereas among adults, adherence to the recommendation to obtain 30 min/day of physical activity was less than 5%.

Neither systematic review (Prince et al., 2008; Adamo et al., 2009) nor studies on the fulfillment of physical activity guidelines, support the "quick-and-dirty" retrospective questionnaire approach; instead, they indicate that actual physical activity is not accurately assessed by subjective self-reports. However, it has to be mentioned that retrospective questionnaire approaches in epidemiology show consistently negative relations between amount of physical activity and cardiovascular diseases or diabetes. Clearly, retrospective questionnaire approaches might be less accurate, but they still show some kind of validity.

MONITORING IN EVERYDAY LIFE

In addition to using objective and multimodal monitoring methods, the investigation of physical activity in everyday life has clear benefits due to the distinction between performance and capacity: "*Performance is about what people do in their daily life . . . and capacity is about what people can do in an optimal environment . . .*" (Bussmann and Ebner-Priemer, 2011). As the literature has shown, the relationship between capacity and performance parameters is generally weak or absent. Therefore, behavior cannot be predicted from capacity tests, and direct measurements of performance are necessary to obtain insight into what people do in their daily life (Bussmann and Ebner-Priemer, 2011). However, there is also a downside to studying everyday life. Compared to a laboratory, the setting and behavior in everyday life cannot be controlled. Isolation of stimuli, manipulation of independent variables, rigorous control of extraneous variables and control of measurement errors are clearly difficult if not impossible (Fahrenberg, 1996). This is especially problematic when the phenomenon of interest is rare in everyday life. Taking into account that many people are too inactive in everyday life, the ability to investigate relationships between physical activity and psychological variables such as affective state is limited. From a statistical point of view, a minimal number (or variance) of active episodes is required to obtain a correlation.

MULTIMODAL MONITORING: THE PROBLEM OF DIFFERENT TIME COURSES WHEN COMBINING THE ASSESSMENT OF PHYSICAL ACTIVITY AND AFFECTIVE STATES

More recent studies have used activity monitors and electronic diaries in assessing the relation between physical activity and mood (Schwerdtfeger et al., 2008; Kanning et al., 2012; Wichers et al., 2012). For example, Schwerdtfeger et al. (2008) used accelerometers and electronic diaries to investigate the association between physical activity and affective states prospectively. Mixed model analyses revealed a significant association between energetic arousal/positive affect and preceding physical activity. However, no relation between physical activity and negative affect was found. Similar findings have been reported by Wichers et al. (2012), who investigated the time-lagged association between daily life physical activity and affect using paper-pencil diaries. Their analysis revealed a significant increase in positive affect following a reported increase in physical activity. However, they did not find an effect of physical activity on negative affect. Kanning et al. (2012) investigated the relationship between actual physical activity and affective states in 44 university students using 24-h accelerometry and electronic diaries. Multilevel analyses showed that physical activity prospectively predicted valence and calmness. The more the subjects were physically active during the preceding 10 min, the more they felt well and satisfied (valence domain), but they also felt agitated and tense (calmness domain). This unexpected discrepancy, between people reporting being more agitated and tense and the findings reported above that physical activity had no effect on negative affect (Schwerdtfeger et al., 2008; Wichers et al., 2012), might be explained by different time courses of the variables of interest.

This idea can be explained with a very simple example. Imagine a very overweight person who had been inactive for a long period over time. After advice from his/her physician, this person starts performing some kind of sport, e.g., running. He might feel uncomfortable, ridiculous, and ashamed while running the first time after a long period. However, he also might feel proud, relieved, and positively exhausted half an hour after having performed running. Similar examples can be found in a variety of situations, e.g., running during bad weather, running when someone is tired, and getting up very early to do sports. The underlying idea is that the time courses of physical activity, positive and negative affective states might not be parallel but may be shifted. Therefore, we propose that multimodal monitoring, in which physical activity and movement are assessed in conjunction with psychological variables and the specific context of the activity and movement, might be necessary to understand real world physical activity and movement. An initial validation of the idea of shifted time courses has been reported by Schwerdtfeger et al. (2010). They took a closer look at the temporal relation between affective states and physical activity. They reanalyzed 12-h ambulatory monitoring data from 124 healthy volunteers from a previously published dataset (Schwerdtfeger et al., 2008). Multilevel analyses revealed that negative affective states were not related to an increase in physical activity in the following 1 or 5 min. However, later on, significant effects of negative affective states on physical activity were detected (15 and 30 min after the affective state assessment).

DEVELOPING THE INTERACTIVE ASSESSMENT APPROACH

INTERACTIVE MULTIMODAL AMBULATORY MONITORING: METHODOLOGICAL CONSIDERATIONS

In summary, to understand the relationships between actual physical activity and affective states, a multimodal monitoring of everyday life using objective and real-time methods seems to be advantageous. Unfortunately, assessing psychological variables and context in everyday life can be difficult. Whereas physical activity can be monitored continuously with a high sampling frequency, psychological variables can only be assessed in discrete intervals such as every 30 min or every hour. Even more daunting, the assessment of psychological variables must be linked temporally to the physical phenomena of interest and not be purely random. Considering our example of the "inactive and overweight person" who might be physically active twice a month, the psychological variables should be assessed during or immediately after this active episode to obtain some variance in physical activity and thereby enable some kind of correlation.

This issue is explained in greater detail in **Figure 1**. **Figure 1A** depicts a hypothetical relationship between physical activity and affective state. It is assumed to be a positive correlation, showing increasing affective state values with increasing physical activity. **Figure 1B** shows empirical data. Physical activity was assessed in 70 undergraduate students from a German university (University of Stuttgart; the 70 students are a subsample of the data reported in Kanning et al., 2012; informed consent and institutional ethical approval were obtained). Physical activity was measured continuously for 24 h using a three-way accelerometer (varioport-E; Becker Meditech, Germany), which was attached at the participant's hip. Acceleration, measured in milli-g (mg), was separated offline into AC and DC components by an Finite Impulse Response (FIR) digital filter with a cut-off frequency at 0.5 Hz. The raw signal, DC-values, and rectified AC-values were averaged across data points for each minute for the 24 h. All offline analyses and artifact checks were performed by the interactive software package "Freiburg Monitoring System" according to a published procedure (Myrtek, 2004). Rectified AC-values of the three channels were aggregated for 10-min episodes. The frequencies of these 10-min episodes are shown in **Figure 1B** (with sleeping time being excluded beforehand). The x-axis unit is mg. For comparison, jogging episodes entail about 1000 mg/min, walking episodes about 350 mg/min, and pure sitting episodes about 10 mg/min. Note that the x-axis intervals increase from 10 to 50 mg intervals after 500 mg/min for graphical reasons. What is evident from **Figure 1B** is that episodes of high physical activity are rare in this sample. This finding is not surprising in light of the complaints regarding low levels of physical activity in the general population (Haskell et al., 2007; Reilly et al., 2008; Troiano et al., 2008). The underlying problem becomes apparent when combining the hypothetical relation (**Figure 1A**) with the empirical data (**Figure 1B**) as in **Figure 1C**. When assessing affective states purely randomly over the day, the chance of obtaining affective states data during an episode of high physical activity is decidedly small. For example, in **Figure 1B**, the chance of having an episode above 350 mg (≈ 10 min of pure walking during a 10-min episode) is less than 3%. A relation between physical activity and affective state (or a reduction of negative affective state due to physical activity) might well remain undetected in the statistical analysis purely due to the low number of episodes with high physical activity.

Solving this problem is possible by changing the affective state assessment strategy from a random or fixed (e.g., hourly) mode to an interactive assessment mode. This approach is depicted in **Figure 2**. **Figure 2A** shows a time course over 24 h of physical activity (moving average over 10 min) in one subject. Over the day,

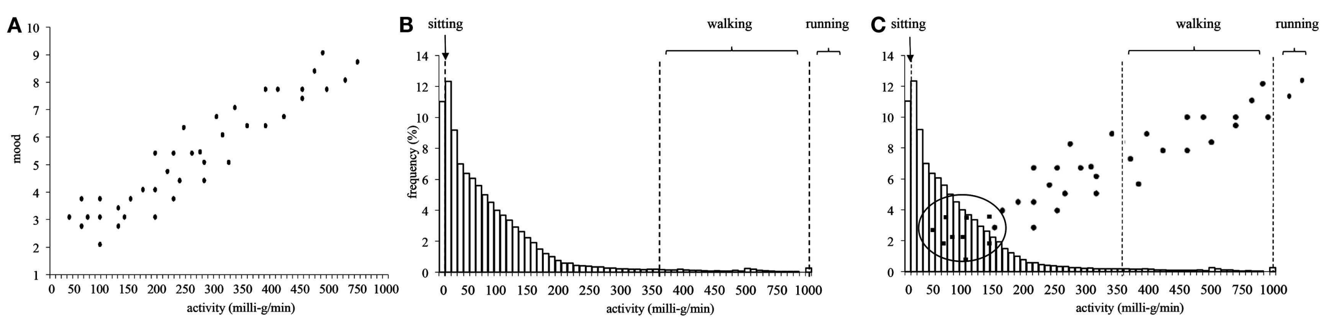

FIGURE 1 | (A) Hypothetical data showing a positive relation between physical activity and affective state; **(B)** frequencies of physical activity (70 students, 24 h) aggregated over 10-min episodes. Please note: X-axis intervals increase from 10 to 50 mg intervals after 500 mg/min for graphical reasons; **(C)** combination of the hypothetical and empirical data.

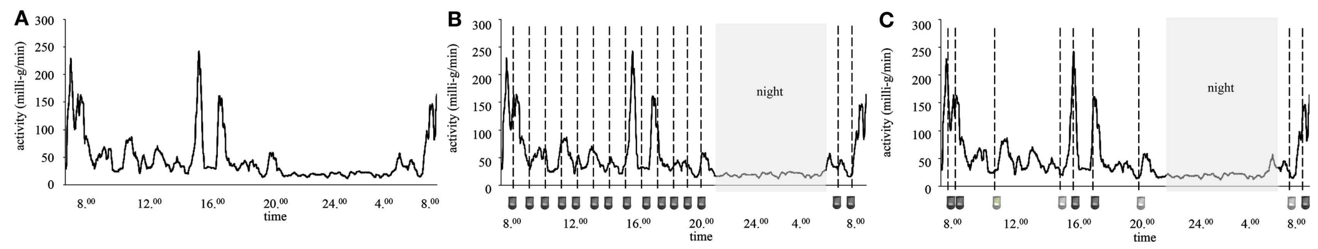

FIGURE 2 | (A) Time course over 24 h of physical activity (10 min moving average) in a single subject; **(B)** combined with a fixed e-diary assessment, or **(C)** combined with an interactive e-diary assessment.

there are several peaks of physical activity. During the night, the physical activity is low. An hourly assessment of affective states, as illustrated in **Figure 2B**, would coincide with some peaks of physical activity but would miss others. From a statistical point of view, maximization of the variance is favored. In our example, this would mean obtaining e-diary assessments of the affective state for several episodes of high physical activity as well as for episodes of low physical activity (see **Figure 2C**). This can be achieved with an interactive monitoring approach. In interactive monitoring, the phenomenon of interest (in our case physical activity, or more technically acceleration) is monitored continuously and analyzed continuously in real-time during everyday life. Interesting episodes are detected in real-time and are used as triggers for the assessment of psychological variables and contextual information. This results in the intentional oversampling of e-diary assessments that are related to episodes with high physical activity compared to the natural occurrence of these episodes. We developed an algorithm that continuously monitors physical activity in everyday life and triggers e-diary assessments when predefined thresholds are surpassed.

THE INTERACTIVE ALGORITHM

The idea of interactive monitoring is not entirely new, as Myrtek (2004) has developed and worked with this methodology. He used interactive monitoring with real-time analysis of physical activity and physiological signals to detect emotional and physical influences on physiological processes, so called additional heart rate. In short, he monitored heart rate and physical activity in daily life and separated out in real-time heart rate increases caused by physical activity. Any remaining additional heart rate increase was assumed to indicate momentary emotional activation or mental load. The recorder/analyzer was programmed to trigger a handheld PC, which in turn signals the participant to self-report on momentary activity, the situation, and their emotions. This occurs when the additional heart rate exceeds a certain threshold. Control periods were obtained by using randomly interspersed trigger signals. The algorithm was used and validated in a series of studies based on many different samples and around 1,300 participants (Myrtek, 2004). Unfortunately, applications of interactive monitoring in everyday life are, aside from Myrtek, still extremely rare. As we used the methodology of Myrtek in an earlier study (Ebner, 2004; Ebner-Priemer et al., 2007) and intensively tested Myrtek's algorithm (Ebner, 2004), the interactive algorithm proposed in this paper is strongly influenced by Myrtek's work.

Hardware

To our knowledge, commercial devices that offer the additional possibility of online analysis, and are therefore known as recorder-analyzer systems, are extremely rare. Ebner-Priemer and Kubiak (2007) list three different systems that support interactive monitoring: the varioport-B, the varioport-E (both from Becker Meditec, Karlsruhe, Germany), and the g.MOBIlab (g.tec, Graz, Austria). MATLAB, C, and Simulink can be used for g.MOBIlab, and the programming language SPIL can be used for the vitaport/varioport family. We selected the varioport-E because of his minimal size and its good cost-benefit ratio. The varioport is a modular, multi-purpose device that can be flexibly adapted to a range of research questions. The varioport-E has an integrated three-dimensional accelerative sensor (ADXL330) and is capable of measuring one additional physiological signal (such as ECG). Because up to now the varioport-E has not been used to investigate the relationship between physical activity and affective states, we initially screened the validity of the varioport-E. We tested three different accelerative devices on a commercial treadmill (Life Fitness 95T Inspire). Two varioport-Es were fixed on the hip (left and right), one actiheart®monitor (Firmware H90.65; Camntech, Cambridge, UK) was attached to the chest, and one Actigraph (GT1M Firmware 7.5.0; The Actigraph, Pensacola, FL, USA) was fixed on the left hip with a belt. Six subjects ran at five different speeds (0, 4.6, 9.2, 13.8, 19.4 km/h) for at least 60 s (only 30 s for the 19.4 km/h). For the actigraph, the two channels were aggregated. For the varioport, all three channels were aggregated.

Whereas both varioport-Es indicated increasing values for the increasing speeds, both of the other devices showed ceiling effects at the higher speeds as shown in **Figure 3**. [varioport-Es: 0 km/h = 22/23 mg; 4.6 km/h = 490/503 mg; 9.2 km/h = 1415/1459 mg; 13.8 km/h = 1893/1984 mg; 19.4 km/h = 2382/2523 mg; actiheart®: 0 km/h = 0 counts; 4.6 km/h = 133 counts; 9.2 km/h = 663 counts; 13.8 km/h = 761 counts; 19.4 km/h = 781 counts; Actigraph GT1M: 0 km/h = 2 counts; 4.6 km/h = 526 counts; 9.2 km/h = 1307 counts; 13.8 km/h = 1386 counts; 19.4 km/h = 1158 counts). Accordingly the (pooled) within-subject correlation between speed and physical activity (mg; counts) was descriptively higher for both varioport-Es ($r = 0.99$; $r = 0.98$) compared to the actiheart® ($r = 0.91$) and the Actigraph GT1M ($r = 0.81$).

Adaptive thresholds

Two basic components were adopted from the algorithm developed by Myrtek. (1) Three events were defined as triggers for

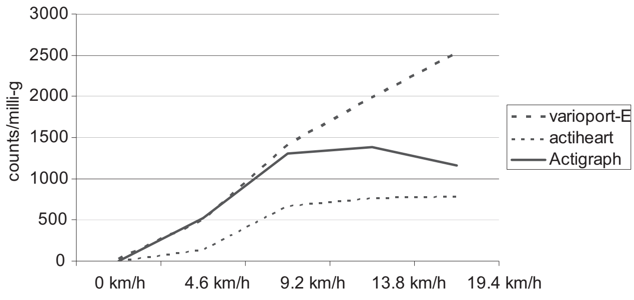

FIGURE 3 | Ceiling effects of actiheart® and actigraph in comparison to varioport-E by increasing running speeds.

the electronic diary: (I) an activity threshold, (II) an inactivity threshold, and (III) a time-limit threshold. (2) The thresholds were defined to be adaptive: in cases of low physical activity across the whole assessment period (≈ very inactive subject), both the activity threshold and the inactivity threshold decrease from one e-diary assessment to the next. This was done to obtain e-diary assessments during the most active and the least active episodes in each individual independently of the absolute amount of activity. The same procedure was used for very active people. If too many episodes of activity are detected, the thresholds for activity episodes and inactivity episodes increase to obtain e-diary assessments during the most active and the least active episodes in each individual.

Basic decisions

Before programming the algorithm for detecting the interesting episodes of physical activity in everyday life, a few decisions had to be made. First, thresholds for both activity episodes and non-activity episodes had to be set. Such a decision can be made (a) theoretically, e.g., based on findings regarding what amount of physical activity leads to acute changes in physiology or affective states; (b) empirically, e.g., according to the usual frequency of activity episodes in everyday life; or (c) from a time-based-design perspective. In electronic diary research, the time-based design is a crucial part of the research design. The time-based design is defined by the number of assessment points, the intervals between assessment points, and the total length of the assessment period (Ebner-Priemer and Sawitzki, 2007). The thresholds were defined using a combination of theoretical, empirical, and time-based-design considerations. First, we assumed that relatively short time frames would be most suitable for analyzing the effects of actual activities of daily life, which are mostly performed in short time periods. Schwerdtfeger et al. (2008) compared the correlation between physical activity and affective states using three different time frames (1, 5, 15 min). The correlation between 15-min averages of physical activity and affective states was higher compared to those of the 1- or 5-min averages. With the idea of integrating actual physical activities of everyday life instead of only athletic activities, this finding, in combination with the guideline that being physically active for a minimum of 10 min leads to health benefits (Haskell et al., 2007), led us to work with episodes of physical activity 10 min in duration. To obtain a minimum number of e-diary assessments per day, we set the number of assessments to 10. We excluded diary assessments during the night (sleeping time: 21.00–8.00). Given a minimum of 10 assessments per 13 daytime hours, we limited the time interval between e-diary assessments to a minimum of 40 min and a maximum of 100 min. This means that after an e-diary assessment, there will be no further e-diary assessment for the next 40 min regardless of any activity. If the algorithm is not able to detect an activity or inactivity episode between 40 and 99 min after the last e-diary assessment, the next e-diary assessment will be triggered at minute 100 (=time-limit threshold). Furthermore, we set the rate for activity/inactivity episodes to 1:1.

Deriving the thresholds from empirical data

We reanalyzed a subsample of 50 healthy subjects from a previously published study (Ebner-Priemer et al., 2007; informed consent and ethical approval were obtained). In this dataset, all participants underwent 24-h ambulatory monitoring of physical activity and ECG. Additionally, an individual reference pattern standard protocol with a fixed sequence of postures and movements (sitting upright, sitting while leaning forward, sitting while leaning backward, standing, lying back, lying on the right side, lying on the left side, walking) was recorded. Subsequently, multivariate within-subjects analyses and pattern similarity coefficients were used for the detection and labeling of an actual segment; that is, a hierarchical strategy was applied that classifies postures and subsequently uses reference patterns to discriminate between subsets of activities (Fahrenberg et al., 1997). Subjects carried a portable Vitaport II physiological digital recorder (Becker Engineering, Karlsruhe, Germany) and a palmtop computer (Psion 3 a, London, UK) for 24 h in their everyday lives. Physical activity was sampled at 32 Hz by two accelerative three-dimensional sensors placed on the chest below the clavicle and on the thigh above the knee. Rectified AC-values from the three acceleration channels at the chest were aggregated for 1-min episodes.

To derive a threshold for activity and inactivity episodes, we used the above-mentioned data set, excluded the night, and searched for the intensity of episodes 10 min in duration (moving average over 1-min segments) with a frequency of at least five per 24 h. This resulted in a cut-off value of 220 mg/min. Given the finding that walking is (on average) about 350 mg, a cut-off threshold of 220 mg would mean that subjects during such an episode walked at least 6 min during the past 10 min, which seems feasible for an everyday life approach. As we obtained a high number of inactivity episodes during everyday life in our dataset, we set the inactivity threshold to 10 mg/min, which is equivalent to the acceleration of sitting (on average). In sum, the constituent parts of the algorithm are as follows.

- (adaptive) threshold for activity episode: >220 mg (10 min moving average)
- (adaptive) threshold for inactivity episode: <10 mg (10 min moving average)
- aimed rate for activity/inactivity episodes: 1:1
- minimum and maximum time interval between e-diary assessments: 40–100 min
- sleeping time: 21.00–8.0

The program

The algorithm was programmed in SPIL for varioport and basically does the following:

(1) Calculates global activity (raw data for each axes, sampled at 32 Hz, were converted into mg, high pass filtered (>0.1 Hz), rectified, and smoothed by a moving average of 1 Hz. The three channels were aggregated using vector addition).
(2) Aggregates the signal over time from 32 Hz to 10-min segments (moving averages).
(3) Sends triggers for the e-diary when (a) the threshold for activity is surpassed, it is not sleeping time, and the last trigger was sent during the last 40 to 100 min, when (b) the threshold for inactivity was reached, it is not sleeping time, and the last trigger was sent during the last 40–100 min, or when (c) the last trigger was sent 100 min ago.
(4) The frequency of triggers is stored, and the ratio between inactivity and activity episode-based triggers is calculated. If there have been at least six triggers and the activity/inactivity trigger ratio is above 2.05, then the thresholds for activity and inactivity episodes are increased by 5% (which is decreasing the likelihood of upcoming activity episodes and increasing the likelihood of upcoming inactivity episodes). If there have been at least six triggers and the inactivity/inactivity trigger ratio is below 0.95, then the thresholds for activity and inactivity episodes are decreased by 5% (which is increasing the likelihood of upcoming activity episodes and decreasing the likelihood of upcoming inactivity episodes). If there have been at least six triggers and the current trigger is a time-limit trigger, then the threshold for activity episodes is decreased by 5% and the threshold for inactivity episodes is increased by 5% (which is increasing the likelihood of upcoming activity episodes and increasing the likelihood of upcoming inactivity episodes).

A VALIDATION STUDY OF THE INTERACTIVE ALGORITHM

We tested the algorithm offline in a dataset from 70 participants (which was described above; the 70 students were a subsample of the data reported in Kanning et al., 2012). Physical activity was measured continuously for 24 h using a three-way accelerometer (varioport-E; Becker Meditech, Germany), which was attached at the participant's hip. To analyze the effectiveness of the algorithm, we compared the frequency of episodes (10 min) above the selected activity threshold (>220 mg/min), between the selected activity and inactivity threshold (>10 and <220 mg/min), and below the selected inactivity threshold (<10 mg/min). A purely random sampling strategy for the e-diary assessment would trigger e-diary assessments in only 9.3% of episodes above the selected activity threshold of >220 mg/min and in 9.4% of episodes below the selected inactivity threshold of <10 mg/min. Thus, most triggers (81.3%) would be sent during mixed episodes (>10 and <220 mg/min; see also **Table 1**).

Using the proposed interactive sampling strategy, the frequency of e-diary assessments during episodes above the activity threshold of >220 mg/min quadrupled compared to a random e-diary sampling, resulting in a frequency of 38% (see also **Table 1**). Similar results were found for episodes below the selected inactivity threshold, the frequency of which increased to 30%. Accordingly, the frequency of mixed episodes (>10 and <220 mg/min) decreased from 81.3 to 32%. The results are shown in **Figure 4** in greater detail. The white bars represent a random e-diary assessment, whereas the gray bars represent interactive sampling. Note that both graphs in **Figure 4** show the same data. In the first graph, the random sampling is in the front, whereas in the second graph, the interactive sampling is in the front. Furthermore, note that the first bar of the interactive sampling was cut from 30 to 14% for graphical reasons. **Figure 4** shows the altered distribution of activity episodes during e-diary assessments. The frequency of inactivity episodes (according to our threshold) increased tremendously, the frequency of medium or mixed episodes between 10 and 220 mg/min decreased, whereas the frequency of episodes above our threshold of 220 mg/min increased. As the thresholds were adaptive, a low number of activity episodes in a subject led to a lowering of the activity threshold in this subject. Accordingly, the frequency of episodes just below 220 mg/min, especially between 180 and 210 mg/min, increased, as shown in **Figure 4**.

Table 1 | Percentage of episodes revealed by an random or interactive sampling separated into three categories: above the selected activity threshold, between the selected activity and inactivity threshold, and below the selected inactivity threshold (please note, that the upper line "random sampling" corresponds to the white bars in Figure 4 and the lower line "interactive sampling" to the gray bars).

	<10 mg/min (%)	>10 and <220 mg/min (%)	>220 mg/min (%)
Random sampling	9.4	81.3	9.3
Interactive sampling	30	32	38

CONCLUSION; LIMITATIONS AND FUTURE PROSPECTS

The primary aim of our interactive multimodal ambulatory monitoring approach was to intentionally increase the number of e-diary assessments during "active" episodes. This goal was achieved, as we quadrupled the frequency of e-diary assessments above the selected activity threshold compared to a random sampling approach. In other words, the proposed interactive algorithm provided an advantageous distribution that might be much better suited, compared to a random sampling, to revealing relationships between activity and affective states in everyday life. We propose that multimodal interactive ambulatory monitoring of everyday life behaviors seems to be a promising approach to enhancing our understanding of real world physical activity and movement.

Several limitations should be mentioned. First, the ability to improve the distribution is limited by the actual frequency of active episodes. For example, when assessing a bedfast patient, no algorithm will be able to find an actual active episode. Although our algorithm uses adaptive thresholds, which are not fixed to absolute values but look for the most active episodes in each subject, the algorithm will work only in people with at least some degree of activity. With "extremely sedentary" and bedfast patients, the algorithm does not provide any advantages.

We used a pragmatic approach to develop the proposed algorithm, making some basic assumptions and borrowing operational

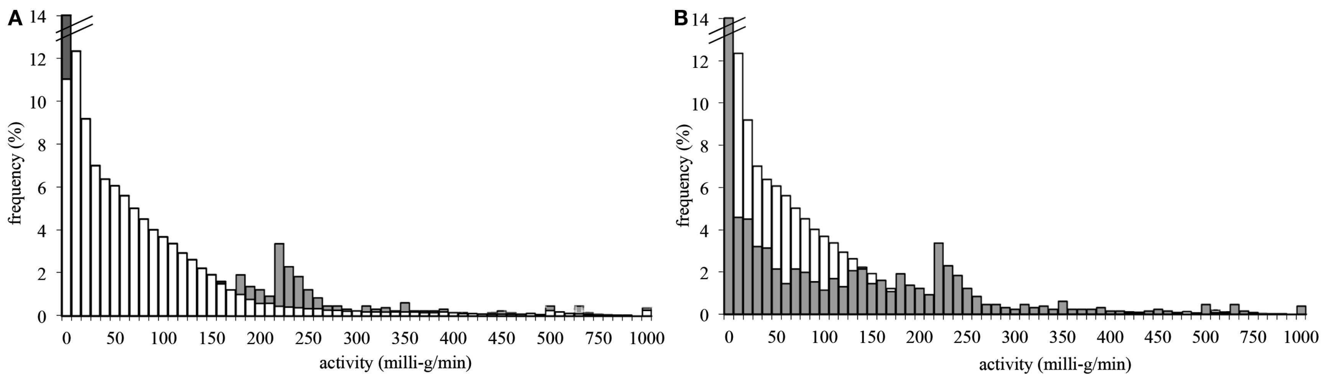

FIGURE 4 | Frequency of physical activity (70 students, 24 h) aggregated over 10-min episodes as revealed by random (white bars) or interactive (gray bars) e-diary assessment. Please note that both graphs show the same data. In the first graph **(A)**, the interactive sampling is in the back, whereas in the second graph **(B)**, the random sampling is in the back. Furthermore, *X*-axis intervals increase from 10 to 50 mg intervals after 500 mg/min for graphical reasons.

procedures from the additional heart rate algorithm developed by Myrtek (2004). We cannot rule out that other assumptions might work better for investigating relationships between physical activity and affective states. Favorable results might be achieved by changing (increasing or decreasing) the 10-min moving average time interval, the activity:inactivity rate of 1:1, or the activity and inactivity thresholds. Although our algorithm improved the distribution by quadrupling the number of episodes above our set activity threshold, further work is necessary. Another questions remains regarding the time sampling strategy. We assessed affect directly after a 10 min episode, if a certain threshold was exceeded. Another promising approach might be, to assess affect 5 min after terminating the physical activity episodes. This would answer questions regarding how participants feel after during physical activity and not during. Clearly, more studies are needed.

The most convincing evidence for the effectiveness of an interactive monitoring might seem to show "higher" correlations between physical activity and affect when using interactive monitoring compared to randomly distributed or fixed-interval assessments (such as every hour) in a single dataset. Unfortunately, showing both correlation on a single data set is not possible. The e-diary assessment has to follow one specific rule (interactive, random, or fixed), and results are based on this specific assessment rule. Therefore, it's not possible recording and analyzing a single dataset using different sampling strategies. Because of that, we focused on improving the distribution in our analysis, to show potential benefits of interactive assessments Future studies might randomize participants into two groups, one with interactive assessment and one with random/fixed assessment. This might enable to compare correlations between physical activity and affect using different sampling strategies.

The proposed interactive multimodal ambulatory monitoring procedure is not limited to investigating the relationship between physical activity and affective states. A similar argument can be made for movement abnormalities in everyday life. Balance problems detectible by movement monitoring can be caused by a certain physical condition or by uneven pavement. Real-time analysis of balance problems may trigger e-diaries. Assessing the context (for example, with a simple photograph of the pavement) can help to decide if a certain episode of movement abnormality should be attributed to a physical condition. Considerations regarding a real-time movement pattern classification system are also possible. If the software is unable to fit a special movement (e.g., bowling) to a fixed standard set of movement patterns because it is not yet part of the classification system, interactive monitoring with real-time classification might detect the unclassifiable pattern in real-time and ask the subject about the nature of his current activity. In a further step, the interactive monitoring system might even integrate this movement pattern into the individual classification system, allowing the completeness and accuracy of the movement classification to be continually improved.

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Using objective, real-time measures to investigate the effect of actual physical activity on affective states in everyday life differentiating the contexts of working and leisure time in a sample with students

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Multiple studies suggest that physical activity causes positive affective reactions and reduces depressive mood. However, studies and interventions focused mostly on structured activity programs, but rarely on actual physical activity (aPA) in daily life. Furthermore, they seldom account for the context in which the aPA occur (e.g., work, leisure). Using a prospective, real-time assessment design (ambulatory assessment), we investigated the effects of aPA on affective states (valence, energetic arousal, calmness) in real-time during everyday life while controlling for the context. Eighty-seven undergraduates students (Age: $M = 24.6$; $SD = 3.2$, females: 54%) participated in this study. aPA was assessed through accelerometers during 24-h. Palmtop devices prompted subjects approximately every 45 min during a 14-h daytime period to assess their affective states and the context. We analyzed within- and between-person effects with hierarchical modeling (HLM 6.0). Multilevel analyses revealed that both aPA and context influenced subsequent affective states. The interaction of aPA and context did predict energetic arousal only. State levels of affects did not differ between men and women. For both men and women, aPA in everyday life has an effect on individual's affective states. For valence and calmness, it seems to be independent of the context in which the aPA occur. For energetic arousal, men reported to have lower feelings of energy and women reported to have more feelings of energy during leisure time compared to working episodes.

Keywords: ambulatory assessment, context of working and leisure time, physical activity and well-being, affective reactions, physical activity in every day life

INTRODUCTION

Positive effects of regular, moderately intense physical activity on mental health has been presented in the literature several times, with small to medium effect-sizes (e.g., recent meta-analyses for positive and negative psychological states: Arent et al., 2000; Puetz et al., 2006; Reed and Ones, 2006; Reed and Buck, 2009). Independent of the impact of physical activity on mental health, to be physically active is a significant behavior to prevent non-communicable diseases (World Health Organization, 2002). Furthermore, positive affective reactions caused during and after a physical active episode will strengthen the maintenance of a regular active life style (Williams et al., 2008).

However, most of the studies that investigated the association between mental health and physical activity focused on structured activity programs only, but rarely on activities during everyday life. Physical activities during every day life include all possible activities in which people are ambulating, walking, do some gardening, or doing some kind of structured exercise for instance. Except of structured sport, those activities done in every day life are often processed automatically and they were performed spontaneously. We named those activities "actual physical activities" (aPA).

If not only structured activities but also activities that were done spontaneously in every day life have positive impacts on affective states, people may be able to regulate their mood in every day life. To encourage the potential effect of aPA on affect, it is important to know which moderators will have an important impact. A crucial moderator may be the context in which aPA takes place. Especially activities during daily routine are mostly embedded in different contexts, that is, the person is active at his or her working place, during leisure time or transport or he or she does some physically active household chores.

Up to now, it is unclear if aPA impacts affective states and whether this association depends on the context. It may be that the effect of aPA on affects is similar during working episodes or during leisure time, but evidence is missing, according to our knowledge. Information about the effects of aPA on affective states during daily routine within different contexts is worth to collect. It has often been shown that breaking times in sedentariness (Healy et al., 2008) or small amounts of moderate intense active episodes like Non-Exercise Activity Thermogenesis (NEAT Levine et al., 2005) have a substantial risk reducing impact on metabolic (e.g., diabetes type 2) and cardiovascular health (Wen et al., 2011).

Kanning and Schlicht (2010), as well as Schwerdtfeger et al. (2008, 2010) assessed affective states and aPA repeatedly during the day. Their results showed that affective states were significantly and positively associated with preceding aPA in every day life. However, the authors did not analyze any moderators that may influence the association in every day life, like the context in which subjects had been or sex differences.

To assess the associations between aPA, affective states, and the relevant context (working, leisure time, transport, chores) in real-time during every day life, we conducted an ambulatory assessment in which aPA was assessed by accelerometer and affective states and the context with electronic diaries.

We hypothesized that aPA in every day life as well as the context in which subjects had been have an impact on affective states. Especially, we were interested in the interaction between aPA and its context on affect. Therefore, we explored whether the context moderated the effect of aPA on affective states in everyday life. In addition, we analyzed sex differences. The meta-analyses about the effects of structured exercise on subjective well-being or affect did not report significant effect differences between men and women (e.g., Arent et al., 2000; Puetz et al., 2006; Reed and Ones, 2006; Reed and Buck, 2009). Thus, we hypothesized that the effect of aPA in every day life on affective states is not different between men and women.

MATERIALS AND METHODS

SUBJECTS

A convenience sample of 87 undergraduate students of sports science (47 females and 40 males) was recruited from a German university (M age = 24.6 years; SD = 3.2) in 2009. Before data recording, subjects were informed about the aim of our study. Following institutional ethical approval, subjects provided informed consent. Subjects received no monetary compensation for their participation.

AMBULATORY ASSESSMENT PROCEDURE

Actual physical activity was measured continuously using a three-way accelerometer (varioport-e; Becker Meditech, Germany) for 24 h. The varioport-e was started and then attached to each subjects's hip. Twenty-four hours later, subjects returned to the laboratory where data recording was stopped. Participants were allowed to take off the accelerometer when sleeping. Ratings for affect and context were assessed via electronic diaries (Palm, Tungsten E2). For this, the palmtop prompted subjects randomly about every 45 min during a defined 14-h daytime period (8:00 a.m. to 10:00 p.m.). If the person made no entry to the electronic diary, the palmtop beeped again 10 min later to remind the person to fill in the questionnaire. The assessment took always place on weekdays.

MEASURES

Affective state

To assess momentary affective state we applied a short scale with six items based on the Multidimensional Mood Questionnaire (MDMQ; Steyer et al., 1997), which has been explicitly developed and evaluated for use in ambulatory assessment (Wilhelm and Schoebi, 2007). The scale contains six items measuring the basic affective states *valence* (unwell vs. well), *calmness* (relaxed vs. tense), and *energetic arousal* (tired vs. awake) by two bipolar items for each subscale. Wilhelm and Schoebi (2007) assessed homogeneity for the between-person level and for the within-person level. The level-specific reliability coefficient reached for the between-person level 0.92 for *valence* and 0.90 for *energetic arousal*, and *calmness*. The reliability coefficient for the within-person level reached 0.70 for *valence* and *calmness* and 0.77 for *energetic arousal*, resulting both in satisfying internal consistency. Subjects indicated on a six-point scale the extent to which they were experiencing different affective states. Answers were given by moving a slider from the left (“0,” i.e., “discontent”) to the right (“5,” i.e., “content”) end of the bipolar scale. Scores for each subscale were obtained by summing item scores resulting in a range from “0” (low value) to “10” (high value). We changed the Likert scale of the original version because we wanted to have a scale with an even number to force the sample to decide between the two poles.

Context

Subjects chose one out of the four following categories on their electronic diaries to define the context in which they had been: *work*, *transport*, *chores*, or *leisure time*. Subjects were prompted 831 times (52%) during leisure activities and 366 times (23%) during their work. For our sample working episodes could be student-related work or maybe job-related work if they have a part-time job. Because we achieved only a small number of episodes for transport (14%) and even fewer for chores (8%), we only account for episodes of leisure time and student-related work in the analyses. Therewith, the analyses did not account for 386 (25%) measurement points in which participants neither indicated leisure time nor working episode. Accordingly, we created a dummy-coded indicator variable named *Leisure/Work* (LW) with *leisure time* coded “1” and *work* coded “0.”

Actual physical activity

The varioport-e measured acceleration (defined as change in velocity over time) and describes the intensity, the rate of occurrence, and the duration of an actual physically active episode. Acceleration was measured in milligrams, than separated offline into AC and DC components by a FIR digital filter with a cut-off frequency set to 0.5 Hz. Raw signal, DC-values, and rectified AC-values were averaged across data points for each minute in the 24-h period. All offline analyses and artifact-checks were performed by the interactive software package “Freiburg Monitoring System” according to a published procedure (Myrtek, 2004). In order to analyze lagged within-subject relations, we aggregated the preceding 10 min of aPA before each entry into the electronic diary.

DATA ANALYSES

We applied multilevel analyses using the statistical program HLM 6.0 (Raudenbush et al., 2004). Multilevel analyses were conducted separately for each affect subscale: *valence*, *energetic arousal*, and *calmness*. At first, we tested an unconditional model, where “y” is not modeled as a function of another variable at level-1 or level-2. Results from these three models revealed that the average levels of *valence*, *energetic arousal*, and *calmness* were $M = 5.2$, 4.4, and

5.1, respectively, which represented a daily affective state in the neutral range. The intra-class correlation was $\rho_I = 0.69$ for *valence*, $\rho_I = 0.45$ for *energetic arousal*, and $\rho_I = 0.65$ for *calmness*.

In the following step, we entered consecutively the predictor variables aPA and LW and the interaction of these two predictors aPA *x* LW into our model. After level-1 models were finalized, we analyzed how significant the level-1 intercept and the level-1 predictors vary as a function of *sex*. The level-2 predictor sex was entered in all level-2 equations. Thus, we examined for each subscale the relationship between the level-1 intercept and sex (Eq. 2) and the cross-level interaction between level-1 slopes and sex (Eqs 3–5).

$$\text{Level-1}: \; Y_{ti} = b_{0i} + b_{1i}(\text{aPA})_{ti} + b_{2i}\,(\text{LW})_{ti} + b_{3i}\,(\text{aPA}x\text{LW})_{ti} + r_{ti} \quad (1)$$

$$\text{Level-2}: \; b_{0i} = \gamma_{00}\,(\text{sex}) + \mu_{0i} \quad (2)$$

$$\text{Level-2}: \; b_{li} = \gamma_{10} + \gamma_{11}\,(\text{sex}) + \mu_{1i} \quad (3)$$

$$\text{Level-2}: \; b_{2i} = \gamma_{20} + \gamma_{21}\,(\text{sex}) + \mu_{2i} \quad (4)$$

$$\text{Level-2}: \; b_{3i} = \gamma_{30} + \gamma_{31}\,(\text{sex}) + \mu_{3i} \quad (5)$$

Level-1 represents within-subject effects. Equation 1 represents the subjects' response (subscript $_i$) given on one out of the three affect subscales (Y_{ti}) in any given diary entry (subscript $_t$). Y_{ti} is defined as the average intercept of one subscale across all subjects (b_{0i}) and three level-1 predictors aPA (b_{1i}aPA $_{ti}$), context (b_{2i}LW$_{ti}$) and the interaction between aPA and context (b_{3i}aPAxLW$_{ti}$). These predictors are group mean centered where group is referring to a person (level-2). Intercept and slopes are conceived as randomly varying. The random effect for the level-1 model is given by r_{ti}, *which* is assumed to be normally distributed with a mean of "0" and a variance of σ^2.

Level-2 expresses between-subject effects. It includes the fixed effects, γ, as the average intercepts and slopes across all persons, the predictor *sex*, and the random effects, μ_{0i}, μ_{1i}, μ_{2i}, and μ_{3i}. The random effects are assumed to be multivariate and normally distributed, both with expected values of "0."

Tests of the significance were conducted. The Alpha-level was defined as $p < 0.05$. Restricted maximum likelihood estimations were used for the multilevel analyses. Considering the nested structure of the model, effect size estimation was done with effective degrees of freedom. Formula 6 calculated the $N_{\text{effective}}$ of the model (Snijders and Bosker, 2011):

$$N_{\text{effective}} = \frac{Nn}{[1 + (n-1) * \rho_I]} \quad (6)$$

Nn indicates the number of measurement points, n stands for the average measurement points per person and ρ_I represents the intra-class coefficient of the mood-subscale of interest. Effective degrees of freedom are analyzed with $N_{\text{effective}}$ minus the number of predictors. We calculate effect size r, using t-values and effective degrees of freedom. According to Cohen (1992) an effect size r of 0.24 is in accordance $d = 0.5$ and represents a medium effect size.

RESULTS

Our sampling protocol generated a total of 1,583 data points belonging to 87 subjects resulting in approximately 19 e-diary entries per subject. All participants answered in any case to the six affects items, but during 39 assessments (2.5%) the participants didn't answer to the item of the context. During the 10 min preceding the e-diary entry, subjects did show aPA of 84.4 mg/min on average (range: 0.4–994.4 mg/min). For comparison, jogging episodes reveal about 1,000 mg/min., walking episodes about 350 mg/min., and pure sitting episodes about 10 mg/min. The average and SD of aPA at person level ranged from 28 to 188 mg/min (SD = 24–308 mg/min).

Variance components are displayed in **Table 1**. Random error terms of some slopes were not significant in all models. They had to be fixed because the random and the fixed variability of that slopes cannot be reliably separated. For *valence* and *calmness*, aPA had to be fixed. LW had to be fixed for *energetic arousal*. Furthermore, the interaction had to be fixed in all models. This implies that these coefficients may vary but they do not vary randomly as a function of *sex*.

As shown in **Table 2**, both the aPA and the dummy-coded indicator variable LW influenced affective states. aPA showed a positive effect on *valence* and *energetic arousal* and a negative effect on *calmness*. Therewith, the more our subjects were physically active, the more they subsequently reported feeling well (*valence*), full of energy (*energetic arousal*), and agitated [calmness (–)]. The effects were each large in effect-sizes $r = 0.36$, 0.52, and 0.29 standardized effects were 0.07, for 0.33 and −0.07 for *valence*, *energetic arousal*, and *calmness*, respectively. Thus if aPA increased by 1 unit, valence will increase and calmness will decrease by 0.07 and energetic arousal will increase by 0.33. Data analysis revealed a significant effect of LW on *valence* (positive), on *energetic arousal* (negative), and on *calmness* (positive).

Table 1 | Variance components of between-person effects are presented for intercepts and slopes.

Variance components between subjects	Variance estimate	SE	c^2 (df)	*p*-Value
MODEL 1: VALENCE				
Intercept (μ_{0i})	4.34	2.08	1963.04 (59)	<0.001
aPA slope (μ_{1i})	Fixed			
LW slope (μ_{2i})	0.36	0.60	85.64 (59)	0.013
Interaction slope (μ_{3i})	Fixed			
Level-1 (r_{ti})	2.00	1.42		
MODEL 2: ENERGETIC AROUSAL				
Intercept (μ_{0i})	2.81	1.67	1059.84 (82)	<0.001
aPA slope (μ_{1i})	0.00004	0.006	174.28 (82)	<0.001
LW slope (μ_{2i})	Fixed			
Interaction slope (μ_{3i})	Fixed			
Level-1 (r_{ti})	3.28	1.81		
MODEL 3: CALMNESS				
Intercept (μ_{0i})	3.94	1.98	1854.14 (59)	<0.001
aPA slope (μ_{1i})	Fixed			
LW slope (μ_{2i})	0.56	0.75	104.47 (59)	<0.001
Interaction slope (μ_{3i})	Fixed			
Level-1 (r_{ti})	1.96	1.40		

Table 2 | Within-subject fixed effects are presented for intercepts and slopes activities.

Within-subject fixed effects	Coefficient	SE	*t*-Value (df)	*p*-Value
MODEL 1: VALENCE				
Intercept (b_{0i})	5.30	0.23	23.94 (82)	<0.001
Sex	0.03	0.46	0.07 (82)	0.94
aPA slope (b_{1i})	0.002	0.0005	4.13 (1188)	<0.001
Sex	−0.0003	0.001	−0.35 (1188)	0.72
LW slope (b_{2i})	0.27	0.14	1.97 (82)	0.05
Sex	−0.42	0.28	−1.51 (82)	0.13
Interaction slope (b_{3i})	0.0005	0.002	0.34 (1188)	0.74
Sex	0.004	0.003	1.28 (1188)	0.20
MODEL 2: ENERGETIC AROUSAL				
Intercept (b_{0i})	4.26	0.19	22.65 (82)	<0.001
Sex	−0.35	0.39	−0.91 (82)	0.37
aPA slope (b_{1i})	0.008	0.001	8.39 (82)	<0.001
Sex	0.002	0.002	1.34 (82)	0.19
LW slope (b_{2i})	−0.39	0.15	−2.72 (1188)	0.007
Sex	0.15	0.29	0.52 (1188)	0.60
Interaction slope (b_{3i})	0.01	0.003	0.33 (1188)	0.74
Sex	0.01	0.005	2.63 (1188)	0.009
MODEL 3: CALMNESS				
Intercept (b_{0i})	5.20	0.22	23.56 (82)	<0.001
Sex	−0.04	0.44	−0.09 (82)	0.93
aPA slope (b_{1i})	−0.002	0.0005	−3.38 (1188)	0.001
Sex	0.0009	0.001	0.84 (1188)	0.40
LW slope (b_{2i})	0.57	0.15	3.83 (82)	<0.001
Sex	−0.55	0.30	−1.83 (82)	0.07
Interaction slope (b_{3i})	0.0002	0.002	0.18 (1188)	0.86
Sex	0.004	0.003	1.5 (1188)	0.13

Compared to working episodes, subjects reported during leisure time feeling more well (valence), feeling a greater sense of calm (*calmness*), and having less energy [*energetic arousal* (–)]. The effects of LW were moderate to large with effect-sizes $r = 0.18$ (standardized effect = 0.05) for *valence*, $r = 0.20$ (standardized effect = −0.07) for *energetic arousal*, and $r = 0.32$ (standardized effect: 0.1) for *calmness*, respectively. The interaction between aPA and LW did not show any significant effect on any affective state with $p =$ of 0.74, 0.74, 0.86 for *valence*, *energetic arousal*, and *calmness*, respectively.

To investigate sex differences we analyzed the effects of intercept and slopes of level-1 with the level-2 predictor *sex*. As shown in **Table 2**, *sex* is not significantly related to the main effects of the three subscales of affective states. But there is a significant effect of sex on the interaction term for the subscale *energetic arousal* ($r = 0.21$, standardized effect: −0.07). Because this finding based on a double interaction effect of a cross-level interaction between a level-2 predictor sex and an interaction term on level-1, we did sub-group analyses for both male and female sample to analyze between-person effects for this interaction. This sub-group analyses showed a significant interaction for both sex only for the subscale *energetic arousal* (for male: coefficient: −0.0078, $t_{(523)} = -2.37$, $p = 0.02$, $r = 0.28$, standardized effect = −0.08; for female: coefficient: 0.0074, $t_{(665)} = 2.52$, $p = 0.01$, $r = 0.25$, standardized effect = 0.09).

DISCUSSION

In our data set aPA as well as the context (working vs. leisure time) did significantly predict affective states. Our subjects reported feeling well, full of energy, but agitated the more they were physically active. The findings are mostly consistent with that of prior studies (e.g., Puetz et al., 2006; Reed and Ones, 2006). However, we revealed greater effect-sizes and that might be due to the fact that we assessed in real-time when the presumed effect actually occurs with objective methods. Kanning and Schlicht (2010) used also ambulatory assessment but they did not objectively assess aPA and they did not use electronic diaries.

In contrast to the study of Kanning and Schlicht, 2010 and for example Markowitz and Arent, 2010) our findings showed that activities in everyday life negatively affected *calmness*. We propose that these differing results are due to our ambulatory assessment. Our subjects did not expect when they were prompted and we had the chance to ask them while they were being physically active. Maybe the relaxing effects of physical activity appear only after some time delay when the acute physiological side-effects of physical activity have been vanished (cf. Kanning et al., 2012). Further studies are needed to analyze the association between physical activity and calmness with different time lags.

The context in which subjects were the 10 min before the e-diary prompt had also an impact on affective states. Compared to working episodes, subjects felt better and calmer during leisure time. This finding is viable because most often, leisure time represents activities aimed at enjoyment and social interaction. Those social objectives and states of feeling are associated with an enhanced subjective well-being (Argyle, 1999). Contrary to our expectations, *energetic arousal* was lower during leisure time in our data. Searching for an explanation, we found that several subjects chose the context leisure time while taking care of their hygiene or while eating (e.g., brushing one's teeth, having a meal). During such episodes, a person may not feel full of energy but could still feel well and calm.

The interaction between aPA and the context did reveal a significant impact only on the subscale energetic arousal. To clarify this effect, we did sub-group analyses: The interaction predicted a negative impact on feelings of energy (energetic arousal) for men and a positive impact on feelings of energy for women. Therewith, men reported to have lower feelings of energy during leisure time compared to student-related working episodes. In contrast, women reported to have more feelings of energy during leisure time compared to student-related working episodes. Furthermore, aPA did seem to have an impact on valence and calmness, independent of the context of work or leisure in which the students were physically active (c.f. Bucksch and Schlicht, 2006).

The last finding was in line with the result of the *Scottish Health Survey* (Hamer et al., 2009). This periodic survey included data from 19,842 individuals. The study examined the association of different types of self reported physical activity (chores, walking, sports) and psychological distress. The regression models showed that all types of activity were independently associated with a lower risk of distress. However, physical activity was not assessed objectively and distress was not assessed in real-time. Teychenne et al. (2008) reviewed the association between self reported physical activity and depression. They compared the effect of leisure time activities with a combination of leisure time and domestic activities (e.g., chores). Leisure time activities alone did show a stronger association with the risk of depression than the combination of leisure time and domestic activities, leading to the conclusion that the volume, not the type of activity, was positively associated with a lower likelihood of depression.

In contrast to these findings were the results of a cross-sectional study of 1,919 adults (Asztalos et al., 2009). The authors analyzed associations between different types of PA (e.g., sports participation, chores – but no occupational activities) and stress. The main outcome was that only participation in sports and no other types of PA was inversely associated with stress. Compared to the study presented here, these studies analyzed negative psychological states. They did not focus on positive affects. Further research is needed to clarify if physical activity in everyday life within different contexts has different effects on positive and negative psychological states.

Furthermore, the state level of *valence*, *energetic arousal*, and *calmness* did not vary between men and women. This finding seems to be incompatible with the fact that e.g., depression is more prevalent in women than men (Centers for Disease Control and Prevention, 2010). However, Diener et al. (1999), reported in their literature survey that men and women were approximately equal in global happiness. When differences were found they often disappeared when other demographic variables were controlled. Fujita et al. (1991) stated that sex accounted for less than 1% of the variance in happiness but over 13% of the variance in the intensity of emotional experience. Women seem to be more open to intense emotional experiences and they express more positive emotions than do men (Nolen-Hoeksema and Rusting, 1999). Thus, women may balance their higher negative effect, resulting in levels of affect similar to those of men.

Strength of the present study is that we used prospective, objective, real-time approach (ambulatory assessment). In most other studies, physical activity was assessed through retrospective self-reports. However, systematic reviews (Prince et al., 2008) have shown that subjective measures of physical activity (e.g., questionnaire, diary) do only correlate low to moderate to real objective measures of physical activity (mostly accelerometry). Similar criticism has been raised regarding the retrospective assessment of affective states, as the recall of affects is often based on biased storage and recollection of memories (Ebner-Priemer and Trull, 2009). Ambulatory assessment methodology has the potential to resolve both problems by investigating self-reports, physiology, or behavior in (nearly) real-time in everyday life using objective methods.

Despite this methodological strength, a number of limitations in our research warrant discussion. First of all, subjects were all students of sports science. They were not only younger, more educated, and generally qualified for university admissions, but the sample had predominantly a special kind of working episodes. Students-related work may be not similar to the working context of the majority of the population. Second, to reduce the time and effort required of the subjects in answering the e-diary questions, we assessed the context of the aPA with a single item, covering four possible contexts (work, transport, chores, leisure time). For some situations (e.g., brushing teeth) this might lead to problems in classification. Third, further moderators of aPA and affective states were not assessed (e.g., weight status). Fourth, the monitoring period of our study was only 1 day. Therewith, it is not possible to analyze within-person variations of aPA and affect across different days. In addition we only used the preceding 10 min before each e-diary assessment for the time-lagged analysis. Future studies might investigate the association between affective state and aPA by an interactive sampling strategy that automatically recognizes inactive and active episodes and subsequently triggers e-diary assessments.

CONCLUSION

The results of this study suggest that physically active episodes in a student's daily life, which could spontaneous or structured and planned has an effect on individual's affective states. The more male or female students were physically active, the more they felt well and full of energy. Surprisingly, they felt agitated, too. The findings for valence and calmness were independent of the context. So, there were no difference in feelings between the two conditions leisure time and working. Interestingly, the effect of the interaction differed between men and women for the subscale energetic arousal. Men reported to have lower and women reported to have more feelings of energy during leisure time compared to student-related working episodes. Further studies should analyze to what extent the context, in which aPA take place, had different effects on feelings of energy for men and for women.

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Physical activity and affect in elementary school children's daily lives

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A positive influence of physical activity (PA) on affect has been shown in numerous studies. However, this relationship has not yet been studied in the daily life of children. We present a part of the FLUX study that attempts to contribute to filling that gap. To this end, a proper way to measure PA and affect in the daily life of children is needed. In pre-studies of the FLUX study, we were able to show that affect can be measured in children with self-report items that are answered using smartphones. In the current article, we show that it is feasible to objectively measure children's PA with accelerometers for a period of several weeks and report descriptive information on the amount of activity of 51 children from 3rd and 4th grade. Additionally, we investigate the influence of daily PA on daily affect in children. Mixed effects models show no effect of PA on any of the four measured dimensions of affect. We discuss that this might be due to effects taking place at shorter time intervals, which can be investigated in future analyses.

Keywords: physical activity, accelerometry, affect, children, daily life, FLUX, smartphone

INTRODUCTION

Many people share the personal experience that physical activity (PA) can be an effective way to lift one's mood. Nevertheless, many people tend to lead a rather inactive, sedentary lifestyle. A recent large-scale survey among German children and youths revealed that only one out of about seven children meets the recommendation of the WHO to be physically active for at least 1 h per day (Krug et al., 2012). An association between PA and mental states has been confirmed in numerous studies. Physical inactivity has been shown to be associated with emotional problems (Kantomaa et al., 2008) and a higher risk for depressive and anxious mood in adolescents (Motl et al., 2004; Birkeland et al., 2009; Monshouwer et al., 2009; Jerstad et al., 2010; Rothon et al., 2010; Wiles et al., 2012). Accordingly, a longitudinal study indicated that PA can help to lift emotional problems in adolescent boys (Sagatun et al., 2007). Furthermore, not only the frequency but also the intensity of an activity has an effect on depressive and anxious affect with more vigorous activity being associated with reduced symptoms of depression and anxiety (Parfitt et al., 2009; Poole et al., 2011; Mata et al., 2012). In a recent meta-analysis, a beneficial effect of PA on mental health has also been shown for children (Ahn and Fedewa, 2011). Taken together, these studies support the notion that being physically active can yield an important contribution to psychological health and well-being. There are, however, some aspects that existing studies did not illuminate so far.

First, a major limitation of many studies is the focus on clinical samples and hence negative emotions. Oftentimes, studies investigate in how far PA can reduce symptoms of, for example, depression. How PA and affect are related in healthy subjects is studied less often. Second, many studies investigating the relationship between PA and affect are intervention studies. This means that subjects are required to do some sort of physical exercise, before and after which their affect is measured. If affect improves between the measurements, this effect is attributed to the exercise. In principle, this is a valid and sensible way to assess the influence of exercise on affect. The conclusions that can be drawn from it are, however, limited to conclusions about the influence of invoked exercise on affect. Whether everyday PA has an influence on everyday affect cannot be investigated (cf. Kanning et al., 2012). An approach that makes it possible to answer those two questions at once are intensive longitudinal studies. By measuring subjects repeatedly over a period of time, conclusions can be drawn about relationships between PA and affect within subjects and about the extent to which those effects differ between subjects. Furthermore, longitudinal studies are usually not designed as intervention studies, but rather measure habitual PA of subjects. Habitual PA must then, however, be reliably measured, which is not an issue in intervention studies. In many longitudinal studies, habitual PA is self-reported by the subjects. It has been shown that self-report measures of PA are not very reliable, especially when done retrospectively (e.g., Ebner-Priemer et al., 2006; Baumeister et al., 2007; Bussmann et al., 2009). In part, this is due to the fact that participants are more likely to answer questions regarding their PA, the more active they are (Dunton et al., 2012).

All of these problems have been stated before and attempts have been made to resolve them (e.g., Kanning and Schlicht, 2010; Kanning et al., 2012; Wichers et al., 2012). One successful approach was to let subjects fill out diaries right after self-induced activities over a prolonged period of time. This made it possible to assess effects within each subject and in their everyday lives. Results often showed that PA also had a positive effect on affect within single subjects (e.g., Kanning and Schlicht, 2010; Wichers et al., 2012). By not relying on retrospectively given information on PA, problems with self-report measures could presumably be reduced, but not completely avoided, in those studies. It is still left to the subject to judge what is considered PA. Clearly, it is desirable to measure PA without the need for self-reports from subjects. Advances in technological development make objective measures of PA a feasible alternative (for an overview of objective activity measurement techniques, see Bussmann et al., 2009; Bussmann and Ebner-Priemer, 2011; Butte et al., 2012).

Most studies fulfilling the above requirements—leaving the problems with subjective measurements of PA aside—are done with adults or adolescents (e.g., Kanning and Schlicht, 2010; Kanning et al., 2012; Wichers et al., 2012). Whether, and to what extent, relationships between PA and affect can be found in everyday life of children is not yet clear. We tried to close this gap, while at the same time avoiding the discussed methodological issues of previous studies. For that, our study needed to fulfill certain criteria. These demands are also stated and discussed in depth in the theoretical work by Kanning et al. (2013). First, we wanted to study the relationship between PA and affect in a group of healthy children. Second, these relationships should be investigated in the everyday life of children, without any intervention on PA. Third, we also wanted to investigate within-person effects. Thus, subjects had to be assessed repeatedly over a prolonged period of time. Finally, we wanted to measure PA objectively and not rely on self-report measures. As a result, bearing restrictions of generalizability in mind, our study should also yield information about the typical PA behavior of children in their everyday lives.

In sum, the current article has three main goals. The first goal is to establish the feasibility of measuring PA in the daily life of children over a period of several weeks. Obstacles to this are to be found on several levels. On the technical level, an objective method must be applied that can reliably measure children's PA. This method has to take specific demands of children's way of moving into account. For example, courses of movement tend to vary more between children than they do between adults, and children's activities are characterized by short bouts of movement (Bailey et al., 1995; Berman et al., 1998; Baquet et al., 2007; Corder et al., 2008). The second goal is to contribute to the description of PA of elementary school children in Germany. In order to do so, we consider average durations of PA per day, as well as differences in activity between children. The third goal is to investigate within-person relationships between children's PA and their affect on a day-to-day basis. Previous research indicates that the effect of PA on affect depends on the affect dimension used. For example, Wichers et al. (2012) found that PA positively influences positive affect, but does not influence negative affect. Therefore, to be able to thoroughly investigate the effect of PA on affect, we consider it very important to measure different dimensions of affect. To the best of our knowledge, to date there is no comparable study with children that would allow to formulate specific expectations about which affect dimensions PA would influence in children. Therefore, our investigation has to be considered exploratory.

MATERIALS AND METHODS

FLUX STUDY

The current study was part of the FLUX (Assessment of Cognitive Performance FLUctuations in the School ConteXt) study, which aims at investigating daily fluctuations in children's cognitive performance in the school context. One-hundred and ten children received smartphones on which they worked on working memory tasks and answered self-report questionnaires several times a day for 4 weeks. Additionally, 82 of these children received accelerometers to wear for the time of the study. This way, mutual relationships between working memory performance, self-report measures such as affect and motivation, and PA can be assessed in real life conditions. The study was approved by the ethics committee of the Goethe-University in Frankfurt, Germany. For their participation, subjects received a reward in the form of money or a gift coupon.

SUB-SAMPLE

In the beginning of the FLUX study, a sample of 82 children (45% girls) received accelerometers to measure their PA. The children were in third or fourth grade, with their age ranging from 97 to 132 months ($M = 117.2$, $SD = 7.4$ months). In total, there were three third grade and three fourth grade classes. The average size of the classes was 22.3 ($SD = 1.4$). On average, the children weighed 34.4 kg ($SD = 6.5$ kg), were 139.7 cm tall ($SD = 6.5$ cm) and had an average *Body-Mass-Index* (BMI) of 17.5 ($SD = 2.6$).

MEASURING PHYSICAL ACTIVITY

Accelerometer

Acceleration was measured with the ActiGraph GT3X+ (ActiGraph, LLC, Fort Walton Beach, FL). The GT3X+ is a triaxial accelerometer that measures acceleration in a range from −6 to +6 g. As it is usual for children, the devices were worn on the waist (Strath et al., 2012). The sampling rate was set to 30 Hz. This sampling rate is sufficiently precise for measuring PA while not producing too much data to be stored on the devices when recording for more than a week.

Reference measurements

Acceleration data were analyzed using *reference-pattern-based classification* (e.g., Foerster and Fahrenberg, 2000). This method is based on the idea that each individual moves in a unique way. This means that the same activity will produce different acceleration data when done by different persons. To correctly classify individual acceleration data into activity categories, individual datasets are required for which it is exactly known which acceleration data corresponds to which activity. Such datasets can be acquired in reference measurements, based on a pre-defined protocol of activities. They can then be used to categorize data as representing a certain activity. In the present study, reference measurements were conducted in classes of children in a single physical education lesson per class. The conducted activities are specified in **Table 1**. To take into account that the children may not always wear their accelerometer, data that was recorded when the device was not worn was also included in the analyses. For that, a recording accelerometer was placed on a table in three different positions. The positions were the ones we identified as

Table 1 | The six activities conducted in the reference measurements, classified as sedentary behavior, inactive behavior, or physical activity (moderate and vigorous).

Sedentary behavior	Lying comfortably Sitting upright
Inactive behavior	Standing upright
Physical activity	Walking at a normal pace Walking at a fast pace Running

most likely for a device lying on a flat surface, due to the shape of the device. The resulting raw acceleration data, measured in g, were summarized in a set of key-values in non-overlapping time frames. These key-values were the mean acceleration value of the frame, the corresponding variance, the correlations between the acceleration values of the three axes, and the energy (see Bao and Intille, 2004). To account for the fact that the movement of children tends to be irregular and characterized by short bouts of vigorous movement (e.g., Baquet et al., 2007; Corder et al., 2008) we chose a relatively short frame length of 2.5 s. With the chosen sampling rate of 30 Hz this means that each frame consisted of 75 acceleration measurements on each of the three axes. With acceleration being measured on three axes, this leads to 12 key-values describing each frame.

The resulting data were classified using *support vector machines* (SVMs), which have proven to be very effective for classification problems (e.g., He and Jin, 2009). The SVM approach was first introduced by Boser et al. (1992) and further developed to what is used in the present study by Cortes and Vapnik (1995). A detailed description of SVMs is beyond the scope of this article. Interested readers who want to delve deeper into this topic are referred to Cristianini and Shawe-Taylor (2000). A rather detailed user's guide that contains theoretical background as well as practical advice for the usage of SVMs is provided by Ben-Hur and Weston (2010). We conducted SVMs with the function "svm" from the package "e1071" (Dimitriadou et al., 2011) of the open-source statistical software R (R Development Core Team, 2012). Regarding the specific settings of the function, we followed the recommendations of the author's manual (Meyer, 2012).The results of the classification process are reported elsewhere (Kühnhausen et al., in preparation). There, we show that our method enabled us to correctly classify activities with great precision. Thus, the trained SVM models were used to classify the acceleration data collected during the 4 week study phase. For those children who were present during the reference measurement, an individual model, only trained on the data of the respective child, was used. For the children who were not present, a general model, based on the reference data of the children who did take part in the reference measurements, was used.

Measures of PA

After cleaning the data (see below), they were collapsed into standard measures of PA. Lying and sitting were classified as *sedentary behavior*. Standing was classified as *inactive behavior*. Slow and fast walking were classified as *moderate to vigorous physical activity* (MVPA). Running was classified as *very vigorous PA*. PA was then defined as the percentage of active time per day (MVPA plus *very vigorous activity*). Due to the finding that not only the total amount of PA, but also the amount of very vigorous PA, may have an influence on affect (Parfitt et al., 2009; Poole et al., 2011; Mata et al., 2012) the percentage of the active time that was spent with *very vigorous activity* was also included as a predictor of affect. The distinction between sedentary and inactive behavior is theoretically important. However, it is not relevant for our current analyses, since we only investigate how being physically active influences affect.

Data cleaning

The resulting activity data was further processed to dispose of spurious data. In a first step, consecutive strings of 1 h of classified *non-wear time* were identified. Within this—at least—1 h of *non-wear time*, 5 min of activity were allowed. Thus, a maximum of 5 min of activity, bordered by at least an hour of *non-wear time*, was identified as spurious activity and re-classified as *non-wear time*. Shorter periods of *non-wear time* were considered very steady phases of *sedentary behavior* and thus re-classified as just that. The second step was to restrict the data to adequate wear times. For this, the self-reported information about sleeping behavior was used. Each morning the children had to report when they went to bed the night before and when they woke up in the morning. This information was used to identify wake time of each child on each day. In further analyses only these time intervals were considered. In a third step, days of data were checked and only valid days remained for further analyses. A valid day was defined as a day with at least 6 h of activity data, that is, a day on which the device was worn for at least 6 h.

MEASURING AFFECT

Affect was measured four times a day with 12 items that have proven to reliably measure affect in children. Each item contained a statement, for example "Right now I feel content", that had to be rated on a 5-point Likert scale, ranging from 1 ("not at all") to 5 ("very much"). The 12 items were selected out of a large item pool in a pre-study of the FLUX project (Leonhardt et al., in preparation). A detailed description of these items and their psychometric properties can be found there. In short, the items were selected for their ability to measure affect structures in groups of children, as well as within children over time. Factor analyses showed that the latent affect factors *pleasantness*, *unpleasantness*, *activation*, and *deactivation* can be represented with three items each and be used to describe affect differences between persons as well as fluctuations in affect within persons over time. The within-person reliability scores of all factors were above 0.59 (for details, see Leonhardt et al., in preparation). For the current study, composite scores were created for each triplet of items belonging to one of these four factors. These scores were averaged across the four measurement occasions for each day. This meant that for each child, one score per day could be obtained for each measured dimension of affect.

ANALYSES

The influence of daily PA on daily affect was analyzed with mixed effects models (also called hierarchical linear models, e.g., Raudenbush and Bryk, 2002). A linear trend over time was included in all models. Separate models were calculated for the influence of both PA variables on each affect dimension. The corresponding regression equations are given by:

$$\text{Level 1}: \text{Affect}_{ti} = \beta_{0i} + \beta_{1i}\,\text{Trend}_{ti} + \beta_{2i}\,\text{PA}_i + \beta_{3i}\,\text{PA}_{ti} + \varepsilon_{ti}$$

$$\text{Level 2}: \beta_{0i} = \gamma_{00} + \sigma_{0i}$$

$$\beta_{1i} = \gamma_{10} + \sigma_{1i}$$

$$\beta_{2i} = \gamma_{20}$$

$$\beta_{3i} = \gamma_{30} + \sigma_{3i}$$

The first level represents the different measurement occasions (i.e., days) within each child. On this level, within-person effects are modeled. Children's daily affect is predicted by a general intercept (β_{0i}), a linear trend over time (β_{1i}), the average PA of each child over the time of the study (β_{2i}), the deviation of each child from its own average PA (β_{3i}), and a residual term (ε_{ti}). The subscript i refers to the different children, the subscript t refers to different measurements of each child. Effects on this level can be interpreted as average effects across all children (fixed effects). The second level represents the level of the different children. On this level, between-person differences in the effects on the first level are accounted for (random effects). The above model equations describe the final model. To assess the relevance of the effects, all corresponding reference models were also fitted to the data for all affect dimensions and PA variables. Thus, first an empty model was obtained. Next, the fixed effects were added to the model. Finally, the random effects were added resulting in the final model. The covariance of the random intercept and random trend was also included in the model. Since this covariance does not play a substantial role for the interpretation of the models, it will not be reported in the Results section. All models were calculated with *restricted maximum likelihood* (REML) estimation using SAS PROC MIXED (SAS Institute, Inc., Cary, North Carolina).

RESULTS

DROPOUT AND VALID DATA

Of the 82 children who received an Actigraph in the beginning, 13 returned their device in the course of the study. Five children lost their Actigraph, and one device was stolen. Two devices turned out to have technical faults, resulting in almost constantly recording the maximum acceleration. This leaves 61 children whose data could in principle be used. Of those children, 10 did not wear their device regularly, leading to less than 4 days of valid data. These children were also excluded from further analyses. This left 51 children with sufficient data to reliably describe their typical activity behavior.

COMPLIANCE

Overall, compliance among the children was satisfying. On average, the 51 children whose data were analyzed had almost 17 valid days of data ($SD = 8$; see also **Figure 1A**). The distribution of the number of valid days has a slightly bi-modal shape. There are several children who have more than 20 days of data. At the same time, a considerable group of children have only ten or less days of data. This is in line with our observation that the compliance differed considerably between children. A satisfying compliance can also be asserted from the average time the devices were worn per day (see **Figure 1B**). On an average valid day, the devices were worn for almost eleven and a half hours ($SD = 2.6$). On the majority of days, the devices were worn between 8 and 15 h. It thus seems that those children who were willing to wear their device until the end of the study did so with good compliance.

DESCRIPTIVES

On an average day, the children were active for about 15% of the time. This corresponds to about 103 min of activity ($SD = 81$). The active time differed considerably between days, as can be inferred from the rather large standard deviation (see also **Figure 2A**). The average active time per day for each child (see **Figure 2B**) shows considerable differences between children. It is clear that there are some children who are generally more active than others. A similar picture can be seen in the time that is spent in very vigorous activity. On average, of the total active time, about 21% was spent in very vigorous activity (see **Figure 3A**). This corresponds to an average of about 21 min of

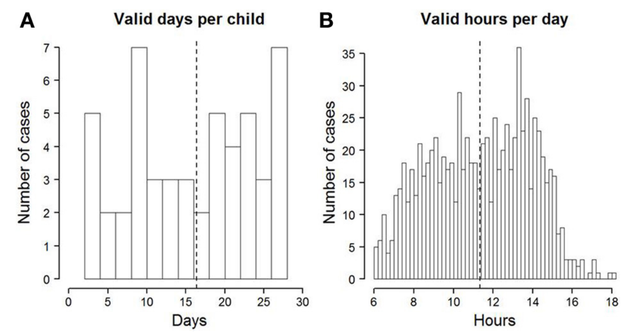

FIGURE 1 | (A) Histogram of the number of valid days per child. The dotted line depicts the mean across all children. **(B)** Histogram of the number of valid hours per day. Days with less than 6 valid hours were excluded from analyses. The dotted line depicts the mean across all days and children.

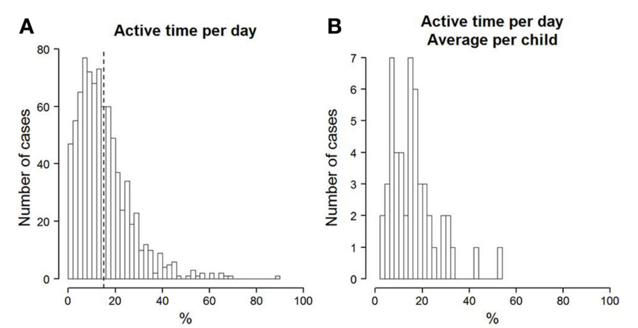

FIGURE 2 | (A) Histogram of the percentage of time per day that children were physically active. The dotted line depicts the mean across all days and children. **(B)** Histogram of each child's mean percentage of time per day spent with PA.

vigorous activity per day ($SD = 24$). Just as the overall activity, the amount of vigorous activity also varied considerably between children (see **Figure 3B**). A two-level multi-group model with maximum-likelihood (MLR, Mplus 7.0, see Muthén and Muthén, 1998–2012) estimation showed no significant difference between boys and girls in the total amount of active time per day. Boys did, however, show a higher percentage of vigorous activity than girls ($M_{\text{difference}} = 0.11$, $SE = 0.05$, $p < 0.05$). Neither the total activity per day, nor the percentage of vigorous activity correlated significantly with children's BMI. The intra-class-correlation (*ICC*) of the measures of total activity was 0.23. The *ICC* of the percentage of very vigorous activity was 0.29. The *ICC* relates the variance that is found between children to the total variance. Thus, one minus the *ICC* is the part of the total variance that can be assigned to within-subject variation. The resulting *ICC* values indicate that there were substantial within-subject fluctuations in the measures of PA.

The results of the affect measurements are depicted in **Table 2**. Overall, children rated their affect relatively high on the more positive affect dimensions (*pleasantness* and *activation*) and relatively low on the more negative dimensions (*unpleasantness* and *deactivation*). The average intra-individual standard deviation (ISD) is the mean of each child's deviation from his or her own average value on the respective affect factor. The resulting values did show that, on average, children's affect varied considerably across days. The *ICC* values of the affect factors also indicate that there were substantial affect fluctuations.

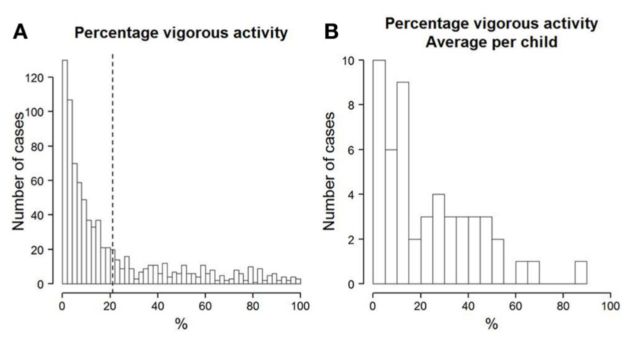

FIGURE 3 | (A) Histogram of the percentage of active time per day that children spent with very vigorous PA. The dotted line depicts the mean across all days and children. **(B)** Histogram of each child's mean percentage of the active time per day that was spent with vigorous PA.

Table 2 | Descriptive statistics of the four factors of affect (measured on a five-point Likert-scale from 1 to 5).

	Mean *(SD)*	Average ISD	ICC
Pleasantness	3.95 (1.00)	0.55	0.51
Unpleasantness	1.46 (0.73)	0.43	0.52
Activation	3.60 (1.19)	0.62	0.59
Deactivation	1.62 (0.78)	0.49	0.44

ICC, intra-class-correlation; ISD, intra-individual standard deviation.

MODELS

The results of all fitted models are depicted in **Table 3**. Overall, there were no reliable effects of daily PA on daily affect. This was the case for the effect of overall PA, as well as for vigorous PA on the four measured factors of affect.

DISCUSSION

We were able to demonstrate the feasibility of objectively measuring PA in the daily life of children over a period of several weeks. There was a considerable group of children who were willing to wear their devices during most of the days of our study and during most of the waking hours of each day. We hope that this can increase the motivation of researchers to conduct similar studies and further contribute to this area of research. By successfully measuring PA in a group of children over a prolonged period of time, we were also able to describe typical PA behavior in those children. This contributes to a more complete picture of typical PA in everyday life of elementary school children in Germany.

We did not find a significant influence of daily PA on any of the four affect factors. There are several possible explanations for that. The most apparent one is a lack of power. The numerical decrease of the residual variance of some of the affect variables when including the fixed and random effects of PA in the model suggests that effects might exist. For example, consider the effect of PA on the affect dimension *activation*. The residual variance of *activation* reduces from 0.340 in the model that only includes the trend, to 0.274 when also including the total active time per day. Thus, including PA to predict *activation* reduces its residual variance by over 19%. However, all effects fail to be statistically significant. This might be attributed to the fact that habitual PA does not show very great variability. To some extent, this might be due to the way we processed the acceleration data and classified it into certain activities. A lack in variability may result in a reduced likelihood of detecting reliable effects. It could therefore well be that with larger samples of children and/or occasions, statistically significant effects could be found. This assertion is supported by the conclusion in the meta-analysis of Ahn and Fedewa (2011) that "effects of PA on mental health were small but significant". By all means, the results are no reason to exclude the possibility that daily PA may have an effect on daily affect in children. This assertion leads to a second possible explanation for the non-significance of the results. It is quite possible that the influence of PA on affect is different for different children. In the literature, this suggestion is supported by the finding that the influence of PA on positive affect in adults depends on the baseline level of positive affect (Kanning and Schlicht, 2010). In the present study, this may be indicated by the fact that adding the random effects of PA on affect to the model slightly decreased the residual variance of some of the affect dimensions. It might be worthwhile to more closely analyze the multivariate time series of single participants to see if for some of them reliable influences of PA on affect can be detected. Finding those effects in some but not all children could also partly explain the non-significance of the results. For the whole group, the effects would just not be strong enough to reach significance. Finally, and maybe most importantly, reasons for the non-significance of the effects might be found in the design of the analyses. All studies that have found an effect of PA on affect

Table 3 | Parameter estimates of the described models (standard errors in parentheses).

	Empty model	Trend only	Total activity: fixed effects only	Total activity: fixed and random effects	Vigorous activity: fixed effects only	Vigorous activity: fixed and random effects
PLEASANTNESS						
Fixed intercept	3.937* (0.11)	4.122* (0.10)	3.982* (0.19)	3.982* (0.19)	4.006* (0.15)	4.006* (0.15)
Trend (time)		−0.014* (0.005)	−0.012* (0.006)	−0.012* (0.006)	−0.011* (0.006)	−0.011* (0.006)
Average activity			0.970 (1.02)	0.970 (1.02)	0.569 (0.51)	0.569 (0.51)
Daily activity			0.054 (0.29)	0.054 (0.29)	−0.056 (0.13)	−0.056 (0.13)
Random intercept	0.63* (0.13)	0.438* (0.10)	0.380* (0.10)	0.380* (0.10)	0.368* (0.10)	0.368* (0.10)
Variance daily activity				0.00 (NA)		0.00 (NA)
Variance trend		0.0009* (0.0002)	0.0009* (0.0002)	0.0009* (0.0002)	0.0009* (0.0002)	0.0009* (0.0002)
Residual variance of pleasantness	0.409* (0.02)	0.324* (0.01)	0.297* (0.02)	0.297* (0.02)	0.297* (0.02)	0.297* (0.02)
−2 Log-Likelihood	2263.6	2095.8	1345.6	1345.6	1348.1	1348.1
UNPLEASANTNESS						
Fixed intercept	1.505* (0.08)	1.435* (0.07)	1.530* (0.15)	1.530* (0.15)	1.507* (0.12)	1.508* (0.12)
Trend (time)		0.006* (0.002)	0.008 (0.005)	0.008 (0.005)	0.008 (0.005)	0.008 (0.005)
Average activity			−0.855 (0.80)	−0.855 (0.80)	−0.525 (0.40)	−0.523 (0.40)
Daily activity			−0.231 (0.22)	−0.231 (0.25)	−0.125 (0.10)	−0.074 (0.16)
Random intercept	0.354* (0.07)	0.241* (0.06)	0.233* (0.06)	0.233* (0.06)	0.228* (0.06)	0.225* (0.05)
Variance daily activity				0.229 (0.49)		0.345 (0.28)
Variance trend		0.0002* (0.00008)	0.0007* (0.0003)	0.0007* (0.0003)	0.0007* (0.0003)	0.0008* (0.0003)
Residual variance of unpleasantness	0.205* (0.009)	0.187* (0.009)	0.157* (0.009)	0.157* (0.009)	0.157* (0.009)	0.150* (0.009)
−2 Log-Likelihood	1512.9	1462.9	910.7	910.7	912.6	909.1
ACTIVATION						
Fixed intercept	3.604* (0.14)	3.857* (0.13)	3.977* (0.26)	3.977* (0.26)	3.847* (0.21)	3.847* (0.21)
Trend (time)		−0.020* (0.006)	−0.018* (0.006)	−0.018* (0.006)	−0.018* (0.006)	−0.017* (0.006)
Average activity			−0.552 (1.36)	−0.552 (1.36)	0.154 (0.69)	0.157 (0.69)
Daily activity			0.112 (0.29)	0.112 (0.29)	−0.109 (0.13)	−0.142 (0.15)
Random intercept	0.905* (0.19)	0.778* (0.17)	0.826* (0.19)	0.826* (0.19)	0.807* (0.19)	0.805* (0.19)
Variance daily activity				0.00 (NA)		0.089 (0.16)
Variance trend		0.001* (0.0003)	0.001* (0.0003)	0.001* (0.0003)	0.001* (0.0003)	0.001* (0.0003)
Residual variance of activation	0.456* (0.02)	0.340* (0.02)	0.274* (0.02)	0.274* (0.02)	0.274* (0.02)	0.272* (0.02)
−2 Log-Likelihood	2329.1	2121.5	1297.4	1297.4	1299.5	1299.5
DEACTIVATION						
Fixed intercept	1.662* (0.08)	1.707* (0.09)	1.738* (0.17)	1.738* (0.17)	1.818* (0.13)	1.819* (0.13)
Trend (time)		−0.003 (0.003)	−0.002 (0.005)	−0.002 (0.005)	−0.002 (0.005)	−0.002 (0.005)
Average activity			−0.640 (0.87)	−0.640 (0.87)	−0.806 (0.42)	−0.809 (0.42)
Daily activity			−0.258 (0.26)	−0.258 (0.26)	0.023 (0.11)	0.034 (0.15)
Random intercept	0.347* (0.07)	0.341* (0.08)	0.321* (0.08)	0.321* (0.08)	0.284* (0.07)	0.284* (0.07)
Variance daily activity				0.00 (NA)		0.054 (0.22)
Variance trend		0.0005* (0.0002)	0.0008* (0.0002)	0.0008* (0.0002)	0.0008* (0.0002)	0.0008* (0.0002)
Residual variance of deactivation	0.280* (0.01)	0.247* (0.01)	0.214* (0.01)	0.214* (0.01)	0.214* (0.01)	0.212* (0.01)
−2 Log-Likelihood	1833.7	1775.3	1107.4	1107.4	1108.4	1108.3

Model results are displayed separately for each measured factor of affect.

$^*p < 0.05$.

have one thing in common. Affect was measured directly after being physically active. Even those studies that measure subjects in their daily lives (e.g., Kanning and Schlicht, 2010; Wichers et al., 2012) let their subjects rate their affect right after a self-reported period of PA. A detailed description of conceptual advantages as well as methodological considerations of an improved version of this method, *interactive ambulatory assessment*, is given by Ebner-Priemer et al. (2013). Most importantly, it enables researchers to measure affect right after an accelerometer has detected that a subject was physically active. This greatly enhances the likelihood to detect an influence of PA on affect (Ebner-Priemer et al., 2013). In the study by Wichers et al. (2012), the positive influence of PA on affect was only present in the 180 min after the activity. Furthermore, Bossmann et al. (2013) found a positive influence on subject's mood by the intensity of the PA that was conducted in the 10 min before the affect measurements. In the present article, we calculated the average affect during the whole day and related it to the PA during the whole day. It is conceivable that this is a reason for the absence of significant effects (cf. Schwerdtfeger et al., 2008). Following this argument, our next steps will include the investigation of the influence of PA on affect on different time scales. Since we measured PA continuously during the whole day and affect four times a day, our data allows for quite some flexibility in this respect. One approach will be to only look at the PA that immediately preceded the affect measurements. The usefulness of this approach is suggested by the discussed empirical findings. In addition, there is the theoretical consideration that "we might expect that different [time] intervals will yield different patterns of variability and result from different influences on the 'system' or individual" (Martin and Hofer, 2004, p. 10).

Studying the relationship between PA and affect can be done in many different ways. Our results indicate that the design of a study, especially with regards to the investigated time-scale, can have an influence on the results. By further exploring sensitive time intervals for the effects of PA on affect, our study may help researchers to choose a proper study design. Furthermore, we were able to show that objective measures of PA are by now feasible, even in prolonged longitudinal studies with children. Intensive longitudinal studies that use ambulatory assessment also allow for the investigation of effects in a way that cross-sectional research designs cannot provide. For example, considering the problems that can be caused by inactivity, it is desirable to investigate possible reasons for people being inactive. Intensive longitudinal studies can clarify these reasons and thus give hints on how to help people to become more active (cf. Ebner-Priemer et al., 2013). Generally speaking, our study shows the great opportunities available for future researchers who want to study PA in children.

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The association between symptoms, pain coping strategies, and physical activity among people with symptomatic knee and hip osteoarthritis

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Effective use of coping strategies by people with chronic pain conditions is associated with better functioning and adjustment to chronic disease. Although the effects of coping on pain have been well studied, less is known about how specific coping strategies relate to actual physical activity patterns in daily life. The purpose of this study was to evaluate how different coping strategies relate to symptoms and physical activity patterns in a sample of adults with knee and hip osteoarthritis (OA; $N = 44$). Physical activity was assessed by wrist-worn accelerometry; coping strategy use was assessed by the Chronic Pain Coping Inventory. We hypothesized that the use of coping strategies that reflect approach behaviors (e.g., Task Persistence), would be associated with higher average levels of physical activity, whereas avoidance coping behaviors (e.g., Resting, Asking for Assistance, Guarding) and Pacing would be associated with lower average levels of physical activity. We also evaluated whether coping strategies moderated the association between momentary symptoms (pain and fatigue) and activity. We hypothesized that higher levels of approach coping would be associated with a *weaker* association between symptoms and activity compared to lower levels of this type of coping. Multilevel modeling was used to analyze the momentary association between coping and physical activity. We found that higher body mass index, fatigue, and the use of Guarding were significantly related to lower activity levels, whereas Asking for Assistance was significantly related to higher activity levels. Only Resting moderated the association between pain and activity. Guarding, Resting, Task Persistence, and Pacing moderated the association between fatigue and activity. This study provides an initial understanding of how people with OA cope with symptoms as they engage in daily life activities using ecological momentary assessment and objective physical activity measurement.

Keywords: accelerometry, chronic pain, coping strategies, ecological momentary assessment, physical activity

INTRODUCTION

Osteoarthritis (OA) is a chronic condition that affects 27 million people in the United States and is a leading cause of disability in adults. For people with knee and hip OA, the experience of symptoms can greatly impair quality of life. Pain is the main reason people seek treatment. Pain in OA affects the ability to engage in activities of daily living, work, and other meaningful activities (Hill et al., 1999; Boutron et al., 2008; Grotle et al., 2008). Fatigue, although not as well studied in OA, is one of the most frequently reported OA symptoms (Wolfe et al., 1996; Power et al., 2008), and one of the strongest predictors of functional disability (Wolfe, 1999). While a link between symptoms of pain and fatigue has been established with physical disability in OA, less is known about how pain, fatigue, and psychosocial factors, such as coping ability, influence physical activity on a day-to-day basis. A better understanding of these interrelationships offers the potential for insight into more effective ways to manage OA.

According to Lazarus and Folkman (1984), people develop methods of coping in response to stressors such as pain and fatigue. Coping strategies may be cognitive (such as an attribute or belief to assign meaning to a stressful situation) or behavioral (such as an action-oriented response). The development of a strategy to cope with adversity such as pain does not insure that it is adaptive. In addition, strategies may be adaptive in the short-term but prove to be maladaptive longer term if pain becomes chronic (Jensen, 1991; Hasenbring and Verbunt, 2010). There have been efforts to identify and categorize specific coping behaviors into maladaptive and adaptive types (Ersek, 2006; Tan et al., 2011; Englbrecht et al., 2012), with different terminology to describe the categories and often times different scales that have been developed to assess the proposed dimensions. One popular means of categorizing behavioral coping relates to how people engage in or approach activity in the context of their medical symptoms. According to this perspective, behavioral strategies that relate to activity broadly reflect three dimensions: avoidance, persistence, and pacing.

AVOIDANCE

The fear-avoidance model (Vlaeyen and Linton, 2000) describes how the pain experience can lead to a pathway where habitually avoiding activity promotes a cycle of disuse and disability. In essence, catastrophizing about pain and its potential consequences, or ruminating, feeling helpless, or exaggerating the threat of pain, leads to pain-related fear or anxiety (Norton and Asmundson, 2003), which causes avoidance behaviors and ultimately reinforces this negative cycle (Leeuw, 2007). Consistent with the idea that avoidance behaviors are maladaptive coping strategies, research examining avoidance usually associates these behaviors to disability or other outcomes such as depressed mood or maintenance of pain. In OA, use of rest as a coping strategy has been associated with physical disability in cross-sectional studies (Hopman-Rock et al., 1998; van Baar et al., 1998) as well as in longitudinal studies (Steultjens, 2001). In addition, rest and restricting activities have also been related to negative mood and pain at follow-up in people with OA (Hampson et al., 1996). Another strategy considered to be avoidant, Guarding (e.g., bracing, limping, flinching, stiffening), had the strongest independent association with disability (Tan et al., 2001) in a study of male veterans with chronic pain. In a similar sample, Tan et al. (2011) found that Guarding and Resting were associated with depression and higher levels of pain interference. Further, Guarding and Asking for Assistance (a behavior considered avoidant because other people are solicited to complete tasks) have also been associated with disability in people who have fibromyalgia (Karsdorp and Vlaeyen, 2009).

ACTIVITY PERSISTENCE

Activity persistence in general refers to persisting in an activity, even in the context of symptoms that may present barriers to engaging in that activity. Persistence may be considered either adaptive or maladaptive, depending on the degree or intensity of activity persistence. For instance, in the avoidance-endurance model of chronic pain, "endurance copers" are those people who persist in activity despite severe pain. They may have high levels of unhealthy activity and may respond to pain by being *excessively* persistent instead of avoidant (Hasenbring and Verbunt, 2010). Studies have revealed both positive and negative relationships between persistence and disability (Jensen, 1991; Kindermans, 2011). Kindermans (2011), who performed a factor analysis using several measures representing the persistence construct, found that excessive persistence (such as doing too much or not respecting one's physical limits) was positively associated with disability on the Pain Disability Index and with depression. In contrast, task-contingent persistence has been found to be associated with less disability (Jensen, 1991; Jensen et al., 1995).

PACING

Time-based activity pacing is a behavioral strategy in which people learn to lessen the effect of symptoms on activity by breaking up activities into smaller pieces, and alternating activity and rest periods to maintain a steady pace (Fordyce, 1976). These behaviors are thought to attenuate the "overactivity-underactivity" cycle in which excessive activity can lead to symptom flares that require a prolonged period of rest to recover (Birkholtz et al., 2004). In some studies, Pacing is associated with lower levels of disability (Nielson and Jensen, 2004), but other studies found Pacing is associated with higher levels of disability (McCracken and Samuel, 2007; Karsdorp and Vlaeyen, 2009; Kindermans, 2011). In a previous pilot study in which activity pacing behaviors and symptoms of pain and fatigue were measured using ecological momentary assessment (Murphy et al., 2008a), we found that people used pacing more frequently as symptoms were increasing throughout a day instead of using pacing as a pre-planned strategy as would be taught in chronic pain management programs. From these findings, we surmise that the natural use of pacing may be associated with higher levels of disability that may reflect the need to cope with problematic symptoms.

COPING STRATEGIES AND THEIR RELATIONSHIP TO ACTIVITY PATTERNS

An understanding of coping strategies and how they contribute to disability over time can influence the design of effective treatments and help to understand how best to avoid pathways to disability. Based on the theoretical models presented, physical activity levels are expected to be lower for avoiders compared to non-avoiders (Vlaeyen and Linton, 2000; Hasenbring and Verbunt, 2010). People who have higher use of task persistence may have higher activity levels compared to those who have lower use of task persistence (Hasenbring and Verbunt, 2010), although in some cases this task persistence could reflect overactivity. People who use pacing may have lower activity levels overall and this relationship was demonstrated in one pilot study (Murphy et al., 2008a). In addition, it is suggested that people who pace less frequently or who excessively persist in activities may have activity patterns that are more variable due to having to recover from overactive periods (Birkholtz et al., 2004; Huijnen et al., 2009).

Current research supports the notion that specific coping strategies can be associated with greater or diminished physical activity levels and activity patterns (Hasenbring et al., 2006; McCracken and Samuel, 2007; Murphy et al., 2008a; Huijnen et al., 2011). For example, people with chronic pain classified as avoiders or as pacers had lower levels of self-reported "up-time" (the hours spent standing or walking daily; McCracken and Samuel, 2007), and task persisters had higher levels of up-time when measured subjectively or objectively (McCracken and Samuel, 2007; Huijnen et al., 2011). In another study, people with low back pain 6 months after disk surgery were classified into subgroups of copers (fear-avoidant, endurance, or adaptive), and their activity was sampled over a day using a triaxial accelerometer. They found that endurance copers (those thought to be at risk for excessively persisting in activities) did not have a significantly different activity levels than adaptive copers, but they had a higher numbers of static strain postures during the day (such as sitting or standing with or without forward bending; Hasenbring et al., 2006). These findings suggest that in addition to activity levels, fluctuations or variability in activity patterns may provide important information about how people engage in activity as they cope with their symptoms. Huijnen et al. (2009) measured within-day activity fluctuations by having people with chronic low back pain categorize their activity into activity types reflecting different levels of effort (e.g., exercise vigorously – sitting or lying down) and found that increased within-day activity fluctuations were associated with disability whereas mean activity level was not. The relationship between coping and physical activity appears complex and is further complicated by the heterogeneous samples of people with different chronic pain conditions and the use of several different coping scales as well as different physical activity assessment methods. This study addressed a clear gap in this literature by examining how coping, symptoms, and physical activity are associated in people with OA.

To develop behavioral treatments for people with OA, our group has been investigating how momentary (i.e., within-day) symptoms relate to physical activity patterns and have found that while pain is related to activity, fatigue is more severe, more variable, and more negatively related to objective physical activity compared to pain (Murphy et al., 2008b). In order to examine how coping is associated with symptoms and activity, we examined both pain-activity and fatigue-activity relationships in this study in a sample of adults with knee or hip OA. Coping strategies were assessed with the Chronic Pain Coping Inventory (CPCI; Jensen et al., 1995) representing the areas of avoidance (Guarding, Resting, Asking for Assistance), Task Persistence, and Activity Pacing. According to the existing literature, we first hypothesized that Task Persistence would be associated with higher average levels of physical activity, whereas coping strategies that reflect avoidance and Pacing would be associated with lower average levels of physical activity. Second, we hypothesized that pacing would be associated with more stable, less variable levels of activity. Third, we hypothesized that coping strategies would moderate the association between pain/fatigue and activity. Specifically, we expected that people with high levels of Task Persistence would display weaker associations between pain/fatigue and activity compared to people with low levels of Task Persistence.

MATERIALS AND METHODS

This is a secondary data analysis of data from a larger three-arm randomized controlled trial (Murphy et al., 2011). The overall goal of the trial was to examine the effectiveness of a tailored activity pacing intervention delivered by occupational therapists for adults with symptomatic knee or hip OA. In the trial, participants were randomized into the tailored activity pacing intervention, general activity pacing, or usual care. Assessments occurred at baseline, posttest, and 6 months. Data from the baseline assessment period were used for these analyses. Ethical approval for this study was obtained by the University of Michigan Medical School Institutional Review Board and the Subcommittee on Human Studies in the Veteran's Affairs Ann Arbor Healthcare System.

PARTICIPANTS AND PROCEDURES

Community-living veteran and non-veteran participants in this study sample were recruited from the University of Michigan and VA clinics, senior housing sites, and through public advertisements. Inclusion and exclusion criteria were designed to identify a cohort of community-living adults who were experiencing symptoms specifically due to their OA. Participants were included if they were age 50 years or older, had pain for at least 3 months duration, reported mild to moderate pain on the Western Ontario McMaster Arthritis Index (WOMAC) pain scale (Bellamy et al., 1988; Goggins et al., 2005), had radiographic evidence of knee or hip OA (Kellgren–Lawrence scale of ≥ 2; Kellgren and Lawrence, 1957), had adequate cognitive status (evidenced by scoring ≥ 5 on the six item cognitive screener (Callahan et al., 2002), could reliably operate the Actiwatch-S accelerometer used in the study, and were English-speaking. Participants were excluded if they: had medical conditions that could interfere with pain and fatigue reporting or activity monitoring (e.g., multiple sclerosis, lupus, rheumatoid arthritis, Parkinson's disease); were diagnosed with cancer in the last year (other than skin cancer) or were currently undergoing treatment for cancer; had medicine changes within the previous 2 weeks, anemia or unmanaged thyroid dysfunction (from blood work result); had two or more days of complete bed rest within last month; had limb hemiplegia or amputation; underwent a knee arthroscopic procedure within the previous 2 months; underwent replacement of any hip or knee within the last 6 months; knee joint injections within the previous 3 months; current receipt of physical or occupational therapy for OA symptoms or knee/hip problems; or currently or recently attended (in the previous 12 months) a cognitive behavioral program or other self-management program that included activity pacing instruction.

To determine eligibility, study personnel first screened potential participants by phone. If eligible based on screening, potential participants were scheduled for a clinic visit to undergo an x-ray of their knees or hips, complete questionnaires, learn how to operate the Actiwatch-S accelerometer, and complete physical performance testing. Participants signed a written consent form at the clinic visit and after completion of that visit, eligible participants were mailed the Actiwatch-S accelerometer and corresponding logbook to undergo the baseline 7 day home monitoring period. For the home monitoring period, participants wore the Actiwatch-S on their non-dominant wrist. The Actiwatch-S collects physical activity data and allows for time-stamped participant-entered responses. Participants were instructed on how to enter responses into the accelerometer using a standardized interactive learning module and were given the opportunity to practice rating their symptoms using the accelerometer's input button to record the information. Participants also became familiar with the logbook that accompanied the accelerometer. The logbook was used to cross-validate the items and served as a back-up if there were missing data from the accelerometer.

A total of 47 participants were enrolled in the study and data from 44 were used in these analyses. One individual was eliminated due to completely missing momentary data (activity, pain, fatigue). One individual was identified as an outlier based on body mass index (BMI; in which BMI = 55.99, nearly 16 points higher than the next highest individual). Another individual who was identified as an outlier was experiencing a "pain flare" with pain ratings of 8/10 compared to "typical" 4–5/10 pain intensity during the study and was consequently unable to finish the physical performance testing [e.g., Timed Up and Go (TUG)].

MEASURES

Primary measures

Coping strategies were measured at the baseline clinic visit using the CPCI, a self-report measure of cognitive and behavioral strategies for coping with pain. The CPCI has demonstrated excellent test-retest reliability and internal consistency and concurrent validity in a chronic pain sample (Jensen et al., 1995). The original questionnaire consisted of 65 items divided into eight subscales: four of which were originally considered wellness-based coping (Task Persistence, Exercise, Relaxation, and Coping Self-Statements), three were considered illness-based coping (Guarding, Resting, Asking for Assistance), and one was neither (Seeking Social Support). A later version included activity pacing as a subscale (Nielson et al., 2001) which was included in the version used in this study. The scores for each item range from 0 to 7 days, with a score of 0 indicating that the participant did not use that coping strategy in the past week. For this analysis, we chose only the subscales that could be best equated to activity patterns identified in the cognitive behavioral models: avoidance behaviors (Guarding, Resting, Activity for Assistance), Task Persistence, and Pacing. These subscales all had adequate internal consistency in the present sample (Cronbach's alpha ranging from 0.72 to 0.82).

Physical activity patterns were measured using a wrist-worn accelerometer, the Actiwatch-S [Philips Respironics, Mini-Mitter, Bend, OR, USA] that measures changes in acceleration. Although it is worn on the wrist, it is highly associated with whole-body movement (Patterson et al., 1993; Westerterp, 1999). The Actiwatch-S has been shown to have excellent inter-unit reliability ($r = 0.98$) and preliminary criterion validity among a sample of chronic pain patients (Gironda et al., 2007). The device records changes in acceleration every 15 s and these are recorded as activity counts. Higher activity counts generally reflect participation in higher intensity activities (Swartz et al., 2000; Murphy, 2009). Physical activity data from the accelerometer are aggregated in different ways. Daytime activity counts were aggregated within a day between symptom reporting periods (which we call "momentary activity"). These are roughly 4 h intervals between wake-up and 11:00 am; 11:00 am to 03:00 pm, 03:00 pm to 07:00 pm, and 07:00 pm to bedtime). Activity counts were also aggregated for each day (i.e., daily activity) and over the 7 day period for each person. Because participants wear the accelerometer continuously for 7 days, it was necessary to establish participants' wake-up and bed times. A previously established algorithm was used to corroborate participant report with the objective measures (Murphy et al., 2008b).

Momentary pain and fatigue severity were measured on 0–10 numerical rating scales that were directly input into the accelerometer five times a day [at rise time in the morning, three times during waking hours (11:00 am, 03:00 pm, 07:00 pm), and at bedtime]. The accelerometer was worn for 7 days at baseline and at the outcome assessment periods. Pain was rated on a scale from 0 = no pain to 10 = pain as bad as you can imagine. Fatigue, defined as tiredness or weariness (Wolfe et al., 1996), was rated on a scale from 0 = no fatigue to 10 = fatigue as bad as you can imagine.

Background measures and covariates

Background demographics included age, sex, marital status, ethnicity, race, employment status, veteran status, and educational level. Health status variables included BMI and OA disease severity as determined from a radiologist's scaling on the Kellgren–Lawrence Scale using the joint x-rays (Kellgren and Lawrence, 1957).

To assess general symptoms and reported physical and mental health, several scales were used. To measure symptom severity and interference, the Brief Pain Inventory (BPI; Keller et al., 2004) and Brief Fatigue Inventory (BFI; Mendoza et al., 1999) were used. Depressive symptoms were measured using the Center of Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977). The State Trait Personality Inventory (STPI) was used to measure anxiety symptoms (Spielberger et al., 1970). The Short Form 12 was also used to measure mental and physical health domains (Ware et al., 1996). The WOMAC physical disability subscale was also used as a measure of arthritis-related physical function (Bellamy et al., 1988). Internal consistency on all of these scales was acceptable ranging from 0.74 on the CES-D to 0.92 on the BFI.

Physical function was measured using two validated objective measures. The TUG test (Podsiadlo and Richardson, 1991) measures the time (in seconds) to get up from a chair, walk 20 feet, and return to the chair. Participants completed three trials and the average was used in the analyses. The 6 min walk test is a walking test in which people are asked to walk at their usual pace for 6 min and overall distance was recorded in feet (Butland et al., 1982).

Data Analysis

Descriptive statistics for all predictor and outcome variables were calculated and examined for distribution normality. Skew (largest range was for TUG = 0.06–1.64) and kurtosis (TUG range = 0.12–4.13) values indicated that all variables were sufficiently normally distributed to conduct the primary analyses (West et al., 1995). To address these modest deviations from normal distribution in the primary analyses, we utilized an asymptotically consistent estimator, the "sandwich estimator," which counteracts problems due to non-normality in the data by generating robust standard errors analyses (described below; Huber, 1967; White, 1980).

Multilevel random effects modeling (MLM) was used to test the study hypotheses. This statistical approach is optimal because these data have a hierarchical structure with momentary evaluations (Level 1) nested within days (Level 2) nested within individuals (Level 3). MLM, using the SAS PROC MIXED procedure can simultaneously model between- (Level 3) and within-person (Levels 1 and 2) variance, can account for auto-correlation between adjacent observations, and has contemporary techniques for addressing missing data (e.g., all available data points are used, cases are not eliminated due to missing Level 1 or 2 data). In addition, with MLM we were able to model random effects, which assume that the independent variable represents a random sample of a larger range of possible values, in addition to fixed effects, which assume that all possible values are represented in the independent variable. Modeling of random effects allows for generalization of results to a broader population of people compared to simple fixed effect analyses. Prior to conducting MLM analyses, variables were centered, based on guidelines for centering data in multilevel statistical procedures (Enders and Tofighi, 2007). Momentary variables were person-day-centered such that values indicate change from a person's average for that day and between-person variables were sample-centered such that values indicate difference from the sample-average. All analyses were conducted using SAS statistical software, Version 9.2 (SAS Institute Inc. 2009. SAS OnlineDoc® 9.2. Cary, NC, USA: SAS Institute Inc.).

To test the first set of questions, the association between coping variables and activity level (H1) and activity variability (H2), two separate multilevel models were constructed. For the first model, all coping variables (Guarding, Resting, Asking for Assistance, Task Persistence, Pacing) were included as predictors simultaneously to predict average momentary activity. For the second model, average activity values were aggregated at the level of a day and the standard deviation of activity for each day was constructed as an indicator of activity variability. *Post hoc* analyses to determine whether the association between coping and activity level and activity variability differed by average level of activity (e.g., highly active versus sedentary) were conducted by testing interaction terms [(COPING) × MEAN ACTIVITY] in the prediction of activity and activity variability. In all models, including the ones described below, age, BMI, TUG score, and KL score were included as covariates.

To test the second set of hypotheses, regarding the moderating effect of coping on the pain/activity and fatigue/activity (H3) associations, MLM models were constructed with interaction terms [e.g., (COPING) × PAIN/FATIGUE] entered as predictors of momentary average activity. Significant interactions were further examined through graphing the simple slopes between pain/fatigue and activity for low (−1 SD), mean, and high (+1 SD) values of the moderating variables (i.e., coping; Aiken and West, 1991).

RESULTS

Complete sample descriptive statistics are depicted in **Table 1**. Results indicate that the sample reported "mild" levels of pain intensity, fatigue, and stiffness and was, on average, obese according to BMI scores. The sample was mostly white (81.8%), female (68%), non-veteran (79.5%), and married (59.5%). For physical function, the sample had an average of 9.1 s on the TUG test which is slightly slower than normative values of people aged 60–69 (Bohannon, 2006), but comparable to a previous sample of women with knee or hip OA (Murphy et al., 2008b). The 6 min walk distance (1249 feet or 381 m) was also slightly slower than norms for healthy adults that range from 400 to 700 m (Enright, 2003).

Prior to conducting the analyses to address the primary study aims, we examined the distribution and correlation of the CPCI coping subscales with each other and with key indicators of functioning. As can be seen in **Table 2**, the CPCI subscales were not generally highly correlated with each other. Some notable exceptions were significant positive correlations between Activity Pacing and Guarding and Resting, a significant positive correlation between Asking for Assistance and Guarding, and a significant negative correlation between Task Persistence and Guarding. Task Persistence was the most commonly reported coping strategy, averaging nearly 4.5 days/week in this sample. The least commonly used coping strategy was Asking for Assistance, which averaged less than 2 days/week in this sample. Correlations with measures of pain and mental and physical health (**Table 3**) indicate a few significant correlations with coping subscales. Guarding showed a positive and moderate association with pain and fatigue intensity/impact and with physical dysfunction. Resting was positively associated with both fatigue and physical dysfunction measures. Asking for Assistance was similarly positively correlated with measure of pain and fatigue and was also associated with greater depressive symptoms. Task Persistence was negatively correlated with depressive symptoms. Pacing was the only activity scale to correlate with less anxiety and greater mental health, but was also related to greater physical dysfunction.

Table 1 | Sample demographics ($N = 44$).

Variable	Mean	SD	Min	Max
Age	66.48	6.93	53	84
BMI†	30.81	5.01	23.34	43.36
TUG‡	9.10	1.86	5.51	16.81
6 min walk	1248.82	224.73	825	1930
Pain (0–10)*	2.98	1.45	0.61	6.46
Fatigue (0–10)*	3.26	3.03	0.71	7.34
Stiffness (0–10)*	3.42	1.52	0.82	7.23
Activity	348.34	83.33	200.88	541.97
			N	%
Sex	Male		14	31.8
	Female		30	68.2
Marital status	Single never married		1	2.4
	Married		25	59.5
	Divorced		9	21.4
	Widowed		7	16.7
Ethnicity	Non-Hispanic		43	100
Race	American Indian/Alaskan native		1	2.3
	Black/African American		5	11.4
	White		36	81.8
	More than one race		2	4.5
Employment status	Working/volunteering ≥ 36 h/week		6	13.6
	Working/volunteering 20–35 h/week		7	15.9
	Retired, not working at least 20 h/week		25	56.8
	Other		6	13.6
Veteran status	Non-veteran		35	79.5
	Veteran		9	20.5
Educational level	12 years		5	11.9
	13–16 years		16	38.1
	17–20 years		18	42.9
	21–25 years		3	7.2

**Variable represents average across the ecological momentary assessment period; † one individual with BMI = 55.99 was identified as an outlier and removed from main analyses; ‡ one individual was unable to complete the TUG in the maximum allotted time of 30 s and these data were not included in analyses.*

COPING AND ACTIVITY LEVEL AND VARIABILITY

Results for the MLM predicting objective physical activity from momentary pain and fatigue, coping subscales, controlling for demographic and clinical variables indicated that among the covariates, only BMI was significantly related to lower activity levels ($p = 0.01$). Momentary pain was not related to activity level, but momentary fatigue was negatively related to activity ($p < 0.001$). In terms of coping, Guarding was significantly related to lower activity levels ($p = 0.03$) and Asking for Assistance was significantly related to higher activity levels ($p < 0.001$). No other coping subscales approached significance in predicting activity level. We also examined whether average activity level (i.e., whether someone was generally inactive or active) moderated the association between coping subscales and activity level by including interaction terms AVERAGE ACTIVITY × (COPING) in the equation. In no case did average activity level moderate the association between coping and momentary activity. All of these results were replicated when we ran the MLM with all coping subscales included and separate MLMs for each subscale (to optimize power to detect differences, given our small *n*).

Table 2 | Correlations and distribution statistics for CPCI subscales (*N* = 44).

CPCI subscales	Guarding	Resting	Asking for assistance	Task persistence	Pacing
Guarding	–				
Resting	0.28	–			
Asking for assistance	0.40**	0.14	–		
Task persistence	−0.31*	0.01	−0.17	–	
Activity pacing	0.33*	0.30*	0.07	0.08	–
Mean	3.40	3.18	1.63	4.47	3.68
SD	1.38	1.45	1.60	1.34	1.67
Skew	−0.18	0.06	0.63	−0.17	0.33
Kurtosis	−0.28	−0.17	−0.86	−1.12	−0.29

**p* ≤ 0.05, ***p* < 0.01.

Results for the MLM predicting activity variability indicated that no demographic or clinical variables were significant predictors. In direct contrast to the findings for activity level, pain (est. = −1.52, SE = 0.63, $t = -2.40$, $p = 0.02$) but not fatigue predicted activity variability – lower pain was associated with higher activity variability. No coping variables were significant predictors of between-person variability in activity. As with the analyses for activity level, we also examined whether average activity level moderated the association between coping and activity variability. In no case did average level of activity moderate the association between coping and activity variability. All of these findings were consistent whether we ran the MLM with all coping subscales included or where we ran separate MLMs for each subscale (to optimize power to detect differences, given our small *n*).

COPING AS A MODERATOR OF THE ASSOCIATION BETWEEN PAIN AND ACTIVITY

Results for the MLM testing whether the various types of coping moderate the association between momentary changes in pain and activity (**Table 4**) indicate that BMI is the only clinical variable that was a significant predictor, showing a negative association with activity. In terms of main effects of coping, consistent with the findings for the first research question, Guarding was significantly related to less activity and Asking for Assistance was related to more activity. Only one coping variable, Resting, moderated the association between pain and activity. Examination of the simple slope between momentary changes in pain and momentary activity at low, mean, and high use of Resting (**Figure 1**), indicate that for those who more frequently use Resting as a coping strategy, there is a positive association between momentary changes in pain and activity. For those with mean levels of use of Resting, there is little association between pain and activity, whereas for those who use Resting infrequently, there is a negative association between pain and activity. In other words, those who experience increases in pain with increased activity, are more likely to use resting as a means of coping that those who either do not experience a relation between pain and activity or who experience increases in pain in the context of lower activity (e.g., such as during resting).

Table 3 | Correlations between CPCI subscales and measures of pain, mental, and physical health.

	Guarding	Resting	Asking for Assistance	Task persistence	Activity pacing
PAIN					
BPI-total score	0.49**	0.29	0.45**	−0.26	0.23
FATIGUE					
BFI-total score	0.41**	0.47**	0.44**	−0.28	−0.04
MENTAL HEALTH					
CES-D (depressive symptoms)	0.29	0.17	0.36*	−0.38**	−0.27
STPI (anxiety)	−0.19	0.10	0.15	0.08	−0.33*
SF-12 mental component score	0.05	0.12	0.03	0.09	0.32*
PHYSICAL HEALTH					
WOMAC (physical dysfunction)	0.35*	0.35*	0.29	−0.21	0.32*
SF-12 physical component score	0.01	0.12	0.04	0.09	0.28

**p* ≤ 0.05, ***p* < 0.01. BPI, Brief Pain Inventory; BFI, Brief Fatigue Inventory; CES-D, Center for Epidemiological Studies Depression; STPI, State Trait Personality Inventory; SF-12, Short Form-12; WOMAC, Western Ontario McMaster Arthritis Index.

Table 4 | Multilevel model results predicting momentary activity from interaction terms including coping subscales and pain.

Covariance parameter	Subject	Estimate	SE	*Z*	*p*
RANDOM EFFECTS					
Intercept UN	ID	6720.36	2263.41	2.97	<0.01
AR(1)	ID	0.09	0.04	2.50	0.01
Residual		19792	887.11	22.31	<0.0001
Effect		**β**	**SE**	***T***	***p***
FIXED EFFECTS					
Intercept		744.21	130.44	5.71	<0.0001
Level 1 (df = 30)					
Age		−2.67	1.67	−1.60	0.12
BMI		−6.85	2.28	−3.00	0.01
Timed Up & Go		3.20	9.39	0.34	0.74
KL		−26.29	26.44	−0.99	0.32
Average pain		3.22	9.19	0.35	0.73
Guarding*		−30.07	13.06	−2.30	0.03
Resting*		−0.21	8.02	−0.03	0.98
Asking for assistance*		39.09	10.42	3.75	<0.001
Task persistence*		11.54	14.78	0.78	0.44
Activity pacing*		−1.00	10.65	−0.09	0.93
Level 3 (df = 1032)					
ΔPain		−0.50	4.80	−0.10	0.92
Level 1 × Level 3 (df = 1032)					
ΔPain × guarding		5.69	3.30	1.73	0.09
ΔPain × resting		8.99	4.55	1.98	0.04
ΔPain × asking for assistance		−4.43	3.73	−1.19	0.24
ΔPain × task persistence		1.21	4.03	0.30	0.76
ΔPain × activity pacing		−1.46	2.91	−0.50	0.62

**Scales from the Chronic Pain Coping Inventory.*

However, it is important to note that we cannot determine from these data whether resting causes a stronger association between pain and activity or whether the strong association between pain and activity precipitates resting behavior.

COPING AS A MODERATOR OF THE ASSOCIATION BETWEEN FATIGUE AND ACTIVITY

Results for the MLM testing whether the various types of coping moderate the association between momentary changes in fatigue and activity level (**Table 5**) indicate that BMI is the only clinical variable that was a significant predictor – those with higher BMI had lower levels of activity. In terms of main effects of coping, consistent with the findings for the first study question, Guarding was significantly related to less activity and Asking for Assistance was related to more activity. In contrast to the findings for pain, four coping subscales moderated the association between momentary changes in fatigue and activity: Guarding, Resting, Task Persistence, and Pacing. The graph of the moderating effect of Guarding (**Figure 2**), which also clearly shows that higher levels of guarding are related to lower levels of activity, indicates that with decreasing use of Guarding, the association between momentary changes in fatigue and activity is more negative. Those who use Guarding the most have the lowest level of activity and the lowest association between momentary fatigue and activity.

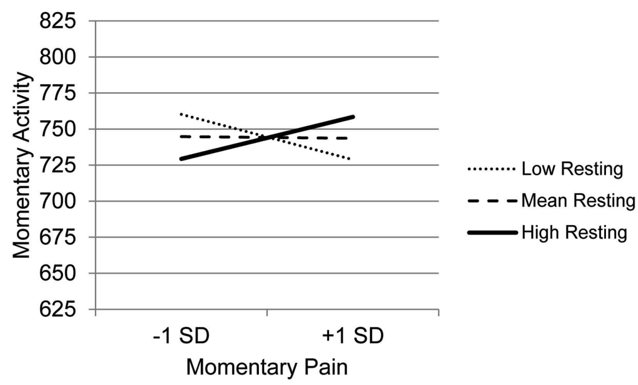

FIGURE 1 | Simple regression slopes for centered momentary pain and use of Resting at low, mean, and high levels of momentary physical activity.

Table 5 | Multilevel model results predicting momentary activity from interaction terms including coping subscales and fatigue.

Covariance parameter	Subject	Estimate	SE	*Z*	*p*
RANDOM EFFECTS					
Intercept UN	ID	6991.39	2400.42	2.91	0.002
AR(1)	ID	0.07	0.04	1.95	0.05
Residual		18649	834.02	22.36	<0.0001
Effect		**β**	**SE**	***T***	***p***
FIXED EFFECTS					
Intercept		712.15	137.59	5.18	<0.0001
Level 1 (df = 30)					
Age		−2.22	1.78	−1.25	0.22
BMI		−6.67	2.33	−2.86	0.01
Timed Up & Go		4.09	9.68	0.42	0.68
KL		−29.38	28.42	−1.03	0.30
Average fatigue		1.31	6.34	0.21	0.84
Guarding*		−31.22	13.35	−2.34	0.03
Resting*		−0.60	8.32	−0.07	0.94
Asking for assistance*		40.09	11.09	3.62	0.001
Task persistence*		13.43	15.05	0.89	0.38
Activity pacing*		−1.28	10.02	−0.13	0.90
Level 3 (df = 1033)					
ΔFatigue		−20.52	2.95	−6.96	<0.0001
Level 1 × Level 3 (df = 1033)					
ΔFatigue × guarding		3.75	1.72	2.18	0.03
ΔFatigue × resting		4.89	1.73	2.82	0.005
ΔFatigue × asking for assistance		−3.56	2.06	−1.72	0.09
ΔFatigue × task persistence		6.41	1.99	3.22	0.001
ΔFatigue × activity pacing		3.84	1.16	3.31	0.001

**Scales from the Chronic Pain Coping Inventory.*

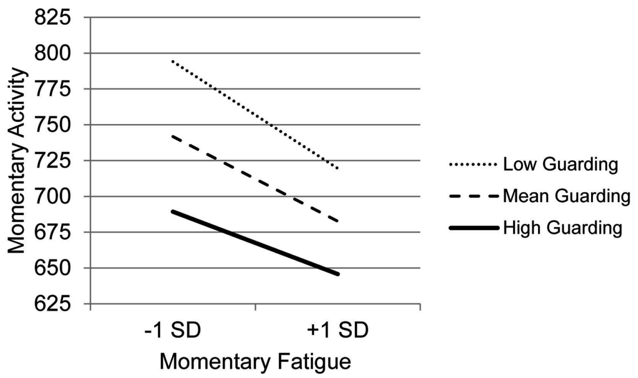

FIGURE 2 | Simple regression slopes for centered momentary fatigue and use of Guarding at low, mean, and high levels of momentary physical activity.

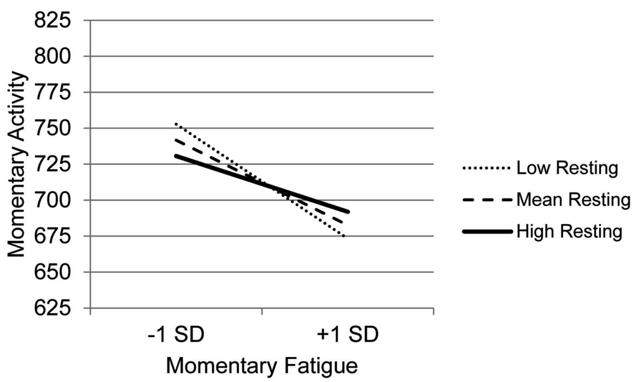

FIGURE 3 | Simple regression slopes for centered momentary fatigue and use of Resting at low, mean, and high levels of momentary physical activity.

The graph for Resting (**Figure 3**) indicates that with decreasing use of Resting, the association between fatigue and activity is increasingly negative. Those who experience the most precipitous drops in activity in the context of high fatigue are the least likely to use Resting as a coping behavior, whereas those who report frequent resting do not show as steep a decline in activity in the context of increased fatigue. The graph for Task persistence (**Figure 4**) indicates that those who with the highest use of Task Persistence have the lowest association between momentary fatigue and activity; the fatigue/activity association becomes increasingly negative with decreasing use of Task Persistence. In other words, those who report high levels of persistence have slightly lower activity levels in the context of increased fatigue; in contrast, those who report low persistence show a rather steep drop in activity with increased fatigue. The graph for Pacing (**Figure 5**) indicates a similar, though less dramatic pattern. Those with the highest use of Pacing have the smallest association between momentary fatigue and activity. With decreasing use of Pacing, the association between fatigue and activity becomes increasingly negative.

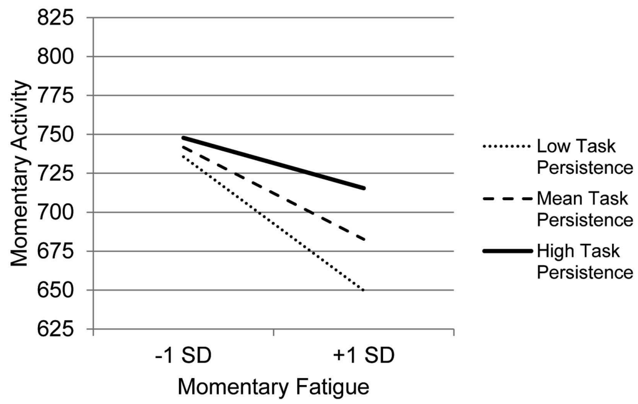

FIGURE 4 | Simple regression slopes for centered momentary fatigue and use of Task Persistence at low, mean, and high levels of momentary physical activity.

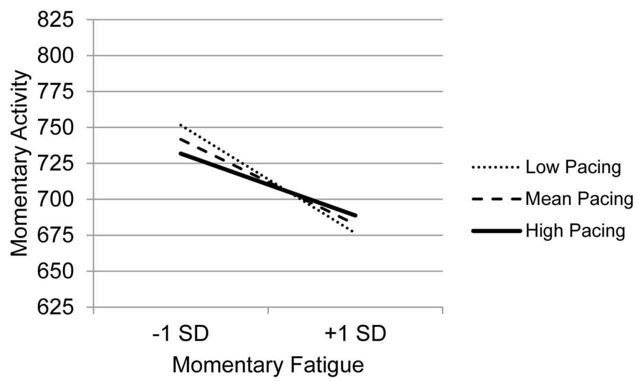

FIGURE 5 | Simple regression slopes for centered momentary fatigue and use of Pacing at low, mean, and high levels of momentary physical activity.

DISCUSSION

In this study, we investigated the relationship between symptoms of pain and fatigue, coping strategies, and objective activity patterns over a 7 day period in a sample of adults with knee or hip OA. There is a paucity of research that has examined how coping relates to the association between symptoms and activity in OA, and the use of ecological momentary assessment in this study provides important insights and brings up additional research questions.

We first examined the relationships between symptoms, coping, and activity in separate models for each symptom (pain and fatigue). We found that pain assessed momentarily was not significantly related to activity levels as measured by accelerometer. This finding is similar to previous studies of low back pain that have also reported a lack of relationship between pain and activity when measured objectively (Vendrig and Lousberg, 1997; Hasenbring et al., 2006; Huijnen et al., 2010). Fatigue, a symptom that is not typically addressed in clinical interventions and not typically examined in OA research studies, was significantly and negatively related to activity levels similar to our findings in a separate sample of women with knee or hip OA (Murphy et al., 2008b). In addition, higher BMI was associated with lower activity levels in all statistical models. Given that many people with knee or hip OA often have high BMI and physical activity interventions are widely recommended for this population, it may be important to address fatigue management in these interventions given its strong association with lowered activity levels.

In these models, only two coping strategies that we initially classified as avoidance behaviors, Asking for Assistance and Guarding, were significantly associated with activity levels, but in opposite directions. Consistent with our hypothesis, Guarding was associated with lower activity. In contrast with expectations; however, Asking for Assistance was associated with higher activity levels. People with the lowest activity levels had the highest use of Guarding and the lowest use of Asking for Assistance. These findings are interesting given that both of these coping strategies were highly associated with pain interference on the BPI. It may be that people who are asking for assistance have more opportunities to interact and ask others for help; however, Asking for Assistance was also associated with depressive symptoms on the CES-D. While Asking for Assistance appears to be associated with a number of negative outcomes, the findings of this study suggest that it is not associated with low levels of activity as one might expect. Since this was the least commonly used strategy from a relatively small sample, future work should further examine how this behavior impacts symptoms and functioning.

When we examined the relationships between symptoms, coping, and activity variability, we found that only pain was negatively associated with activity variability, suggesting that those who have relatively high levels of pain maintain a more consistent level of activity across a day than those who experience less pain. No coping variables were associated with activity variability. Some studies suggest that increased activity variability is associated with poor outcomes (Huijnen et al., 2009; Kindermans et al., 2011). As a result, activity pacing is often encouraged as one solution to high variability in daily activity. People who use pacing (Fordyce, 1976) should have less variability in their activity as they are trying to maintain a steady pace and reduce periods of high activity that could lead to a flare in symptoms (Birkholtz et al., 2004). In a pilot study, we found that people who participated in a tailored activity pacing intervention had reduced variability in their activity and reduced fatigue levels after the intervention while maintaining similar average activity levels found at baseline (Murphy et al., 2012). However, it is important to note that pacing could potentially be viewed as an adaptive or maladaptive behavior depending upon whether or not people are instructed how to pace (Murphy and Clauw, 2010). For instance, some studies have found positive associations between the natural use of pacing and measures of disability (McCracken and Samuel, 2007; Karsdorp and Vlaeyen, 2009; Kindermans et al., 2011). Therefore, it is notable that self-reported natural levels of pacing are not related significantly to daily variability in activity. More research is needed to determine how the use of pacing (both use of pacing naturally and after pacing instruction) affects physical activity variability over longer periods of time.

COPING AS A MODERATOR VARIABLE

Tests of interaction effects in this study are important because they examine some key assumptions about how the behavioral coping strategies under consideration work on a moment to moment basis. For example, it is thought that when people experience days or moments of high pain or high fatigue, these symptoms will affect their level of activity. The assumptions underlying the avoidance, persistence, pacing categories is that use of these coping strategies will modify the expected relationship between pain or fatigue and activity. Avoidance strategies are thought to encompass a group of behaviors that result in restricted activity (rest, guarding, asking for assistance) in the context of symptoms. Persistence strategies are thought to reflect independence of activity and symptom severity due to the assumption that a person who persists carries on despite their discomfort. Pacing, like persistence, is thought to reflect a strategy of intentionally planning and carrying out activities, somewhat independent of pain or fatigue severity. This is the first known test of these assumptions about the types of coping. We found that our hypotheses were partially supported and that the effects of the moderators were different depending on whether we were examining pain or fatigue.

For the relationship between pain and activity, only Resting was a significant moderator. People who use Resting most frequently had a positive relationship between pain and activity. It appears that people who rest the most frequently have the highest levels of activity-related pain, whereas people who rest the least have a negative relationship between activity and pain. It seems sensible to conclude that those who experience that greatest increases in pain with increased activity might be more prone to rest as a means of attempting to cope with the pain. It is possible that people who use Resting the least may get relief from pain with activity and/or slight increases in pain with lower activity (e.g., resting), either due to physiological processes or psychological processes such as being distracted from pain by high activity, but further study is needed to examine the nature of this relationship. Though this seems like the most plausible explanation, given the correlational nature of our data and analyses and the fact that the association between pain and activity is the opposite of what we had expected, we cannot draw causal conclusions from these data. Further examination that looks at moment to moment dynamic associations between resting as a means of coping, changes in pain, and activity level would help to delineate the direction of these associations.

For the relationship between fatigue and activity, several coping variables were significant moderators. Although we expected that people who most frequently use coping strategies considered avoidant would have the strongest relationships between symptoms and activity, high levels of Guarding and resting were associated with the weakest associations between fatigue and activity. Specifically people who use Guarding most frequently had the smallest association between fatigue and activity. However, because we found that people who use Guarding are less active than people who use other coping strategies, it may be that these people do not engage in activity at a level that increases fatigue. Taken together with the findings for the moderating effect of resting on the pain/activity association, these findings suggest that use of avoidant coping strategies may be driven by increases in pain or fatigue in the context of activity. This is in contrast to the notion that people select a coping strategy (based on training or natural inclination) and that coping strategy is a main determinant of the experience of symptoms and activity. Though these data are considered preliminary and in need of further examination, these findings may suggest that the direction of the relationship between some coping strategies and symptoms/activity that we are observing here are different from what is commonly assumed.

Turning to persistence coping, we hypothesized that people who most frequently use task persistence would have the lowest relationship between fatigue and activity level and this was supported. People who reported high levels of persistence had the highest activity levels and for these people there was a dissociation between symptoms and activity such that engaging in activity was not dependent on having low fatigue. For people who used Task Persistence less, when fatigue was high, there was a steep decline in activity level. This finding is significant in that it provides objective evidence that people who say they persist in tasks are actually doing so in terms of persisting through their fatigue, and seems to support other studies in which Task Persistence as measured by the CPCI is considered a positive coping strategy (Jensen, 1991;Jensen et al., 1995). It is important to note that of all the CPCI subscales that we examined, only Task Persistence showed negative correlations with pain and fatigue. Although these correlations were small and non-significant in this sample, these data may suggest that Task Persistence is more feasible for those with relatively lower pain or that Task Persistence somehow results in lower pain intensity and fatigue. Also notable is that Task Persistence was moderately negatively related to depressive symptoms. As with the other symptoms, it is both possible that those who are not depressed find it easier to persist than those with greater depression or, alternatively, that persisting through tasks results in better mood.

The use of Pacing also moderated the relationship between fatigue and activity. While all groups of pacers had negative relationships between fatigue and activity, the people who most frequently used activity pacing had the weakest relationship between fatigue and activity. Whether a person used pacing frequently or not, increases in fatigue were related to decreases in activity; but, for those with the highest level of pacing behaviors, the drop in activity was less severe compared to those who reported low levels of pacing. Like Task Persistence, Pacing was related to indicators of positive mental health. Specifically it was related to lower levels of anxiety and higher overall mental health. Given that we cannot infer causation from these data, it is possible that pacing is more feasible strategy for those who have better mental health, or that something about Pacing behavior promotes better mental health.

STRENGTHS AND LIMITATIONS

This is the first study to our knowledge that investigated how coping strategies relate to the association between symptoms and activity in people with knee and hip OA. As such, it is somewhat difficult to compare our findings to other studies. In addition, we are measuring activity patterns using a wrist-worn device which may yield different findings than studies that use devices worn on different sites of the body and that measure other variables such as position change or energy expenditure. The use of ecological momentary assessment of symptoms with concurrent physical activity reporting provides rich information on people's daily life patterns. The use of the CPCI to measure coping strategies was an important starting point in this research; however, this measure which involves a 7 day recall of past coping strategies restricted our treatment of coping strategy as a personal trait. It is likely that people with OA have more complex coping strategy use, that is, they may not be only a "task persister" or an "avoider," and selection of coping strategy may be depend on the particular situation. It should be noted that in this study, the CPCI, which asks participants to recall their coping during the previous 7 days, was completed at the baseline visit instead of the week of the home monitoring which could have potentially attenuated associations between coping strategy use, symptoms, and activity. Future studies should examine momentary use of coping strategies to better examine how within-day use of these strategies relates to subsequent physical activity and symptoms. Due to the fact that our sample was mostly white females diagnosed with OA, with low levels of pain and fatigue, our ability to generalize our findings to other populations is somewhat limited. Our conclusions regarding these findings would be strengthened by replication in other samples.

CONCLUSION

In conclusion, we found that coping strategies moderated the relationship between pain and activity and fatigue and activity in different ways. Many coping strategies were moderators of how people engage in activity with fatigue. While most treatment efforts in OA are focused on pain, this study supports the importance of examining how people cope with fatigue in their daily lives to help develop treatments that also address this symptom.

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Using text messages to bridge the intention-behavior gap? A pilot study on the use of text message reminders to increase objectively assessed physical activity in daily life

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Sedentarism is a serious health concern in industrialized countries throughout the world. We examined whether a text message-based intervention, targeted at increasing daily levels of physical activity, would be more effective than a standard psychoeducational intervention and a control condition. Sixty-three individuals (43 women) with a mean age of 23.7 years participated in the study. They were randomly assigned to a psychoeducational standard intervention; an augmented intervention with additional short text messages sent to the mobile phones to remind participants of their action plans, and a control condition. Objectively assessed physical activity and self-efficacy were assessed pre- and post-intervention. Participants in the control condition showed a significant decline in physical activity from pre-assessment to post-assessment, whereas participants in both intervention arms exhibited a slight increase. Moreover, the augmented intervention resulted in a marginally significant increase in self-efficacy, whereas the standard intervention resulted in a significant decrease. The findings suggest that short text messages reminding individuals of their action plans are not more effective than an intervention without text messages, although there seems to be a beneficial effect on self-efficacy, which might facilitate behavior change in the long-term. Challenging aspects of the research design (e.g., reactivity of the assessment protocol) are discussed and suggestions for future research are highlighted.

Keywords: accelerometer, daily life physical activity, intention-behavior gap, mobile phone, reactivity, sedentary lifestyle, short message service, text reminder messages

INTRODUCTION

About 80% of individuals in industrialized countries can be considered sedentary (i.e., expending less than 10% of their daily energy in the performance of moderate and high intensity physical activity; Bernstein et al., 1999). A sedentary lifestyle is a known risk factor for various diseases (e.g., cardiovascular diseases, diabetes, osteoporosis, cancer; Warburton et al., 2006). Consequently, regular physical activity is inversely related with morbidity and mortality (for meta-analyses and reviews, e.g., Blair and Brodney, 1999; Oguma et al., 2002; Löllgen et al., 2009; Samitz et al., 2011; Sattelmair et al., 2011; Woodcock et al., 2011). In sum, there is robust evidence that physical activity (i.e., bodily movement that substantially increases energy expenditure) is reliably related to better physical health and lower mortality. Importantly, drawing on previous research, exercising at least five times a week for 30 min has been recommended as a positive impact on health (e.g., United Kingdom Department of Health, 2004). However, this amount of physical activity is rarely achieved in industrialized countries and has even been considered to demotivate individuals from becoming physically active (e.g., Sallis et al., 1986; Cox et al., 2003).

Of note, a recently published study suggested that even moderate-to-low doses of physical activity may positively impact health (Wen et al., 2011). Specifically, in this prospective cohort study, over 400,000 individuals in Taiwan were tracked for an average of 8 years to predict mortality risk from (self-reported) weekly exercise. Wen and colleagues showed that exercising 15 min a day (i.e., approximately 90 min per week) resulted in a 14% reduction in all-cause mortality, suggesting that even modest doses of regular physical activity may have beneficial effects on health. Several other studies support this finding (e.g., Andersen et al., 2000; Löllgen et al., 2009; Woodcock et al., 2011). In accordance with this, the National Institutes of Health (1996) Consensus Development Panel on Physical Activity and Cardiovascular Health recommended implementing moderate bouts of physical activity for 30 min each day. This recommendation implies various daily life physical activity episodes (e.g., occupational activities, brisk walking, cycling, yard work). Thus, there is consensus among researchers that rather than persuading individuals to engage in vigorous physical activity to secure health, it might be more promising to encourage them to increase their daily amount of moderate intensity physical activity. Importantly, this recommendation relies on the assumption that moderate-to-low doses of physical activity are accompanied by rather favorable affective responses, which – in turn – should be related to better adherence, thus ultimately increasing the likelihood of engaging in more vigorous physical exercise in the future (Consensus Development Panel on Physical Activity and Cardiovascular Health, 1996; for a discussion of this assumption, see Ekkekakis et al., 2008).

Given the robust evidence of physical and psychological benefits of even low-to-moderate doses of physical activity, various intervention studies have been carried out to examine the effectiveness of programs to reduce sedentary behavior and to increase physical activity in adults (for meta-analyses and reviews, see, e.g., Kahn et al., 2002; Foster et al., 2005; Conn et al., 2011; Williams and French, 2011). In general, it seems that intervention programs are modestly effective in reaching this aim with effect sizes ranging from 0.19 to 0.28, thus indicating rather small effects.

A possible explanation for these rather marginal effects is that interventions targeting behavior change might lose impact once participants are involved with their daily routines, which could distract them from their action plans. Weinstein (1988), for example, used a "messy desk"-analogy to illustrate the obstacles that may emerge when aiming to transform intentions into action. He argued that various factors could intervene between intentions and action. Specifically, daily routines and other competing plans struggle for attentional resources and could therefore interfere with the motivation to change behavior. To counter this, Weinstein suggested using reminders to keep intentions active. Indeed, there is evidence that periodic prompts and reminders could increase the effectiveness of health intervention programs, although analyses of long-term effects are largely missing to date (for reviews, e.g., Marcus et al., 1998; Fry and Neff, 2009).

In the last decades, new mobile technologies have become available that might prove useful to keep intentions active and, thus, to facilitate behavior change (e.g., Riley et al., 2011). In particular, mobile phones are now common companions in everyday-life, and Short Message Service (SMS) pervades the general public to nearly 100% (Patrick et al., 2008). SMS has the potential to reach an individual at any time, place, or setting, thus constituting a promising addendum of health promotion programs (for a review, e.g., Fjeldsoe et al., 2009). In a recent study, Prestwich et al. (2010) randomly assigned participants to one of three conditions. In one group, participants took part in a short psychological intervention to increase their daily amount of brisk walking by forming implementation intentions (e.g., Gollwitzer, 1993). In particular, they were instructed "to think when and where would be the most convenient or enjoyable for them to walk 30 min per day for 5 days a week in bouts of at least 10 min" (Prestwich et al., 2010, pp. 42–43). In addition, for four consecutive weeks they received text messages to remind them of their action plans (i.e., in which situation they intended to walk briskly). In a second group, participants also took part in a psychological intervention and also received text messages. However, in this group the text messages aimed to remind them of their goals (i.e., to walk briskly five times a week). Participants in the control group did not form implementation intentions but were merely informed about the governmental guidelines for physical activity and the health benefits thereof. At the beginning and at the end of the study participants completed a self-report measure of brisk walking, which constituted the main outcome measure. The results showed that participants in both intervention arms significantly increased brisk walking relative to the control group. Moreover, both intervention groups were better able to recall their plans and goals, respectively, following the intervention. However, the main outcome variable was assessed via self-report, and the study could not answer the important question whether an augmented psychological intervention (i.e., with additional text messages) is, *per se*, superior relative to a standard intervention (i.e., implementation intentions without SMS reminders), thus demonstrating incremental utility.

Hence, we were interested to examine whether the use of text message reminders in addition to a standard intervention relates to a higher amount of physical activity performed in everyday-life as compared to a standard intervention and a control group. We expected that reminding participants of their intentions to become more physically active would result in a more successful behavior change as compared to a standard intervention. Importantly, contrary to previous studies, we aimed to assess physical activity by means of objective data. That is, we recorded bodily movements by means of accelerometers the week prior to the intervention and the week following the intervention (i.e., for two consecutive weeks). Finally, we also assessed self-reported change in physical activity, self-efficacy, and participants' satisfaction with both intervention arms.

MATERIALS AND METHODS

PARTICIPANTS

Overall, 63 individuals with an age range from 18 to 34 years voluntarily agreed to participate in the study. They were recruited via oral communication and flyers distributed at the university campus. Participants were randomly assigned to one of three intervention arms: no intervention ($n = 21$, 17 women), standard psychoeducational intervention ($n = 20$, 12 women), and augmented intervention ($n = 22$, 14 women). The study was advertised as a study on objectively assessed physical activity as performed in everyday-life. Only individuals who owned a mobile phone and reported to not exercise extensively on a regular basis (i.e., exercising a maximum of 1 day a week for less than 1 h) were eligible for study participation.

INTERVENTION ARMS

The standard intervention was a solitary session (approximately 35 min) aimed at encouraging participants to increase their daily physical activity by providing information about the psychological and physical benefits of even mild doses of daily physical activity. Specifically, the intervention was grounded on to two prominent theories in health psychology, the social-cognitive theory (Bandura, 1986), and the theory of implementation intentions (Gollwitzer, 1999). In particular, participants were taught that life conditions have changed dramatically during the last centuries, and in modern societies physical activity has dramatically decreased. They were then informed about the physical and psychological short-term consequences of physical activity and that even small doses of everyday physical activity are beneficial to health (outcome expectancies). Finally, participants received information about various ways to increase daily life physical activity (e.g., using the stairs instead of the elevator, walking/cycling instead of taking the car/bus, get off the bus one stop ahead). They should then indicate whether they could carry out this activity several times a day, once every day, several times a week, once a week, or less often. Moreover, they were encouraged to think of other alternative plans of how to increase their daily amount of physical activity. In a final step, participants should quote in detail which behavior they intended to perform in which situation during the next week (when, where, and how; i.e., forming implementation intentions). Participants took part in this intervention in small groups of 4–11 individuals. The sessions were led by the second (Catalina Schmitz) and third author (Matthias Warken).

In the augmented intervention arm, participants attended the same session but additionally received short text messages on their mobile phones in the week following the session, which aimed to remind them about their action plans. Each day, only one message was sent in a time frame from 9 a.m. to 7 p.m., thus totaling seven messages throughout the week. The messages aimed to remind participants about their intentions, were formulated in variants, but were not tailored to the individual (e.g., "Do you still think of your intention to become more physically active?", "Did you think of your intentions yet?", "This is just to remind you of your intention to become physically active." "Do you still know the wording of your intentions?"). Each day a different text was sent to secure attention. Participants were not requested to respond to these reminders, hence we could not verify if messages had been read. However, *post hoc* evaluations suggested that the messages were read. Text messages were sent automatically by an online service (www.sms-one.de). We refer to this group as the intervention plus SMS-group or augmented intervention group. Individuals in the control group did not receive any intervention but underwent repeated assessment of physical activity.

PHYSICAL ACTIVITY

Physical activity was recorded by means of uniaxial accelerometers (Actigraph GT1M) attached to the ankle of the non-dominant foot 1 week prior to the intervention session (week 1) and 1 week following the session (week 2). It should be noted that some research suggests that accelerometers should be attached to the hip to quantify metabolically relevant whole-body movements with sufficient accuracy (for a review, see Trost et al., 2005). However, it seems that recordings at the ankle are more sensitive over a wide intensity range of physical activity as compared to recordings at the hip, suggesting that ankle recordings might be more appropriate to index human movement (Guinhouya et al., 2005). The GT1M is well-validated and has been shown to measure physical activity with sufficient reliability (e.g., Matthews et al., 2002; Trost et al., 2005). The sensitivity of the device ranges from approximately 0.05–2.00 G (gravitation) and the relevant measure is counts/min. Activity counts were sampled at 30 Hz and stored in memory for each minute.

Moreover, ratings of perceived change in physical activity were assessed. At the end of the intervention, participants were instructed to rate on a 3-point scale to what extent they believed their physical activity had changed from pre-assessment to post-assessment (physical activity increased, stayed about the same, decreased). We decided to assess subjective change in physical activity instead of absolute activity for each week because we believe that it is easier for individuals to report relative change of a certain behavior across a period of 2 weeks as compared to absolute levels. Moreover, our aim was to validate the changes in objectively assessed physical activity with subjective ratings. Therefore, we opted for a simple change score with adequate face validity.

PSYCHOLOGICAL AND DEMOGRAPHIC MEASURES

Use of the mobile phone was assessed via two items: How often do you use your mobile phone? How often do you carry your mobile phone with you? Answers were given on a 3-point frequency scale (seldom, sometimes, often). Familiarity with SMS was assessed via two questions: How many text messages do you send each month? How many text messages do you receive each month? Answers were given on 4-point frequency scales (between 0 and 10, more than 10, more than 50, more than 100). Responses were summed for both mobile phone use and familiarity with text messaging. Both scales were positively interrelated ($r = 0.49$, $p < 0.001$). These variables were collected to assure comparability across experimental groups.

Self-efficacy was assessed in both intervention groups immediately after the intervention session and 1 week later after the second assessment of physical activity by means of a self-constructed scale. We used a modified version of the self-efficacy scale for physical exercise (Fuchs and Schwarzer, 1994). This instrument comprises six items assessing self-efficacy with respect to the planned physical activities participants gathered in the intervention session despite of psychological, social, or contextual obstacles (e.g., "I am confident that I manage to follow my plans with respect to physical activity even when I feel tired," ". . . even when I feel stressed," ". . . even when I am in a hurry," ". . . even when I am busy," ". . . even when I am socially involved," ". . . even when being physically active seems incompatible with other people's behavior"). Individuals are instructed to rate their confidence to be physically active on a 7-point Likert scale between the poles 1 (not at all confident) and 7 (absolutely confident). The reliability of this scale was fair (Cronbach's alpha = 0.68). This scale was not filled out by participants in the control condition because it was explicitly framed to the action plans that were developed during the intervention sessions and participants in the control condition were not asked to develop any plans to change behavior.

Furthermore, participants' satisfaction with both intervention arms was analyzed. Therefore, they completed a short questionnaire at the end of the study evaluating whether the standard intervention was perceived as meaningful (vs. meaningless), informative (vs. pointless), helpful (vs. needless), effective (vs. ineffective), and interesting (vs. boring) on 7-point bipolar items (ranging from 1 to 7). The mean sum score of this scale was 15.17 (SD = 5.38), suggesting mediate scores of satisfaction. Internal consistency of this scale was 0.57 (Cronbach's alpha). Although the reliability was rather low, we decided to include this measure in further analysis, because it may help exploring how the intervention session was perceived and whether satisfaction with the intervention needs to be considered when evaluating the effectiveness of these intervention programs. In order to evaluate the quality of the text messages participants in the augmented intervention group additionally filled out a short scale asking whether the text messages were perceived as meaningful (vs. meaningless), bothersome (vs. unobtrusive; reversely coded), helpful (vs. needless), joyful (vs. stressful), surprising (vs. predictable), attention grabbing (vs. unspectacular), and interesting (vs. boring) on 7-point bipolar items (ranging from 1 to 7). The mean sum score of this scale was 28.71 (SD = 7.75), suggesting that participants had a rather favorable attitude toward the messages. Internal consistency of this scale was good (Cronbach's alpha = 0.80).

Body Mass Index (BMI) was assessed objectively by measuring participants' weight and height. Moreover, participants worked on questionnaires assessing demographic and lifestyle variables (age, sex, smoking status). Outside temperature was assessed for each day during data collection via an online weather information system.

PROCEDURE

The study protocol was approved by the institutional ethics committee. Participants were enrolled in two waves. About 40% of the participants took part in the study from January to March with an average outside temperature of 2.17˚C (SD = 1.40), whereas 60% of the sample took part during the months May to August with a mean outside temperature of 21.08˚C (SD = 1.53). Only participants who owned a mobile phone were eligible for study participation. They were requested to report their mobile phone numbers prior to participation. Upon arrival at the department, informed consent was obtained and participants were informed that they could discontinue participation in this study any time without giving a reason. Then they were made familiar with the study protocol. They were equipped with the accelerometers and instructed to wear the devices for two consecutive weeks. Moreover, they filled out questionnaires on demographic and lifestyle variables and on their habitual use of the mobile phone. They were then randomly assigned to one of the three groups. Participants in the control group were requested to wear the devices for two consecutive weeks without taking part in an intervention. Participants in the standard intervention and augmented intervention groups also wore the accelerometers for two consecutive weeks but returned to the department after the first week to take part in a psychoeducational session of approximately 35 min duration. Participants of both intervention arms attended the psychoeducational session in mixed groups and were not informed beforehand about their membership in one of the two intervention groups. However, they were told that some of them would receive short text messages during the next week. At the end of the session, they were asked to fill out a questionnaire on self-efficacy. Individuals in the augmented intervention group received short text messages on their mobile phones the week following the intervention session in a time frame from 9 a.m. to 7 p.m. After the second assessment, participants returned to the laboratory to hand over the equipment and to fill out the self-efficacy scale and a short questionnaire on satisfaction with the intervention (only individuals in the intervention groups) and satisfaction with the text messages (only individuals in the augmented intervention group). Then their height and weight were assessed by the experimenter. We decided to measure these variables at the end of the study because of two reasons: First, we wanted to make sure that BMI-measurement could not affect the level of physical activity, because participants might change behavior in accordance with presumed expectations (i.e., being overweight could suggest lower levels of physical activity). Second, we did not expect weight to change substantially across the 2 weeks of study participation, because the intervention focused on rather low-intensity everyday-life physical activity that might not result in significant weight loss. There was no monetary compensation for study participation but participants could receive course credit when applicable and were offered a printout of their activity levels at the end of the study.

DATA PARAMETERIZATION AND ANALYSIS

Accelerometer data were analyzed for each day between 9 a.m. and 10 p.m. We evaluated wearing time by instructing participants to record time intervals when devices were not in use and deleting these time slots. Moreover, when activity counts revealed no movement at all for at least 1 h data were deleted. Night time data were also not analyzed. Thus, the maximum wearing time summed up over 14 days could total 180 h for each individual. Across the sample, 2.20% of the cumulated recording hours were lost due to non-compliance (excluding night time). Activity counts were then aggregated for each week to yield an average score per minute. One individual in the augmented intervention group did not wear the device at all at post-assessment, thus leaving a total sample size of 21 individuals in this group.

RESULTS

In a first set of analyses, we aimed to examine whether the sample was sedentary (i.e., spending less than 10% of the daily energy in the performance of moderate and high intensity physical activity; Bernstein et al., 1999) by calculating the proportion of physical activity episodes (as assessed via accelerometers) prior to the intervention that were of moderate, high, or very high intensity. To quantify these intensity ranges, we used the cutoff-scores published by Matthews (2005). We found that on average 11% of activity episodes were conducted in the moderate, high, or very high intensity range, thus suggesting that the sample was indeed predominantly sedentary. Only individuals with access to a mobile phone were eligible for study participation. All participants were regular mobile phone users and were well experienced with the use of text messages. Descriptive data are presented in **Table 1**.

The mean age of the sample was 23.71 years, the mean BMI was 23.69. There were 19 smokers (31%). We analyzed whether the three experimental groups were comparable on a number of measures. Therefore, we calculated several analyses (Univariate ANOVAs, Cramers V, and Kruskal–Wallis tests) to examine possible differences in age, sex, BMI, mean outside temperature, smoking, and use of the mobile phone. The results are presented in **Table 1**. Overall, there were no significant differences between groups in neither variable, thus suggesting that they were comparable.

We also analyzed whether participants differed with respect to data collection wave (colder months vs. warmer months). In short, we found no significant differences with respect to age [$t(60) = -0.21$, n.s.], BMI [$t(60) = -1.01$; n.s.], sex ($\chi^2 = 0.57$; n.s.), smoking status ($\chi^2 = 0.14$, n.s.), use of mobile phones (Mann–Whitney-$U = 351.50$, n.s.), and familiarity with text messages (Mann–Whitney-$U = 396.50$, n.s.), thus suggesting that participants were comparable across data collection waves.

Table 1 | Sample characteristics and descriptive statistics.

	Control		Intervention		Intervention + SMS		*p*
	M	SD	*M*	SD	*M*	SD	
Age	23.62	3.60	23.60	4.31	23.90	4.12	0.96[a]
BMI	24.12	4.23	23.86	5.15	23.09	4.82	0.77[a]
Mean outside temperature (°C)	13.10	9.84	13.34	9.69	13.86	9.41	0.97[a]
	Percent		**Percent**		**Percent**		
Smokers	48		25		19		0.11[b]
Female sex	81		60		67		0.33[b]
	Mean rank		**Mean rank**		**Mean rank**		
Use of mobile phones	30.36		31.15		32.98		0.88[c]
Familiarity with text messaging	30.79		31.58		30.65		0.98[c]

[a] Univariate ANOVA, [b] Cramers V, [c] Kruskall–Wallis test.

Next, we analyzed if there was a difference in mean physical activity between the three groups from pre-assessment to post-assessment. Therefore, we calculated a repeated measures-ANOVA with group as between-subject factor (control, intervention, intervention plus SMS) and time as within-subject factor (pre- vs. post-assessment). There was a significant interaction of group and time [$F(1, 59) = 4.07$, Wilks-$\lambda = 0.88$, $p = 0.02$, $\eta_p{}^2 = 0.12$], indicating that groups differed with respect to the time course of physical activity. *Post hoc t*-tests suggested that groups did not differ on pre-assessment (control: $M = 707.15$, $SD = 273.01$; intervention: $M = 744.15$, $SD = 202.99$; intervention plus SMS: $M = 696.52$, $SD = 242.42$). However, at post-assessment there was a significant difference between the control group ($M = 610.57$, $SD = 203.57$) and the standard intervention group [$M = 774.49$, $SD = 202.99$; $t(39) = -2.58$, $p = 0.01$, Cohen's $d = 0.81$], and a marginally significant difference between the control group and the augmented intervention group [$M = 738.62$, $SD = 245.69$; $t(40) = -1.84$, $p = 0.07$, Cohen's $d = 0.57$)]. Further analyses revealed that only the control group showed a significant change (i.e., decline) from pre- to post-assessment [$t(20) = 2.72$, $p = 0.01$, Cohen's $d = -0.41$)]. Physical activity in both intervention arms did not change significantly [intervention: $t(19) = -0.77$, $p = 0.45$, Cohen's $d = 0.16$; augmented intervention: $t(20) = -1.06$, $p = 0.30$, Cohen's $d = 0.17$]. This pattern of result is depicted in **Figure 1**.

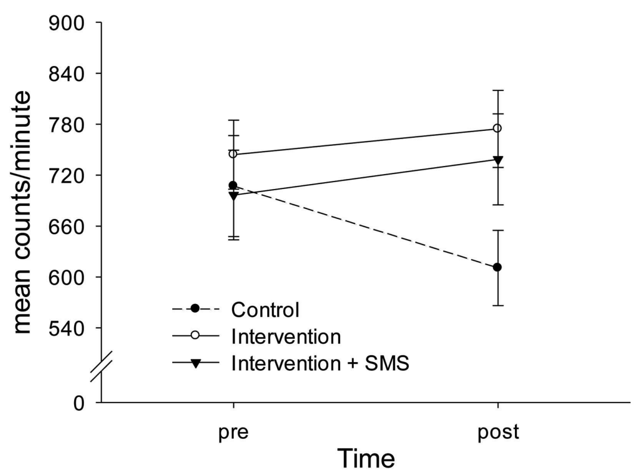

FIGURE 1 | Interaction of group and time on objectively assessed physical activity. The control group showed a significant decline in physical activity from pre- (week 1) to post-assessment (week 2), whereas both intervention groups increased their levels of physical activity moderately. There was no significant difference between the standard intervention and the augmented intervention group (with text messages). Whiskers indicate ± 1 standard error.

To examine whether groups differed in subjectively reported change in physical activity, we analyzed participants' reports of whether they believed their physical activity level had changed from pre-assessment to post-assessment. Overall, 27% believed that their daily amount of physical activity had increased, 63% believed that it stayed about the same, and 10% were of the opinion that it had actually decreased. There was a significant correlation between the subjectively reported change in physical activity and the objectively assessed pre-/post-difference (Spearman rank $\rho = 0.44$, $p < 0.001$). Hence, both subjectively reported and objectively obtained changes in physical activity were moderately interrelated, thus confirming validity of the assessment. Furthermore, we calculated a non-parametric Kruskal–Wallis test with group (control, intervention, augmented intervention) as between-subject factor and subjectively reported change in physical activity as an ordinal dependent variable. There was a significant effect for group (Kruskal–Wallis $H = 12.38$, $p = 0.002$), indicating that individuals in the control group more frequently reported a decline in physical activity (29% of the participants) as compared to the intervention group (0%) and the augmented intervention group (0%). On the contrary, 53% of the intervention group believed that they increased their activity level from pre-assessment to post-assessment as compared to 35% in the augmented intervention group, and 12% in the control group. Thus, the subjective ratings complement the objectively obtained result that a substantial proportion of individuals in the control group showed a decline in physical activity from pre-assessment to post-assessment, whereas individuals in the intervention groups more frequently showed an increase.

Moreover, we examined whether the intervention groups differed significantly in self-efficacy. Therefore, we calculated a repeated measures-ANOVA with group as between-subject factor (intervention vs. intervention plus SMS) and time as within-subject factor (intervention session vs. after post-assessment). We found a significant interaction of group and time [$F(1, 37) = 12.15$, Wilks-$\lambda = 0.75$, $p = 0.001$, $\eta_p^2 = 0.25$]. This effect was due to a significant decline in self-efficacy in the intervention group [$t(17) = 3.44$, $p = 0.003$, Cohen's $d = 0.40$], whereas there was a tendency for the augmented intervention group to show an increase [$t(20) = -1.72$, $p = 0.10$, Cohen's $d = 0.22$]. Moreover, there was a marginally significant difference between groups after the intervention session but no significant difference after post-assessment [$t(39) = -0.01$, $p = 0.99$]. In particular, the intervention group showed higher self-efficacy ratings after the intervention session ($M = 4.14$, SD $= 1.02$) as compared to the augmented intervention group [$M = 3.50$, SD $= 1.06$, $t(37) = 1.91$, $p = 0.07$, Cohen's $d = 0.61$]. **Figure 2** depicts the Group × Time interaction for self-efficacy.

We also calculated Pearson correlations to analyze the relationship between satisfaction with the intervention session and the pre-difference/post-difference in physical activity (activity post-intervention − activity pre-intervention). The correlation was $r = 0.32$ ($p < 0.05$), indicating that those individuals who were more satisfied with the intervention showed a stronger increase in objectively assessed physical activity from pre-assessment to post-assessment.

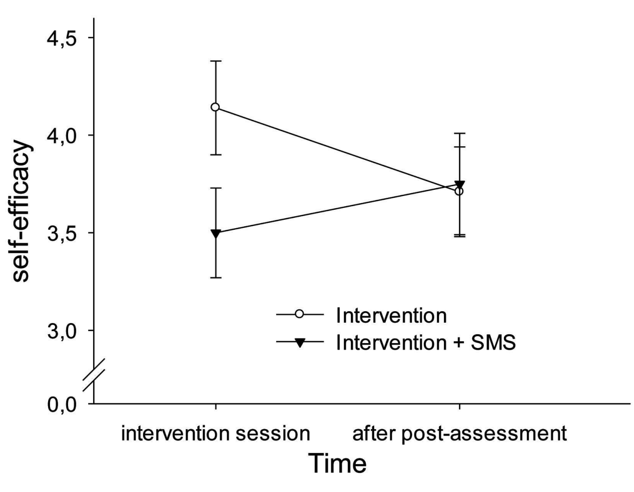

FIGURE 2 | Interaction of group and time on self-efficacy. The augmented intervention group (with text messages) showed an increase in self-efficacy ratings after post-assessment (week 2), whereas the standard intervention group showed a decline. However, both groups marginally differed immediately after the intervention session with the augmented intervention group showing lower ratings than the standard intervention group. Whiskers indicate ± 1 standard error.

Finally, we exploratively tested whether the outside temperature had an impact on the effectiveness of the intervention. Therefore, we re-calculated the repeated measures-ANOVA with group and wave as between-subject factors, and time as within-subject factor. There was a main effect for wave [$F(1, 56) = 8.60$, $p = 0.005$, $\eta_p^2 = 0.13$], indicating that participants were physically more active during warmer temperatures ($M = 773.65$, SD $= 211.02$) as compared to colder temperatures ($M = 618.66$, SD $= 177.01$; Cohen's $d = 0.80$). Moreover, we could confirm the Group × Time interaction [$F(2, 56) = 3.29$, Wilks-$\lambda = 0.90$, $p = 0.045$, $\eta_p^2 = 0.11$], thus replicating that participants in the control group showed a decline of physical activity from pre-assessment to post-assessment, whereas participants in both intervention arms showed a non-significant increase. Of note, there was no significant Group × Wave × Time interaction [$F(2, 56) = 1.17$, Wilks-$\lambda = 0.96$, $p = 0.32$], thus indicating that outside temperature did not differentially impact the effectiveness of the interventions.

DISCUSSION

The study's aim was to examine whether an augmented intervention (with occasional SMS reminders of formerly expressed intentions) would be more effective in increasing objectively assessed physical activity relative to a standard intervention and a control condition. We found a significant interaction of experimental group and time (pre-intervention vs. post-intervention), documenting that individuals in the control group showed decreasing activity levels from pre-assessment to post-assessment. This effect was moderate in size ($d = -0.41$). In contrast, individuals in both intervention arms slightly – however not significantly – increased their physical activity levels as became evident by rather small effect sizes ($d = 0.16$ and $d = 0.17$, respectively). Of note, contrary to expectation, individuals in the augmented intervention arm did not increase activity above those in the standard intervention arm. This finding suggests that an augmented intervention with additional short text reminders is not more effective in changing behavior as compared to a standard psychoeducational intervention, at least not in the short run. It should be noted, however, that we did not control whether text messages had been actually read by the participants or had been discarded without grabbing attention. Hence, the failure to show a beneficial effect of the augmented intervention might be explained by non-adherence with the instructions. However, as the evaluation of the text messages revealed, participants were rather positive about the messages, thus suggesting that the messages had been processed to a certain degree. Nonetheless, in order to secure adherence in future studies participants could be requested to reply to these messages.

Of note, findings for subjectively reported change in physical activity confirmed the general pattern of result. That is, individuals in the control group acknowledged to a greater extent that they exhibited a decline in physical activity during post-assessment as compared to pre-assessment, whereas individuals in both intervention arms were to a larger degree of the opinion that they increased their daily amount of physical activity.

It is particularly striking that participants in the control group showed a substantial decline in physical activity from pre-assessment to post-assessment. This shrinkage might be interpreted in terms of the reactivity of the assessment protocol. Specifically, when participants are aware that physical activity is assessed by means of accelerometers they may increase their daily level of physical activity just to put the devices to a test. Indeed, it has been discussed that methodological reactivity is a challenging topic in ambulatory monitoring studies in general (e.g., Fahrenberg, 1996; Barta et al., 2012). Notably, a recent study seems to support our finding of a tentative reduction in objectively assessed physical activity from pre- to post-intervention. Using a similar research design Motl et al. (2012) found that patients with multiple sclerosis undergoing a social-cognitive internet intervention to increase physical activity showed an approximately 30% decline in accelerometer counts in the week following the intervention. Interestingly, pedometers are powerful tools to increase daily amounts of physical activity by instructing individuals to reach a certain goal each day (e.g., 10,000 steps per day; Kang et al., 2009). Although, in our study the daily amount of physical activity could not be retrieved by the participants, the accelerometers may have tempted them to become physically more active because the procedure was novel. Conversely, when individuals were familiarized with the devices (on post-assessment), they seemed to adjust their daily amount of physical activity to normal (i.e., sedentary) levels. In accordance with this interpretation, the average percentage of moderate, high, or very high intensity physical activity dropped from 11% at pre-assessment to 9% at post-assessment. Hence, although the psychoeducational interventions did not result in reliable increases of physical activity, they seemed to have prevented a decline of physical activity to sedentary levels, which was observed in the control group, indicating reactivity of the measure.

Of note, the standard intervention group showed a significant decrease in self-efficacy ($d = -0.40$), whereas individuals in the augmented intervention arm exhibited a moderate increase in self-efficacy ($d = 0.22$). This finding may suggest that individuals in the standard intervention group became discouraged by the experience that they could not fully transform their intentions into action. On the contrary, the text message reminders in the augmented intervention group might have assisted sedentary individuals to strengthen the confidence to become more active. Importantly, there is robust evidence that self-efficacy is a prerequisite for successful behavior change throughout a variety of health-related domains, including physical activity (e.g., Holden, 1991; Rovniak et al., 2002; Sharma and Sargent, 2005; Gwaltney et al., 2009). Moreover, several recent studies have shown that self-efficacy mediates the effects of health promotion interventions on objectively assessed physical activity (e.g., Burke et al., 2008; Dutton et al., 2009; Darker et al., 2010). Thus, our results tentatively suggest that, although the augmented intervention was not related with elevated levels of physical activity, it might have increased the likelihood of the participants to become more active in the long run, because they were more confident to do so. We have to admit, however, that the standard intervention group showed a tendency toward higher self-efficacy ratings as compared to the augmented intervention group after the intervention session. This difference was moderate in size and may suggest that both groups showed a regression to the mean at post-assessment, which could have biased the finding. Hence, further studies are needed to verify the psychological benefits of text message reminders for increasing daily life physical activity.

Notably, although outside temperature was meaningfully related to the amount of physical activity exhibited in daily life (i.e., during warmer months there was more activity than during colder months), this variable did not interact with experimental group, documenting that both interventions prevented a decline in physical activity in the course of the study irrespective of weather conditions.

Taken together, the findings of this pilot study suggest that psychoeducational interventions are moderately successful in facilitating physical activity in the short-term. There was, however, no evidence of a beneficial effect of short text message reminders to keep intentions active during post-assessment. In our view, there are several reasons for this. In the following, we will discuss these reasons and offer recommendations for future research:

1. When examining the impact of an intervention on objective physical activity, researchers are advised to familiarize participants with accelerometers prior to assessing baseline activity in order to account for the reactivity of the method. In this study, individuals exhibited comparably high levels of physical activity prior to the intervention, thus overestimating baseline physical activity in everyday-life. Consequently, the change from pre-assessment to post-assessment in both intervention groups was most likely underestimated.
2. Although the intervention was generally perceived well, there were individuals who were not satisfied and those individuals did obviously not benefit from the intervention. Given that satisfaction with the intervention was positively correlated with the amount of physical activity change from pre-assessment to post-assessment, future research should identify individuals who are most likely to benefit from this kind of intervention and those who might not.
3. Text messages were sent out once a day (randomly from 9 a.m. and 7 p.m.) throughout the week following the intervention. Thus, the time interval between the intervention session and the mobile reminders might have been too short to effectively contrast this condition with the standard intervention arm. In keeping with Weinstein's "messy desk"-analogy, we would recommend sending out reminders with a longer latency, i.e., when the impact of the intervention session is likely to fade out (e.g., 3–4 weeks after the intervention).
4. Text messages were provided in a non-tailored fashion. That is, participants received standard messages asking if they still thought of their intentions. Future research might want to tailor messages more closely to the personal needs of the individual (with respect to timing and content), because previous research has shown that tailoring messages to the needs of the particular individual is more effective than a "one size fits all"-approach (e.g., Noar et al., 2007; Latimer et al., 2010).

Nonetheless, our findings suggest that a single psychoeducational intervention might be effective in increasing everyday-life physical activity in the short run. Moreover, short text messages reminding participants of their action plans compiled during the intervention session could be an effective tool for increasing self-efficacy to become physically active, which is a well-known antecedent of successful behavior change.

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Characteristics of the activity-affect association in inactive people: an ambulatory assessment study in daily life

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Acute and regular exercise as well as physical activity (PA) is related to well-being and positive affect. Recent studies have shown that even daily, unstructured physical activities increase positive affect. However, the attempt to achieve adherence to PA or exercise in inactive people through public health interventions has often been unsuccessful. Most studies analyzing the activity-affect association in daily life, did not report participants' habitual activity behavior. Thus, samples included active and inactive people, but they did not necessarily exhibit the same affective reactions to PA in daily life. Therefore the present study investigated whether the association between PA and subsequent affective state in daily life can also be observed in inactive individuals. We conducted a pilot study with 29 inactive university students (mean age 21.3 ± 1.7 years) using the method of ambulatory assessment. Affect was assessed *via* electronic diary and PA was measured with accelerometers. Participants had to rate affect every 2 h on a six item bipolar scale reflecting the three basic mood dimensions energetic arousal, valence, and calmness. We calculated activity intensity level [mean Metabolic Equivalent (MET) value] and the amount of time spent in light activity over the last 15 min before every diary prompt and conducted within-subject correlations. We did not find significant associations between activity intensity and the three mood dimensions. Due to the high variability in within-subject correlations we conclude that not all inactive people show the same affective reactions to PA in daily life. Analyzing the PA-affect association of inactive people was difficult due to little variance and distribution of the assessed variables. Interactive assessment and randomized controlled trials might help solving these problems. Future studies should examine characteristics of affective responses of inactive people to PA in daily life. General assumptions considering the relation between affect and PA might not be suitable for this target group.

Keywords: ambulatory assessment, affect, daily life, inactive, physical activity

INTRODUCTION

The relationship between physical activity (PA) and different affective states has been studied for decades. Early studies focused on the association between acute and regular exercise on specific negative affective states such as depression and anxiety (Ekkekakis and Petruzzello, 1999). There is evidence that exercise reduces self-reported negative affective states, namely anxiety and depression (Arent et al., 2000; Landers and Arent, 2001; Wipfli et al., 2008; Rethorst et al., 2009). Later studies integrated a rather dimensional approach of affect including positive and negative affective states.

Reed and Ones (2006) published a review about the effects of acute exercise on positive activated affect. People with lower pre-exercise affect values had higher increases in positive activated affect. Low intensity as well as moderate and vigorous exercise increased post exercise affect, with the highest observed increase after low intensity exercise. The increase of positive activated affect in response to low and moderate doses of exercise seems to be generalizable, with low intensity having the highest effect sizes ($d = 0.57$). There is more variability in affective responses to high intensity exercise. Both short and long bouts of acute exercise can induce affective improvements; however exercises lasting longer than 75 min seem to decrease positive affect. Even short bouts of brisk walking can increase activation and positive affect (Ekkekakis et al., 2000). Exercise intensity seems to have an important impact on post exercise affect and future adherence to exercise. Based on several study results, the dual mode theory was developed to show that valence declines beyond the aerobic-anaerobic transition (Bixby et al., 2001; Ekkekakis and Petruzzello, 2002; Ekkekakis and Acevedo, 2006). The authors claimed that affective states have to be assessed more frequently during exercise because affective states during exercise may explain the variability in post exercise affective states as response to high intensity exercise. Their assumption was confirmed by recent studies showing that especially inactive people show higher affective states if exercise intensity is moderate. In addition, it was recently shown that self-selection of activity intensity may help to identify the activity intensity that fits best for an individual to increase affect (Ekkekakis et al., 2011).

Considering the effects of regular exercise on positive activated affect, research draws a similar picture, regular aerobic exercise increases positive affect (Berger, 2000; Ekkekakis et al., 2000; Reed and Buck, 2009). Participants with lower baseline positive affect values had larger increases in positive affect. The highest effects were found for high and low intensity exercise programs. In contrast to the variance of affective reactions to acute sessions, repeated high intensity exercise seems to, maybe due to physiological and psychological adaptations, reach a similar level of affective changes as low intensity exercise (Reed and Buck, 2009). Additionally, the positive affective changes observed in regular exercise programs seem to be independent of training response and fitness changes (Ekkekakis et al., 2000) and the magnitude of effects was similar in acute and regular exercise (Reed and Ones, 2006; Reed and Buck, 2009).

While earlier studies focused on the potential of acute and regular exercise to improve affect, PA in daily life has become an important issue. Current activity guidelines promote daily PA and accumulated short bouts (duration of 10 min) of daily PA to be health effective (Haskell et al., 2007). As a consequence interventions recently started to include the promotion of single short bouts of activity to become more active. Thus, a growing number of studies try to examine whether PA in daily life also has the potential to improve positive affect (Schwerdtfeger et al., 2008; Kanning and Schlicht, 2010; Hyde et al., 2011; Poole et al., 2011; Kanning et al., 2012; Wichers et al., 2012).

Hyde et al. (2011) showed that people who were more physically active in general had higher pleasant activated feelings than less active people. Moreover, higher levels of pleasant activated feelings arose on days people were more active than typical for them. Kanning and Schlicht (2010) examined 13 older adults and revealed that subjectively reported activities in daily life increased energetic arousal and calmness. The authors assumed that PA is able to modify mood if there is a low baseline level but is not able to induce changes if mood state is already high.

To assess the relationship between affective states and PA in daily life, ambulatory assessment studies seem to be an appropriate method. Earlier studies mainly used retrospective self-report measures of affect and PA which are vulnerable to recall bias (Ebner-Priemer and Trull, 2009). Ambulatory assessment involves repeated respectively continuous sampling of current behavior and emotional reactions in real time. Thus, this approach allows the capturing of individual variability in affective responses to physical activities. Thereby it provides the potential to identify responders and non-responders that cannot be detected by means of the group aggregate considering the fact that one individual does not always react the same way (Backhouse et al., 2007; Shiffman et al., 2008). Additionally subjective self-reports of physical activities tend to overestimate activity and correlations between objective and subjective measures are low to moderate (Prince et al., 2008; Bussmann et al., 2009). Ambulatory assessment has the potential to measure PA occurring in daily life quite accurately *via* accelerometers. Furthermore self-reported affective states as well as contextual information can be assessed "*in situ*" (Fahrenberg et al., 2007; Bussmann et al., 2009).

Kanning et al. (2012) did an ambulatory assessment study with 44 university students. They assessed PA continuously *via* accelerometry, affective states, and the relative autonomy index were conducted with electronic diaries every 45 min for 1 day. They replicated the findings of Kanning and Schlicht (2010) for the valence and energetic arousal dimension being higher due to higher PA. In contrast to Kanning and Schlicht (2010) the calmness dimension was negatively correlated with PA. In addition, autonomous regulation moderated the PA-affect association.

Another ambulatory monitoring study in 24 healthy participants (aged 18–73 years) assessed the relation between PA and mood in daily life. Schwerdtfeger et al. (2008) recorded PA for 1 day and assessed positive activated and negative affect every hour *via* PDAs. They showed significant effects of PA (5, 10, and 15 min before PDA prompt) on positive activated affect, but not on negative affect. Even low intensity walks predicted higher positive activated affect.

Wichers et al. (2012) examined the effects of PA on positive and negative affective states in a large sample of 504 people. PA and affect were both assessed subjectively with electronic diaries. Participants had to state the current context (activity, location, social contact) and affect every 90 min on five consecutive days. Higher activity levels indicated higher subsequent levels of positive affect, but not of negative affect.

Affect is assumed to be an important motivator for continuing and maintaining PA (Dishman, 1990). Despite the postulated "feel better effect" of acute and regular exercise as well as PA in daily life, drop outs in exercise interventions are high and adherence to regular exercise and PA is low. More than half of our population is inactive (Centers for Disease Control and Prevention, 2008). For example, less than half of the US population meets the current PA guidelines (Haskell et al., 2007) and the problem can be seen worldwide (Bauman et al., 2009). Sedentary behavior is an increasing health risk in our society (Owen et al., 2010b).

Latest research showed that people can suffer from metabolic and cardiovascular health risk factors or diseases if they have prolonged sedentary episodes, even if they achieve the activity guidelines (Hamilton et al., 2004; Warren et al., 2010; Koster et al., 2012).

As a consequence, one of the main public health goals currently is the interruption of these long sitting times through performance of light activities. Light intensity activity was beneficially associated with resources against health risks (Hamilton et al., 2007). Light activities contribute to overall energy expenditure, but do not count for achieving the activity guidelines yet. Reducing prolonged sitting time through "sedentary breaks" calls growing attention as potential "easy to introduce intervention" in everyday life and has been shown to have beneficial impact on health (Healy et al., 2008; Brown et al., 2009; Owen et al., 2010a). Based on the evidence that not only exercise but also PA in daily life is health preventive, the question whether PA in daily life also has the potential to increase affect was studied more intensively. The importance to reduce long sitting times in addition to be active raises the question whether light activities performed to interrupt prolonged sitting offer the potential to increase affect in daily life.

There is growing evidence in low intensity activity being effective for health and mental well-being (Ekkekakis et al., 2000, 2008; Hamilton et al., 2004; Camhi et al., 2011). Inactive people may also profit from low intensity exercise (Bixby and Lochbaum, 2006;

Carels et al., 2006). Daley and Welch (2003) found that sedentary inactive people had the highest affect ratings during low intensity exercise.

Unstructured PA in daily life includes a lot of low intensity physical activities such as walking from one place to another. There is consensus of different scientific fields that affect plays a central role in decision making (Baumeister et al., 2007) and this also seems to be suitable for the decision to engage in PA and exercise (Carels et al., 2006). Based on a finding of Simonen et al. (2003), Ekkekakis et al. (2005, p. 484) interestingly assumed that there is a "genetically determined pleasure-based mechanism that has evolved to reward and promote PA." Moderate activities (intensities below the lactate threshold) made up most of people's time for hundreds of years to ensure surviving (Ekkekakis et al., 2005). Along with the industrialization, the increasing sedentariness induced obesity and a reduced fitness level, too. Ekkekakis et al. (2005) assume that, in combination with factors as muscular and skeletal aches, as well as cognitive factors and physical ineffectiveness, affective responses to moderate intensity have changed negatively. Thus, it is possible that the pleasure-based mechanism to reward and promote PA is light but not moderate activity for inactive people.

If low intensity PA increases positive affect, sedentary people might choose such activities to increase PA levels in daily life. Sedentary persons might perceive low intensity activities as less aversive compared to high intensity activities (Daley and Welch, 2003). Interventions to promote low intensity activity in daily life such as enhancing the accumulation of short bouts of activity or reducing longer periods of sedentary behavior by sedentary breaks may induce different affective reactions. Schwerdtfeger et al. (2008) found that the higher the body mass index (BMI) of participants, the higher was the association between PA in daily life and energetic arousal/positive affect. They assumed that obese people may be able to influence more positively energetic arousal, which is generally lower in this population. The study did not take into account habitual PA as a moderator of the relation between affect and PA in daily life. Thus one cannot conclude that the results found in obese people can automatically be transferred to sedentary people but there is a close link between sedentariness and obesity.

In conclusion, research shows that acute and regular exercise has the potential to enhance positive affect and these effects partly apply for sedentary people (Bixby and Lochbaum, 2006; Carels et al., 2006).

The exercise intensity seems to be an important issue considering adherence and dropout rates from exercise programs of sedentary people. Studies show that sedentary people prefer exercises of lower intensity compared to active people and exercise of lower intensity can improve affective states (Parfitt et al., 2006; Ekkekakis et al., 2011).

In addition, ambulatory assessment studies showed that unstructured PA in daily life can increase affect. These studies account for the importance of inter-individual differences and perceptions for activities inducing increases in affect. In addition an individual's affect in response to PA in daily life can be captured in many different situations. High positive affective states after PA in daily life were observed especially for light and moderate activities. Out of the studies that analyzed the association between unstructured PA in daily life and affective states, none examined sedentary people or controlled fitness and habitual PA level. As habitual exercise participation can mediate affective responses to acute bouts of exercise (Hallgren et al., 2010), this may also be appropriate for habitual PA.

Unstructured PA of moderate and light intensity in daily life may be a better opportunity to achieve and maintain higher activity levels in inactive people than exercise. In addition recent research shows that reducing prolonged sedentary episodes through performance of light activities is important besides achieving current activity guidelines.

Thus this pilot study aimed at providing new insights in the PA-affect association of inactive people in daily life. Because we were interested in affective states after PA in different situations of an individual in real life, we used the method of ambulatory assessment.

We hypothesized that PA in daily life was associated with subsequent affective state in inactive people. Thus we analyzed how PA was associated with subsequent affective state.

In a secondary analysis, we addressed a possible association between interrupted sedentariness and affective states. To our best knowledge no study has yet examined whether breaks in prolonged sedentary episodes are associated with affective states in young inactive adults in daily life.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-nine students (mean age: 21.3 ± 1.7 years; mean BMI: 24.5 ± 4.4) of the electrical engineering and information technology department (3rd and 5th semester) were recruited at a German University. They were informed about study goals and written consent was obtained according to the guidelines set for by our institution. All participants were inactive (being defined as exercising once a week or less) and had a mean relative VO_2 max of 40.9 (± 5.6) ml/min/kg measured *via* gas analysis during a progressive treadmill test.

PHYSICAL ACTIVITY

Physical activity was assessed with the Move II sensor (movisens GmbH, Karlsruhe, Germany) placed to the chest. Move II consists of a triaxial acceleration sensor (adxl345, Analog Devices) with a range of ± 8 g, 64 Hz sampling frequency and 12 bit resolution. The measuring unit has an additional air pressure sensor (BMP085, Bosch GmbH) with a sampling frequency of 8 Hz and a resolution of 0.03hPa (corresponding to 15 cm at sea level). The recorded raw data was saved on a SD card and was transferred to a computer for further analysis *via* a USB 2.0 interface.

Based on the hypothesis, we operationalized PA in two ways. First we calculated mean activity intensity and energy expenditure expressed by the MET value. Using MET values is an established method to estimate and classify the energy cost of human PA. Activity intensity is displayed on the basis of their energy cost as multiple of 1 MET, which is defined as the energy cost of a person at rest (Ainsworth et al., 2011). Activities ranging from 1 to 1.5 MET are defined as sedentary, from 1.6 to 2.9 MET as light, 3–5.9

as moderate, and ≥ 6 as vigorous (Ainsworth et al., 2011). Second, we calculated the minutes spent in the light activity category to analyze whether the proportion of time spent in light activities during the activity episode was associated with subsequent affect.

In the first step the activity was classified in intervals of 4 s. For further explanation of the activity recognition process see the publication of Anastasopoulou et al. (2012). The classification algorithm differentiated between the following seven activities: lying, rest (sitting/standing), cycling, uphill, downhill, level walking, and jogging. Based on the detected activity class, the appropriate activity-dependent EE model was selected and the EE was estimated. Input for the EE estimation models were the acceleration magnitude, the altitude change, and some subject related parameters (sex, age, height, and weight). MET was calculated as the ratio of the associated metabolic rate for the specific activity divided by the resting metabolic rate (RMR) (for details, see FAO/WHO/UNU, 1985).

AFFECTIVE STATE

For the assessment of affective states, My Experience movisens Edition (movisens GmbH, Karlsruhe, Germany) was used to install the mood scale on the PDAs (personal digital assistant; HTC Touch Diamond 2) and to program time stamp and intervals between the diary prompts. We used a six item short scale (Wilhelm and Schoebi, 2007) which measures the three basic mood dimensions with two bipolar items for each dimension: energetic arousal (E: tired-awake; full of energy-without energy); valence (V: content-discontent; unwell-well) and calmness (C: agitated-calm; relaxed-tense). The scale was developed based on the Multidimensional Mood Questionnaire (Steyer et al., 1997) and validated especially for momentary assessment of mood in daily life (Wilhelm and Schoebi, 2007). Participants rated their current mood based on the statement "At the moment, I feel. . ." on a seven-point bipolar rating scale with two opposed adjectives as endpoints (0–6). Prior to analyses three items were reversely coded to ensure that higher scores indicated higher values of E, V, and C. Subscale scores for each dimension ranged from 0 (low value) to 12 (high value).

PROCEDURE

The measurement equipment was handed out to the participants in an introductory session at the university 1 day prior to the start of the assessment period. PA was objectively conducted with the Move II accelerometer (movisens GmbH, Karlsruhe, Germany) over 12 h on 2 days (10 a.m.–10 p.m.). Participants had to record the duration during which they did not wear the device. Ratings of affective states and activities were prompted *via* PDAs. Participants were alerted by the vibrating signal of the PDA approximately every 2 h between 12 a.m. and 10 p.m. with a random component to avoid subjects waiting for the signal. Subjects had to answer the prompts within 15 min, and if they missed a signal, they were reminded by two further signals after 5 and 10 min. PDA morning entries (10 a.m.) were excluded from the analyses because the accelerometer registration of PA started at 10 a.m., and analyzing the previous 15 min of the 10 a.m. PDA entry was, therefore, not possible. Additionally, the variable waking time of subjects caused numerous 10:00 a.m. prompts to be missed. PDA and accelerometer time were synchronized by the initialization of the computer.

DATA ANALYSES

PDA prompts corresponding to non-wearing times of the activity sensor were excluded from the analyses. MET values were averaged across data points for each minute in a 12 h period for both days (10:00 a.m.–10:00 p.m.).

To analyze the within-subject association between preceding PA and mood, the average PA intensity was calculated over the preceding 15 min before the PDA prompt. Based on recent studies, a 15 min interval was chosen to include as much activity as possible but within a time frame that ensures that increased affect after activity would still be visible (Ekkekakis et al., 2000; Schwerdtfeger et al., 2008). The mean MET level was calculated by averaging MET values (per minute) of this time interval. To investigate the potential of light activities to increase affective states, we calculated minutes spent in light activities (1.6–2.9 MET). This level is the most performed activity of sedentary people. Thus, one might get more intervals of light activity compared to moderate or vigorous intervals, especially in an inactive sample. We summed up minutes spent in light activity over the 15 min interval and did within-subject correlations for the three affect dimensions with light activity.

For the secondary analysis we calculated the number of sedentary breaks to reflect interruptions of at least 1 min in sedentary time. Thus, one sedentary break reflected an interruption of sedentary behavior (≤ 1.5 MET) of at least 1 min. To calculate breaks of sedentary periods, we used intervals of 30 min length.

For this pilot study within-subject correlations of the activity and affect variables were assessed to show the range of within-subject correlations in the sample. Due to the small sample size ($n = 29$) and the lack of variance in activity, as well as the distribution of the affect variables, we decided to take a more robust statistical method instead of using multilevel analyses. Therefore we calculated the within-subject correlations between activity variables (mean MET, minutes spent in light activity and sedentary breaks) and the three dimensions (valence, energetic arousal, and calmness) of affect. To calculate the mean correlation coefficient, we did Fisher's z-transformation to convert Pearson's r values into normally distributed z values. The mean correlation coefficient was transformed back *via* inverse fisher's z. Significance (p) was tested *via* t distribution (Bortz and Schuster, 2010).

RESULTS

ASSOCIATION BETWEEN ACTIVITY INTENSITY/MINUTES SPENT IN LIGHT ACTIVITY AND AFFECT

Three hundred thirty-four data points for activity variables and corresponding affective state variables were available. Across all 15 min intervals, participants had a mean activity intensity level of 1.44 ($\pm$0.42) MET. Participants spent on average 1.62 ($\pm$2.46) min in light activity across all 15 min intervals. Across all 15 min intervals, participants spent 86% in sedentary behavior, 10.4% in light activities and 3.6% in moderate to vigorous activity. The activity spent during the 15 min intervals was significantly associated to overall measured PA (2 days) for both mean MET level ($r = 0.724$; $p = < 0.001$) and minutes spent in light activity ($r = 0.710$; $p = 0.00$). Mean affective states were 7.44 (±2.41) for energetic arousal, 8.78 (±1.94) for valence, and 8.74 (±2.2) for calmness. Participants rated the two measurement days as either quite (3) or predominantly (4) typical (on a scale ranging from 1 not at all to 5 absolutely).

By calculation of 90th and 10th percentiles, we identified that 80% of the data points of E were located between the affect scale scores of 4 and 10, and 80% of V and C were located between the scores 6 and 11 (**Table 1**). The calculation of 10th and 90th percentiles for both mean MET level (10th = 1.25; 90th = 1.94) and minutes spent in light activity (10th = 0; 90th = 5) showed that most of the time was spent in an intensity reflecting primarily sedentary behavior (see **Table 1**; **Figure 1**).

None of the affect variables, E, V, and C, showed significant associations to the activity intensity level precedent to the affect assessment (**Table 2**), with energetic arousal showing the highest mean correlation coefficient for both activity variables, mean MET level ($r = 0.17$; $p = 0.82$) and minutes spent in light activity ($r = 0.13$; $p = 0.75$). The within-person correlations between energetic arousal (E) and mean MET level ranged from $r = -0.42$ to 0.89. To illustrate the number of persons having low, high negative, or high positive correlation coefficients, the results of the correlations were categorized [1 = 0.3–0.99; 0 = −0.29 to 0.29; −1 = −0.3 to −0.99]. Sixteen subjects had a correlation coefficient between 0.29 and −0.29, 10 subjects had a correlation coefficient of 0.3–0.99 and three subjects fell into category −1 (−0.3 to −0.99). The within-person correlations for the association between minutes spent in light activity and E ranged from $r = -0.42$ to 0.93 (see **Table 2**). Participants rated higher as well as lower energetic arousal when they spent little time in light activity. Low ratings of E together with high numbers of minutes spent in light activity did not occur.

The results of the within-person correlations of the two other mood dimensions, valence and calmness, showed even lower correlation coefficients (**Table 2**). Within-subject correlations between valence and mean MET level ranged from −0.97 to 0.67, (min light: $r = -0.93$–0.94). The within-subject correlations between calmness and mean MET ranged from −0.90 to 0.52 (min light $r = -0.94$–0.35). Participants rated higher as well as lower affective scores (valence, calmness) when they spent little time in light activity. Low ratings of affective states together with high numbers of minutes spent in light activity did not occur (see **Figure 2**).

Table 1 | Means and standard deviations of the activity variables mean MET, minutes spent in sedentary, light, moderate, and vigorous activity (across all 15 min intervals); sedentary breaks (across all 30 min interval) and affect variables (across all diary prompts); 90th and 10th percentile of each variable.

	Mean (SD)	10th percentile	90th percentile
Mean MET	1.45 (±0.42)	1.25	1.94
Min sedentary	13.39 (±3.75)	8	15
Min light	1.63 (±2.46	0	5
Min moderate	0.51 (±1.38)	0	2
Min vigorous	0.04 (±0.51)	0	0
Sedentary breaks	5.05 (±5.8)	0	14
Energetic arousal (E)	7.44 (±2.41)	4	10
Valence (V)	8.78 (±1.94)	6	11
Calmness (C)	8.74 (±2.2)	6	11

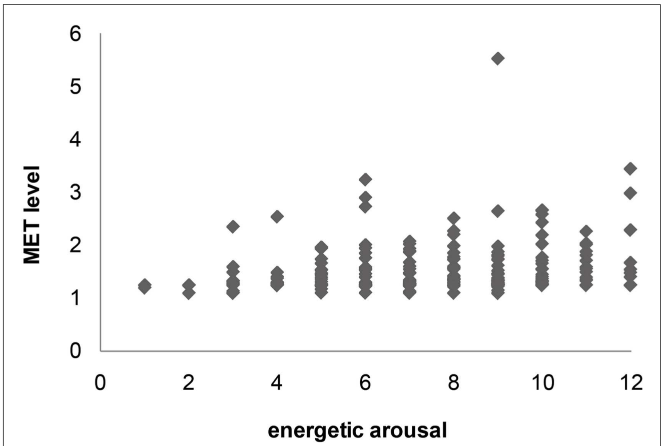

FIGURE 1 | Scatter plot of E (energetic arousal) score and activity intensity (mean MET level during 15 min interval).

SECONDARY ANALYSIS: ASSOCIATION BETWEEN SEDENTARY BREAKS AND AFFECT

Across all 30 min intervals, the mean number of sedentary breaks was 5.1 (±5.8). The scatter plot shows that few as well as lots of sedentary breaks during the 30 min interval induced higher as well as lower arousal states. Participants did not have low arousal states and a high number of sedentary breaks at the same time (see **Figure 3**).

Table 2 | Correlation coefficient (*r*) of within-subject correlation ($n = 29$; df = 27) between mean activity intensity (mean MET during 15 min interval) and E (energetic arousal), C (calmness), and V (valence); amount of minutes spent in light activity (during 15 min interval) and E, C, V; sedentary breaks (during 30 min interval) and *E, C, V*; range of within-subject correlations; significance (*p*); effect sizes (r^2).

	r	Range	*T*	*p*	r^2
mean MET_E	0.17	−0.42–0.88	0.92	0.82	0.03
mean MET_C	−0.09	−0.90–0.52	−0.45	0.33	0.01
mean MET_V	−0.03	−0.97–0.67	−0.13	0.45	0.00
min_light_E	0.13	−0.42–0.93	0.69	0.75	0.02
min_light_C	−0.08	−0.94–0.35	−0.44	0.33	0.01
min_light_V	0.08	−0.93–0.94	0.40	0.65	0.01
sed_breaks_E	0.20	−0.57–0.82	1.04	0.85	0.04
sed_breaks_C	−0.08	−0.81–0.70	−0.42	0.34	0.01
sed_breaks_V	0.07	−0.83–0.85	0.38	0.65	0.00

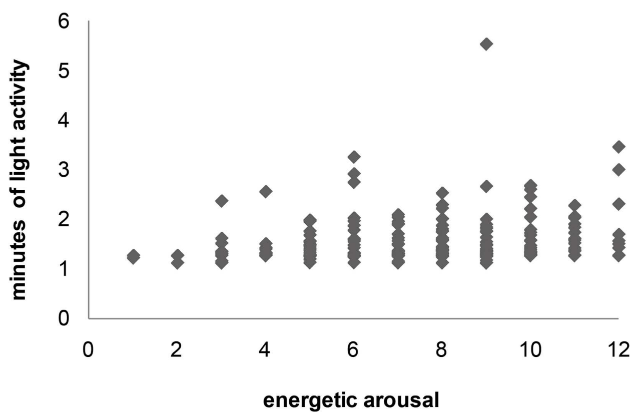

FIGURE 2 | Scatter plot of E (energetic arousal) score and amount of minutes spent in light activity (during 15 min interval).

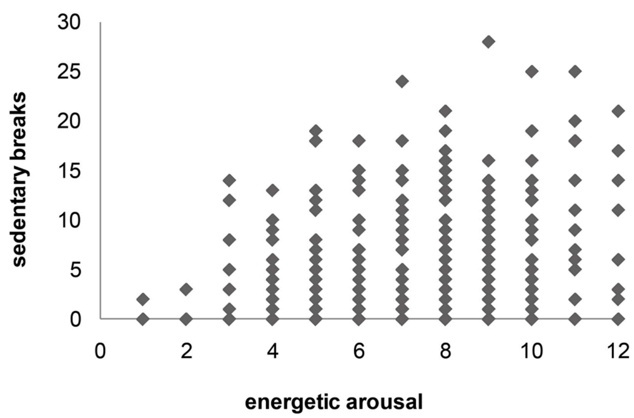

FIGURE 3 | Scatter plot of E (energetic arousal) score and sedentary breaks (during 30 min interval).

Again energetic arousal showed the highest correlation with sedentary breaks ($r = 0.2$; $p = 0.85$) with a range of within-subject correlations from −0.57 to 0.82, but did not reach significance. Valence and calmness were not related to sedentary breaks (**Table 2**).

DISCUSSION

In the present pilot study we investigated whether the PA intensity level of inactive young adults was associated with affective states in daily life. Moreover, we were interested whether affective states of inactive young adults changed in response to the amount of time spent in light activities. Our results are not in direct agreement with earlier studies demonstrating a relationship between PA and positive affect in daily life (Schwerdtfeger et al., 2008; Kanning and Schlicht, 2010; Hyde et al., 2011; Kanning et al., 2012; Wichers et al., 2012). We found small and statistically insignificant associations between energetic arousal and activity intensity level as well as low intensity activity. The two other affect dimensions, valence and calmness were not related to PA.

Despite the variety of variables used to display activity (active versus inactive episodes, number of counts, milligram) and the fact that other studies did not control habitual activity or fitness level of participants (or did not report it), it seems adequate to assume that our sample was more inactive compared to samples of former studies. Kanning and Schlicht (2010) registered 28% of active episodes and 72% of inactive episodes, compared to 86% inactive and 14% active (mainly light activities) episodes in this study. Kanning et al. (2012) reported 77.3 mg/min compared to the mean MET level of 1.44 MET in the present study (reflecting the sedentary behavior category).

Compared to earlier studies, we extended our analysis to 2 days. Thus, we reduced the risk for picking an untypical day, but reduced the chance to capture activity episodes by programing PDA prompts every 2 h (compared to every hour).

The distribution of the valence and calmness dimension variables was shifted to high positive affective state scores. It is possible, that for people having general high mood scores, PA is less effective in altering mood. Kanning and Schlicht (2010) as well as Gauvin et al. (1996) discuss ceiling effects as a possible explanation and studies show stronger improvement in affect if the baseline level is low (Reed and Ones, 2006). The constant high valence and calmness levels of subjects in this study may partially explain the lack of finding an activity-affect relation.

The results of the present pilot study highlight the difficulty of analyzing the relation between affect and PA of inactive people. It is difficult to relate affective states to active episodes if they hardly appear during the day (Ebner-Priemer et al., 2013). We anticipated the difficulty to capture a lot of vigorous and moderate activity episodes, but we did not expect that even light activity episodes would hardly occur in the present study. Of the 334 data points, only 60 had a mean MET level >1.6. The calculation of the 10th and 90th percentiles illustrated the immense lack of variance of the activity data, thus the data was insufficient to detect associations.

To solve the problem of identifying less frequent appearing behavior, interactive assessment is a promising approach for future studies. The methodology of interactive monitoring was developed by Myrtek (2004). Ebner-Priemer et al. (2013) introduced an algorithm for the analysis of the activity-affect relation. Diary signals can be triggered by an algorithm, developed for interactive monitoring, when a predefined activity threshold is surpassed. This method has the potential to quadruple the e-diary assessments during activity episodes compared to the method of this study (Ebner-Priemer et al., 2013).

Recently few authors claimed to analyze affective states not only pre and post but during exercise, because it is not yet determined whether during exercise affect or post exercise affect plays a greater role for future adherence to exercise and activity (Backhouse et al., 2007). Interactive monitoring offers the potential to meet the demand of exercise psychologists to measure affective states not only before and after exercise but also during exercise. Specific activities inducing positive affective states during an activity might be suitable for the promotion in daily life.

As sedentariness holds high risk factors for several diseases (Hamilton et al., 2004; Owen et al., 2010b; Warren et al., 2010) one of the main public health goals is getting sedentary people more active and achieve sustained active lifestyles. As current activity guidelines (Haskell et al., 2007) promote an increase in accumulated short bouts of PA in daily life, more studies examined the appearance of this behavior. Affect may influence one's behavioral intention (Baumeister et al., 2007). Thus intensities, activities, and types of activity improving an individual's affect may lead to future repetition of the behavior.

Based on the current literature one can assume that low intensity activities as often performed in daily life, can increase positive affect (Ekkekakis et al., 2000, 2008). Low intensity activities can increase affective states in sedentary inactive people because they experience them as less aversive than high intensity activities (Daley and Welch, 2003; Bixby and Lochbaum, 2006; Carels et al., 2006). In addition, they are easy to perform in daily life. Thus sedentary people might choose such activities to increase PA levels in daily life. The present study revealed a high inter- and intra-individual variability in affective responses to light intensity activity. This is in line with the claim of some authors to account for inter- and intra-individual variability and the dual mode theory (Backhouse et al., 2007). Due to the lack of active episodes no distinct conclusions can be drawn.

Randomized controlled trials increasing PA episodes and therefore data points to analyze may be a promising approach to get more insights into the daily life activity-affect relation of inactive people. To promote low intensity activity in daily life, for example, enhancing the accumulation of short bouts of activity or reducing longer periods of sedentary behavior by sedentary breaks may induce different affective reactions. Based on results of their study, Schwerdtfeger et al. (2008) assumed that obese people have the potential to increase energetic arousal through PA of daily life. This assumption should be taken into account when continuing research of the activity-affect association of inactive people in future projects based on the present study. Daily life activities having the potential to increase arousal (for example short walks) should be promoted by interventions and the effectiveness can be assessed by ambulatory assessment.

The present study has several limitations that should be discussed. The lack of moderate to vigorous activity episodes might reflect that assessing affect every 2 h over 2 days and relating it to the preceding 15 min before the PDA prompt may not be the method to choose in any sedentary sample. To get more active episodes, more days and more affect prompts have to be conducted. Another option to capture more active episode is looking for an active episode and relate it to the subsequent affect rating.

Clearly for the analysis of this ambulatory assessment study considering the association between PA and affect in daily life, multilevel analysis would be the common statistical method to use. It offers the potential to identify both within-subject and between-subject variability. Additionally, one can control confounding variables like contextual variables, habitual PA of subjects, and PA of the subsequent activity interval after the PDA prompt, etc., Due to the sample size, insufficient variance of the activity variables and the distribution (not normally distributed) of the valence and calmness variable in the present pilot study, we decided to calculate within-subject correlations instead of multilevel analyses. In addition, we wanted to take a special look on within-subject correlations.

However, there are some important aspects this study illustrates. The wide range of within-subject correlation coefficients seems to underline the responder-non-responder discussion or the consideration of the inter-individual affective reaction to PA in the activity-affect paradigm (Backhouse et al., 2007). It means that there might not only be one activity intensity, duration, and type of activity that enhances affective states. Every individual and its contextual situation might induce different reactions and different preferences of activity characteristics (as dose, duration, and type). Moreover, the low intraclass correlations in some participants illustrate, that some individuals' affective response to PA differed from situation to situation. Both the inter- and intra-individual variability the present study revealed are in line with the concept of the dual mode theory. Interestingly, if participants were inactive, they showed high as well as low affective state scores, but lower affective states did not occur together with people being more active.

In conclusion, the present study attempted to address the potential of daily life activity to increase affective states of inactive people. The difficulty to capture active episodes of inactive people to identify which activities increase affect illustrated a general paradox. How can we assess which physical activities in daily life are useful for inactive people if they hardly perform any PA? Randomized controlled trials increasing PA in daily life, might solve this problem. However, inactive people probably do not like to be active, thus affective states might be negatively influenced by this aversion against activity. Future studies have to assess whether low intensity exercise and self-selected activities in daily life are less aversive to inactive people and thus useful to enhance activity in daily life.

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Acute and medium term effects of a 10-week running intervention on mood state in apprentices

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Exercise and physical activity have proven benefits for physical and psychological well-being. However, it is not clear if healthy young adults can enhance mood in everyday life through regular exercise. Earlier studies mainly showed positive effects of acute exercise and exercise programs on psychological well-being in children, older people and in clinical populations. Few studies controlled participants' physical activity in daily life, performed besides the exercise program, which can impact results. In addition the transition from mood enhancement induced by acute exercise to medium or long-term effects due to regular exercise is not yet determined. The purpose of this pilot study was to examine the acute effects of an aerobic running training on mood and trends in medium term changes of mood in everyday life of young adults. We conducted a 10-week aerobic endurance training with frequent mood assessments and continuous activity monitoring. 23 apprentices, separated into experimental and control group, were monitored over 12 weeks. To control the effectiveness of the aerobic exercise program, participants completed a progressive treadmill test pre and post the intervention period. The three basic mood dimensions energetic arousal, valence and calmness were assessed via electronic diaries. Participants had to rate their mood state frequently on 3 days a week at five times of measurement within 12 weeks. Participants' physical activity was assessed with accelerometers. All mood dimensions increased immediately after acute endurance exercise but results were not significant. The highest acute mood change could be observed in valence ($p = 0.07$; $\eta^2 = 0.27$). However, no medium term effects in mood states could be observed after a few weeks of endurance training. Future studies should focus on the interaction between acute and medium term effects of exercise training on mood. The decreasing compliance over the course of the study requires the development of strategies to maintain compliance over longer periods.

Keywords: mood, activity intensity, ambulatory assessment, aerobic exercise, randomized controlled trial, inactive people

INTRODUCTION

Several studies have shown that regular exercise and physical activity increased emotional well-being. Ross and Hayes (1988) as well as Stephens (1988) demonstrated that physical activity improved mood, and symptoms of depression and anxiety could be reduced. Research conducted to examine the effects of exercise on mood addressed either acute effects of exercise on mood or effects of aerobic exercise programs on mood. Acute exercise of low and moderate intensity showed the highest effects on mood while there was more variability between individuals' mood states during and after exercise of high intensity (Ekkekakis et al., 2011; Reed and Ones, 2006).

Several randomized controlled trials showed that regular aerobic exercise of low intensity as well as moderate and high intensity improved positive affect (Reed and Buck, 2009). In both acute and regular exercise, people with lower baseline mood values reported higher mood changes due to exercise (Reed and Ones, 2006; Reed and Buck, 2009).

Despite several studies showing benefits for mood induced by regular exercise, reasons remain undetermined yet. Reed and Buck (2009) reviewed different explanations of several authors. Mood effects due to regular exercise might be induced by the accumulation of acute effects induced by exercise. Repeated exercise may result in stress adaptation and thus improve affect. Alternatively, acute exercise improves positive affect and observed changes in combination with regular exercise reflect the repeated acute affective improvement. The maintenance explanation is supported by the aspect that according to Ekkekakis et al. (2000) affective changes induced by exercise are independent of fitness changes. Acute effects are observed regardless of training response. One would expect higher effects of regular exercise on mood compared to acute effects, but reviews only showed slight differences in effect size (Reed and Buck, 2009). In addition, Steinberg et al. (1998) found similar instead of increasing acute mood effects every week over the course of his study.

Most former studies examining the effect of regular exercise on mood focused on clinical or older populations. Samples including young adults mainly considered student samples. In addition, these studies did not control daily life physical activity besides the exercise intervention which might impact the results. In addition to progressive exercise tests to check the effectiveness of the exercise intervention, objective activity monitoring allows for important continuous insights into physical activity behavior of both control and experimental group pre, during and post the intervention.

Former studies mainly conducted exercise programs assessing affect pre and post the exercise program using single occasion retrospective self-report measures. In general assessing emotional states by means of retrospective reports holds the risk of systematic recall biases. During self-reporting, subjects typically use a variety of heuristics, namely not only retrieving their emotional state, but also aggregating and summarizing experiences (Cohen and Java, 1995; Hufford et al., 2001; Fahrenberg et al., 2007; Shiffman et al., 2007).

The positive effects of regular exercise on mood are probably expected by most of the society. The social desirability of reporting higher mood states if asked once after an exercise intervention may have led to relatively constant results showing mood improvement due to regular exercise in the past.

In general, ecological momentary assessment allows for real-time assessment of mood to increase accuracy and reduce retrospective biases. In addition, the assessment in real-life situations enhances generalizability and the repeated assessments allow for the investigation of dynamic processes. In this study, EMA was used to get real time data immediately before and after exercise and to examine medium term variations over the whole study period.

With the growing interest of the effects of physical activity on mood in daily life, some recent studies have addressed this question. Kanning and Schlicht (2010) observed increased mood after self-reported physical activity episodes. Two studies using ambulatory assessment showed that an increase in physical activity induced an increase in positive affect in everyday life (Schwerdtfeger et al., 2008; Kanning et al., 2012).

To our best knowledge no study analyzed the interaction between acute and medium term effects of acute and regular aerobic exercise on mood in everyday life of apprentices. Only one study investigated mood more frequently (weekly basis) during an exercise intervention period. In addition, no study examining effects of regular aerobic exercise on mood in everyday life controlled daily life physical activity besides the exercise intervention. With the present pilot study we wanted to check if enhanced mood due to acute exercise transfers to increased mood trends in daily life induced by regular exercise. In addition, we were interested if more frequent mood measures in daily life during an exercise program confirm the results of earlier studies.

To capture more situations of acute changes in mood due to exercise and to better understand the interaction between acute and medium term effects of exercise by measuring mood more frequently during the exercise intervention, we addressed this question using ambulatory assessment. To control daily life physical activity besides the exercise intervention, we objectively monitored physical activity continuously via accelerometry. In addition, we expected to get insights into the activity behavior of both groups during different phases of the study. To secure the effectiveness of the aerobic endurance program, a sample of apprentices was chosen which was not engaged in aerobic endurance training before. As established in the literature, the highest improvements in fitness can be achieved in participants with low baseline fitness level (Zintl, 1997).

We hypothesize that acute aerobic endurance exercise induces increases in mood in young adults. We further estimate that regular exercise leads to medium term effects reflected by increased mood in everyday life.

METHOD

PARTICIPANTS AND PROCEDURE

Participants were recruited from the age group of apprentices who started at Karlsruhe Institute of Technology (KIT) in 2010. Due to an information letter from the KIT vice president and an information event, 25 apprentices gave written informed consent to participate in the study. Participants were divided into control and experimental group by lot based on stratification of gender to balance the distribution in both groups.

23 participants (12 f, 11 m) were included in the analyses, as two participants of the experimental group dropped out due to injury or motivational reasons. Due to the stratification of gender, the percentage of male and female in the experimental group (EG: ♀ = 6; ♂ = 6) and the control group (CG: ♀ = 6; ♂ = 5) had a similar distribution. The average age of all participants was 19.43 (±1.85) years. The participants of the *EG* were on average 6 months younger (19.17 ± 1.47 years) than those of the *CG* (19.73 ± 2.24 years).

All data of this pilot study was assessed during a period of 8 months between September and April. All pre- and post-tests (T0 and T4: see **Figure 1**) were carried out in the outpatient medical center and at the Institute of Sport and Sports Science of the KIT. Since there was not sufficient time to carry out the pre-tests with the entire sample before the start of the intervention, few participants of the control group were tested after the start of the intervention. Baseline mood assessment (T0) was conducted before the start of the intervention.

An aerobic endurance intervention was conducted over a period of 10 weeks during winter months. Participants of the *EG* had to participate in an instructed outdoor running training twice a week. The *CG* participants were instructed not to alter their physical activity and exercise patterns during the control period. During the intervention/control period participants' mood states were recorded using electronic diaries on three consecutive days during the second (T1), sixth (T2), and tenth (T3) week (see **Figure 1**). After the 10-week intervention period the post-tests of aerobic endurance capacity and a final monitoring of mood states were conducted (T4: see **Figure 1**) as a retention measurement to capture possible long-term effects in the twelfth week. Additionally, mood ratings pre and post the endurance training were conducted in the experimental group. Physical activity was monitored continuously during the whole study. A detailed description of measurement procedures is given in the following section.

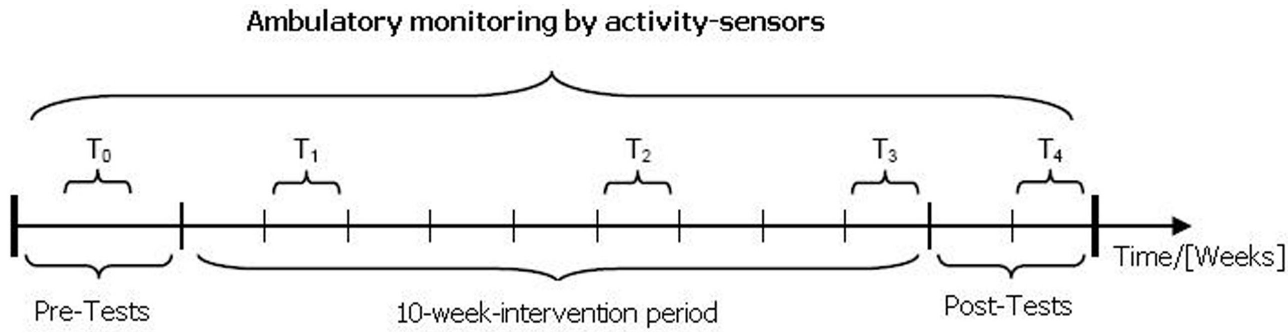

FIGURE 1 | Study design (Test of aerobic endurance capacity at T0 and T4, assessment of activity and mood at T0–T4).

MEASUREMENT PROCEDURES

The pre- and post-tests to assess endurance capacity took place at T0 and T4. The data acquisition of subjective variables (via electronic diaries) and objective variables (via accelerometry) was conducted at T0 and T4 as well as during the 10-week intervention/control period (T1–T3).

TEST OF ENDURANCE CAPACITY

To assess the aerobic endurance capacity, a progressive treadmill test to exhaustion with gas analyses was conducted. A 6-2-3 protocol (6 km/h initial load — 2 km/h increment per stage — 3 min duration of stage) was used (Dickhuth et al., 2007).

Since the participants were not experienced in running on a treadmill and had not performed a treadmill test before, they were instructed to warm up by running slowly for a short period (1–2 min) in order to get used to the treadmill and to practice the straddling position on the outer surfaces of the treadmill (to facilitate the acquisition of blood samples). After the warm up period, the test started at the initial speed of 6 km/h. At the end of each stage, the heart rate was recorded using POLAR® heart rate monitors, model "RS 800." Within a standardized break of 20 s between stages, an arterial blood sample was taken from the participants' earlobe into a 20 μl end-to-end capillary for the analysis of blood lactate.

For the design of the endurance training, the main outcome variables were running speed at 4 mmol/l lactate, at the lactate threshold (LT), at the individual anaerobic threshold (IAT) and the maximum speed (see Heck et al., 1985). Based on the LTs, the individual heart rate zone was determined using the software Ergonizer® (Sports medicine Freiburg, K. Röcker).

ASSESSMENT OF MOOD STATES

To assess mood states frequently in everyday life, the short-scale developed by Wilhelm and Schoebi (2007) to measure the three basic mood dimensions valence, calmness and energetic arousal, was used. The scale incorporates only two items per mood dimension. The participants had to respond to the statement "At the moment I feel …" by providing information relating to six bipolar items, which were each graded on a seven-step scale (0–6) with the contrary adjectives as endpoints. Energetic arousal was assessed by the items tired-awake and full of energy-without energy; calmness by agitated-calm and relaxed-tense and valence by content-discontent and unwell-well.

Each dimension was, therefore, ascribed both a negatively and positively polled item. In order to obtain rectified scale values for each dimension, the items relating to the negative mood pole ("content-discontent," "full of energy-without energy," and "relaxed-tense") were recoded. Thus, low values indicated low calmness, valence and energetic arousal and higher values indicated a higher level of the three mood dimensions. The mean value per dimension was used for statistical analysis (Wilhelm and Schoebi, 2007).

To be able to assess changes of mood over time, the recording tool has to have sufficient sensitivity to change. The sensitivity to change relates to the "characteristic of a psychological test value [.], to show real changes, i.e., mapping not only measurement errors but functionally important adjustment processes within the variability of a time series" (Fahrenberg et al., 2002). Wilhelm and Schoebi (2007) demonstrated that the three dimensions of the short-scale have a high sensitivity to change and therefore are deemed a suitable measuring tool for recording changes in mood over time. Intra-individual reliability rates (r.70 for valence and calmness, $r = 0.77$ for energetic arousal) provide satisfactory internal consistency.

The assessment of mood states via electronic diaries was carried out at each time of measurement (T0– T4) on 3 days per week: Tuesday, Wednesday, and Thursday. Since mood state on Mondays and Fridays might be influenced by past or forthcoming events at the weekend. Furthermore, the KIT apprentices sometimes did not follow their normal daily work routine on Fridays due to instruction at the vocational training school. Thus, the collection of data was avoided on these days.

My Experience movisens Edition (movisens GmbH, Karlsruhe) software was used to install the mood-scale (Wilhelm and Schoebi, 2007) on a PDA (personal digital assistant; HTC Touch Diamond 2) and to program the time intervals between the daily queries. Over the course of the day, the participants were reminded via a vibrating and/or an acoustic signal to answer the queries via touch screen at the specified times (after getting up in the morning, 10 am, 1 pm, 4 pm, 8 pm). In addition, the participants of the *EG* had to answer the questions at three given times after the training session, immediately after the end of the training, 20 and 40 min after the training session. To avoid anticipation of the signal and thus the possibility of associated changes in behavior, a random component of ±15 min was chosen. If the study participant did not respond immediately, the signal was repeated at 5, 10, and up to 15 min after the original request. If the last request was not answered within 5 min, the request was labeled as a missing value.

ACTIVITY MONITORING

Participants' physical activity was recorded with the Move II accelerometer (movisens GmbH, Karlsruhe) attached to the hip. The Move II is a light weight sensor (17 g; 50 × 36 × 17 mm) recording raw acceleration data by means of 3-axis (64 Hz, ±8 g, 12 bit, 4 mg) with battery life of up to 7 days. The sensor had to be replaced each week in order to obtain data for the entire study period. The sensors were individually configured via an USB port for each participant (according to age, sex, height, and weight) with the appropriate software (SensorManager, UnisensViewer and DataAnalyzer, movisens GmbH, Karlsruhe). The recorded acceleration raw data was saved on a micro SD card. The raw data after a complete measurement was transmitted to a computer via an USB 2.0 interface. Mathematical and statistical procedures applied to the raw data can be used to differentiate between several activities: rest (standing, lying, or sitting), cycling/ergometer, climbing stairs, walking (jogging, slow, or normal walking), and "unknown activities" (for details see Härtel et al., 2011). For this study the raw data captured by the accelerometer was used to calculate the activity intensity in mg.

AEROBIC ENDURANCE INTERVENTION

The *EG* had to complete an instructed aerobic running training session twice a week over a period of 10 weeks. To achieve good compliance, three instructed running sessions per week at suitable times during apprentices' daily routine were offered. The running sessions took place in a natural outdoor environment. Most sessions were held in the afternoon and few during lunch breaks.

Based on the LT and the IAT, individual training heart rate zones (THRs) were determined for the *EG* participants (Dickhuth et al., 2007). The range within heart rate zones was established as follows:

The *EG* participants were fitted with the POLAR® Modell "RS800" heart rate monitors which they wore throughout the entire intervention period and which were used to monitor individual THRs during training sessions. To ensure that participants practiced within their individual THR, the heart rate monitors were programmed to emit an acoustic signal to increase or reduce running speed if heart rate was below or above the individual THR. In the exceptional case that a participant had to complete a running session on his/her own, completion of this session was monitored by the heart rate monitors. To develop the basic aerobic endurance, a continuous endurance method suitable for beginners was applied to the experimental group. The initial duration of 30 min was continuously increased to 60 min over the 10 weeks. Besides the increase of duration, intensity was progressively increased by adding short intervals of 2 min above the individual THR after week 6. As part of a variable endurance method, the aerobic-anaerobic functional range was improved (Kubukeli et al., 2002; Tanisho and Hirakawa, 2009).

DATA ANALYSIS

Only *EG* participants who had completed at least 50% of the prescribed 20 training sessions were included in the analysis. One female participant did not achieve this requirement and was therefore excluded from the statistical analysis. We assumed that participants who completed fewer training sessions during the 10-week intervention period couldn't achieve a training effect.

The statistical analysis of all group differences was conducted with a maximum of $n = 22$ participants ($EG = 11$; $CG = 11$). Two *CG* participants did not engage in the post-test of endurance capacity at T4. Thus, the sample size for the analysis of the pre and post-endurance capacity was reduced to $n = 20$ ($EG = 11$; $CG = 9$).

SHORT-TERM EFFECTS OF ACUTE EXERCISE ON MOOD

To analyze short term effects of the endurance training on current mood, the queries which were answered immediately prior to and immediately after the training session were considered. For the mood values prior to the training only data collected within the last hour before the training was considered. It was assumed that earlier queries did not reflect the current mood state of participants before the training. Due to a high number of missing values prior to and immediately after training, only 37 out of possible 72 data entries (two training sessions per time of measurement T1–T3; $n = 12$ for EG) were available for analysis. According to earlier studies a mean value of each *EG* participant's completed queries before and immediately after the training was calculated (Alfermann and Stoll, 1996).

MEDIUM-TERM EFFECTS OF REGULAR EXERCISE ON MOOD

To analyze medium term effects of the exercise intervention on mood (recorded via electronic diaries) data of participants who completed at least six queries at each time of measurement (T0–T4) on at least 2 days and more than 1/3 of all queries was included. Due to the additional three queries after the training sessions, each participant of the *EG* had a maximum number of 21 data entries per week if all queries were answered.

The compliance to mood assessments of experimental and control group was calculated as sums for each time of measurement to analyze the change over time. **Table 3** shows the answered queries for *EG* and *CG* at every time of measurement (sum), the maximum number of queries (max poss), and the actual compliance as the rate of answered queries (percentage), overall and separated for *EG* and *CG*, respectively at T0–T4 (Stone et al., 2003).

MOOD-DIMENSIONS

To analyze the mood dimensions mean daily (DV) and weekly values (WV) were calculated for each mood dimension (calmness, valence, and energetic arousal). The daily value was calculated as the mean of the daily queries for each participant and dimension. For each time of measurement (T0–T4), a weekly value was calculated as the mean value of the three daily values.

To analyze the short-term effects of training sessions on current mood, a mean value for all available data entries prior to the training sessions (MVpre) was calculated for every participant and dimension. Second a mean value for all available data entries immediately after the training sessions (MVpost) was calculated for each participant and dimension. The number of data entries included in the calculation of the mean values differed considerably among participants. For some participants, up to seven data entries were available while for others only two were available.

ACTIVITY INTENSITY

Participants' physical activity was recorded via accelerometry during the entire study period. The raw acceleration data captured by the accelerometer (acceleration in g) was used to calculate the activity intensity in mg. Here, activity intensity is the average amount of acceleration per minute. If activity intensity fell below a threshold of 20 mg for at least 1 h, it was defined as "non-wearing time." The non-wearing time was compared to the 24 h during which the sensor could be worn as maximum wearing time per day (off ratio). Values below the minimum wearing time of 8 h per day or an off ratio >67% were not considered for analysis.

The time spent in different activity intensity levels (see **Table 2**) was calculated for the pre- and post-intervention period as well as during the intervention period. Based on the individual daily values, overall and group specific values were calculated. For the pre-intervention period (pre), the mean value of 7 days of acceleration data was calculated. For the intervention period (int), all daily values during the 10 weeks intervention period were averaged. Post-intervention values (post) were calculated based on 7 days of activity assessment after the intervention period. Due to technical errors and missing data during the intervention period, the number of days included in the analysis varied from 7 to 62 across participants.

RESULTS

PHYSICAL ACTIVITY BEHAVIOR

It was assumed that each participant wore (more or less) the accelerometer for at least 8 h per day, excluding sleeping time and the time in which the sensor was taken off for technical reasons (showering, swimming, etc.).

In addition, participants were instructed to take off the sensor during the night. Nevertheless a very few participants apparently continued to wear the sensor during sleep. If a participant had an off-ratio <10% it was assumed that the sensor was worn during sleeping time. Thus, days with an off-ratio <10% were excluded from analysis to get comparable results across participants.

A minimum wearing time of 7 days (10080 min) was required for each period of activity assessment [pre, during (int), and post-intervention period]. During the intervention period, wearing time varied extremely across participants. Some participants achieved the required minimum of at least 7 days; others wore it up to 62 days in total. The calculation of wearing time only included "active wearing time" during daytime.

While the wearing time was almost equal before the intervention period in both groups (*CG* = 46%; *EG* = 44%; 10080 min reflecting 7 days = 100%), the experimental group wore the sensor significantly more during intervention period (*EG* = 266%; *CG* = 148%). While the *EG* was in contact with the principal investigator twice a week due to training sessions, making appointments with participants of the *CG* to exchange the accelerometers was not feasible.

Participants' wearing time decreased in both groups from pre to post-intervention (−15% wearing time). While participants wore the accelerometer about 73 h during the pre-intervention period, it was worn not more than approximately 55 h in *EG* and 40 h in *CG* during the post-intervention period.

The physical activity level (mean activity intensity) analyzed over the entire intervention period (pre, int, post) differed between the control and experimental group. The analysis of variance for mean activity intensity showed a significant interaction within "group × time" [$F_{(2, 36)} = 3.40$; $p = 0.04$; $\eta^2 = 0.16$].

Mean activity intensity (mean mg value, **Table 1**) prior to the intervention (pre) was similar in both groups (difference not significant). While mean intensity level tended to decrease from prior (pre) to during the intervention (int) in the *CG*, it increased significantly in the *EG* ($t = -3.35$; df = 9; $p = 0.008$). In the post-intervention period, the *CG* showed a similar activity intensity level as before the intervention period (pre). The activity intensity of the *EG* tended to decrease after the intervention period (post) but was still on a higher level than before the intervention period (n.s).

Both groups spent most of their time in the lowest intensity-level (0–99 mg) during all three periods of activity measurement. No significant changes could be observed for the time spent in different activity intensity levels from pre to int and post. The *EG* increased their time spent in the highest intensity level (1000–9999 mg) from 0 to 1% during the intervention period illustrating the intensity of a running training (Kanning et al., 2012), but showed a decrease post the intervention period (0.2%) (**Table 2**).

CHANGE IN ENDURANCE CAPACITY

To test if endurance training was effective and thus participants' endurance capacity improved from T0 to T4, the following parameters were taken into account: running speed at 4 mmol/l (v4 mmol/l), at the vLT, at the vIAT and at the time the test was terminated (vmax). *EG* increased their running speed from T0 to T4 for all parameters [v4 mmol/l (+0.58 km/h), vLT (+0.10 km/h), vIAT (+0.38 km/h), vmax (+0.85 km/h)]. In contrast the *CG* showed a slightly reduced running speed for these parameters (range of reduction: 0.11 km/h to 0.36 km/h) at T4.

The repeated measures analysis of variance revealed a significant interaction between time and group for v4 mmol/l [$F_{(1, 18)} = 4.74$; $p = 0.04$], vIAT [$F_{(1, 18)} = 9.02$; $p = 0.01$] and

Table 1 | Mean activity intensity (mg) for *EG* and *CG* during the three periods (pre, int, and post) of activity monitoring.

	Mean activity intensity in mg (±*SD*)		*n*	
	EG	***CG***	***EG***	***CG***
pre	83.9 (±33.4)	82.5 (±17.6)	10	10
int	98.0 (±15.3)	78.0 (±16.1)	10	10
post	87.5 (±23.7)	81.0 (±27.1)	10	10

vmax [$F_{(1, 18)} = 7.59$; $p = 0.01$]. The effect size for these parameters ranged from 0.21 to 0.33.

COMPLIANCE TO MOOD ASSESSMENTS

Prior to the intervention period (T0) more than 2/3 of all possible queries were answered by both *EG* (72.22%) and *CG* (70.90%). At the end of the study (T4) *CG* answered less than half (47.27%) and *EG* answered even less than 1/3 (30%) of the maximum possible queries (see **Table 3**).

A repeated measures analysis of variance revealed significant differences for the factor "time of measurement" [$F_{(4, 0)} = 3.19$; $p = 0.04$; $\eta^2 = 0.42$]. *Post-hoc* analyses showed that compliance was significantly reduced from T0 to T3 ($t = 2.83$; $df = 22$; $p = 0.01$).

CHANGE IN MOOD—ACUTE EFFECTS

Due to insufficient compliance for the mood ratings pre, directly after and 20, 40 min post-training, acute effects after training could only be analyzed pre and post-training. In addition, acute effects due to exercise training could not be calculated for training sessions separately for each time of measurement. Thus, acute mood effects pre and immediately after training (post) were calculated both for T1 and averaged over T1–T3 (intervention period).

ACUTE EFFECTS AT T1

Immediately after the training, participants rated 10.38% higher values of energetic arousal than before the training. Valence (−8.68%) and calmness (−9.97%) both decreased from pre to post-training. The analysis of variance revealed no significant differences between pre and post-training in energetic arousal [$F_{(1, 9)} = 1.93$; $p = 0.199$; $\eta^2 = 0.18$], valence [$F_{(1, 9)} = 1.74$; $p = 0.22$; $\eta^2 = 0.16$], and calmness [$F_{(1, 9)} = 3.27$; $p = 0.10$; $\eta^2 = 0.27$].

ACUTE EFFECTS ACROSS THE INTERVENTION PERIOD (T1–T3)

Immediately after the training participants, on average, rated higher scale values for all three dimensions compared to prior to the training ($E = +10.6\%$; $V = 17.8\%$; $C = 6.2\%$). The most distinct change could be observed in valence. While mean valence was 3.48 (±0.57) prior to the training, the participants achieved an average scale value of 4.10 (±1.10) immediately after the training. The smallest changes (+6.2%) from pre (C: 3.73 ± 1.24) compared to post (C: 3.96 ± 0.58) training session were observed in calmness.

The analysis of variance revealed a marginally significant difference between the scale values of valence pre and post-training sessions [$F_{(1, 11)} = 3.99$; $p = 0.07$; $\eta^2 = 0.27$]. No significant differences could be identified between the two times

Table 2 | Percentage of minutes spent in different activity intensity levels (mg) pre, during, and post the intervention period for *CG* and *EG*.

	Minutes in total (min)		Minutes spent in activity intensity level (AL in mg) in percent (%)									
	EG	*CG*	AL 0–99 mg		AL 100–199 mg		AL 200–299 mg		AL 300–399 mg		AL 400–499 mg	
			EG	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*
pre	844.7	831.0	75.2%	76.8%	13.1%	13.9%	5.5%	4.8%	2.7%	2.0%	1.8%	1.1%
int	808.2	816.3	73.3%	75.8%	13.7%	14.4%	5.7%	4.8%	2.6%	2.1%	1.6%	1.3%
post	828.1	814.2	73.7%	75.7%	14.1%	13.8%	5.8%	5.0%	2.9%	2.5%	1.7%	1.6%

	Minutes spent in activity intensity level (AL in mg) in percent (%)											
	AL 500–599 mg		AL 600–699 mg		AL 700–799 mg		AL 800–899 mg		AL 900–999 mg		AL 1000–9999 mg	
	EG	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*
pre	1.1%	0.7%	0.4%	0.5%	0.2%	0.1%	0.1%	0.0%	0.1%	0.1%	0.0%	0.1%
int	1.0%	0.8%	0.5%	0.5%	0.2%	0.2%	0.1%	0.1%	0.1%	0.0%	1.0%	0.3%
post	0.9%	0.9%	0.4%	0.5%	0.2%	0.3%	0.2%	0.2%	0.0%	0.2%	0.2%	0.6%

Table 3 | Compliance to mood assessments at the different times of measurement (T0–T4).

Queries	T0		T1		T2		T3		T4	
	EG	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*
Sum	130	117	133	87	109	95	99	77	54	78
Max poss	180	165	252	165	252	165	252	165	180	165
Percentage	72%	71%	53%	53%	43%	58%	39%	47%	30%	47%
Sum (*CG* + *EG*)	247		220		204		176		132	
Max poss (*CG* + *EG*)	345		417		417		417		345	
Percentage (*CG* + *EG*)	72%		53%		49%		42%		38%	

of measurement for energetic arousal—[$F_{(1,\ 11)} = 0.80$; $p = 0.39$; $\eta^2 = 0.07$] and calmness [$F_{(1,\ 11)} = 1.19$; $p = 0.30$; $\eta^2 = 0.09$].

CHANGE IN MOOD—MEDIUM-TERM EFFECTS

Due to the significantly decreasing compliance at T3 and T4 resulting in a smaller sample size, inferential statistics could not be conducted to analyze medium term effects of the 10-week endurance training on mood in daily life. *EG* participants report a continual reduction of all dimensions across the five times of measurement except for energetic arousal, which rises between T2 and T3. In contrast enhanced mood values of energetic arousal, valence, and calmness were observed for the *CG* at the end of the study. Due to insufficient data available at T4 (see **Table 4**), the mean values and standard deviations of the three mood dimensions C, V, E are shown descriptively for the five times of measurement (see **Table 4**).

To be able to calculate inferential statistics, the mood ratings of T2 and T3 were summed to obtain a larger sample size. We selected the time of measurement with the highest number of data entries, if a minimum of six queries was answered. The resulting sample sizes are presented in **Table 5**.

The *T*-test revealed no significant differences for the mood dimensions at T0 and T2/3. The comparison of mood changes from baseline to T2/3 showed decreasing values of the *EG* for all three dimensions. In the EG, C scale values decreased by 2.8% while they increased in the *CG* [$t_{(15)} = 0.45$; $p = 0.23$]; (Cohen's d $= -0.62$). A similar result was found for the E dimension [$t_{(15)} = 0.81$; $p = 0.59$]; (Cohen's $d = -0.27$). Valence decreased by 2.56% in the *EG* and by 5.89% in the *CG* [$t_{(15)} = 0.61$; $p = 0.63$]; (Cohen's $d = 0.25$).

PARTICIPANTS WITH GOOD COMPLIANCE

No inferential statistics was calculated for medium term effects due to significantly decreasing compliance at T3. Seven participants showed good compliance answering at least eight queries at every time of measurement. For these participants (EG: $n = 3$; *CG*: $n = 4$) individual trends are displayed for the valence dimension (highest increase in examination of acute effects compared to other mood dimensions) in **Figure 2** (*EG*) and **Figure 3** (*CG*).

DISCUSSION

In the present ambulatory assessment study we examined acute effects and medium term effects of endurance exercise on mood states in everyday life of apprentices during a 10-week endurance intervention.

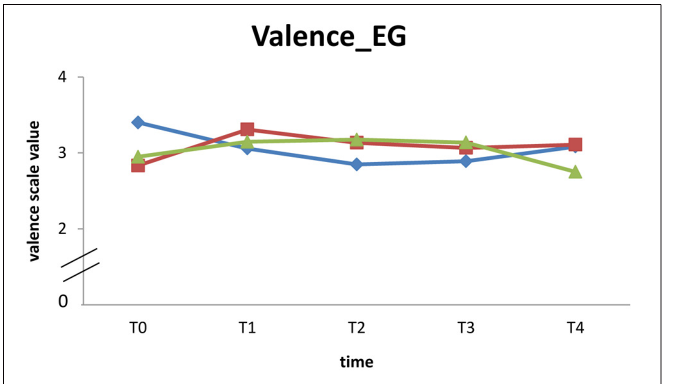

FIGURE 2 | Individual trend of valence from T0 to T4 of participants (*EG*) with good compliance.

Table 4 | Mean scale values of the mood dimensions *E, V, C* at T0–T4, respectively for *EG* and *CG*.

	T0		T1		T2		T3		T4	
	EG	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*
E_MV	3.82	3.41	3.44	3.96	3.22	3.82	3.55	3.32	3.35	3.91
E_SD	0.86	0.81	1.21	0.89	0.77	0.87	0.86	0.77	0.87	0.74
V_MV	4.14	4.24	4.02	4.55	3.87	4.52	3.84	4.38	3.64	4.56
V_SD	0.74	0.71	0.83	0.82	0.93	0.7	0.78	0.5	0.75	0.65
C_MV	4.1	4.37	3.87	4.47	3.9	4.48	3.8	4.36	3.74	4.52
C_SD	0.63	0.71	0.37	0.75	0.76	0.58	0.73	0.44	0.72	0.65
n	9	9	10	8	9	8	6	6	4	5

Table 5 | Differences in mood dimensions *E, V, C* (mean scale values) between T0 and T2/3 for both groups.

	T0		T2/3		Diff		Diff%	
	EG	*CG*	*EG*	*CG*	*EG*	*CG*	*EG*	*CG*
E_MV	3.25	3.08	3.17	3.1	−0.09	0.02	−2.77	0.65
E_SD	0.279	0.296	0.307	0.260	0.47	0.34		
V_MV	3.13	3.22	3.05	3.04	−0.08	−0.19	−2.56	−5.89
V_SD	0.430	0.223	0.116	0.350	0.43	0.44		
C_MV	3.25	3.15	3.16	3.22	−0.09	0.07	−2.77	2.23
C_SD	0.323	0.304	0.346	0.171	0.26	0.25		
n	9	8	9	8	9	8	9	8

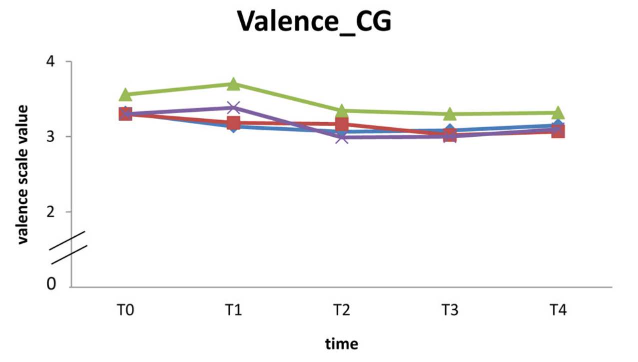

FIGURE 3 | Individual trend of valence from T0 to T4 of participants (*CG*) with good compliance.

ACUTE EFFECTS OF EXERCISE

At the beginning of the in intervention period (T1) only energetic arousal tended to increase immediately after training, whereas the valence and calmness values tended to decrease.

Due to the low compliance of apprentices to rate mood states five times a day, our intention to examine acute effects of training on a weekly basis was not feasible. Intra- individual differences as supposed to exist in previous studies (Ekkekakis et al., 2011) were not considered due to the high number of missing data. Despite the fact that most participants completed the acute mood assessments pre and post the training we could not show significant effects with the small sample size. With averaging all assessments of acute effects of training on mood dimensions we showed marginally significant effects for valence. In contrast to earlier studies mood state pre and post-training was assessed more frequently to test if effect sizes of acute effects increased over the course of the intervention. By averaging multiple acute assessments more situations are captured but inter and intra-individual variability may cover the tracks of real effects.

However, for the mean values across the whole intervention period (T1–T3) all three mood dimensions energetic arousal, valence and calmness increased immediately after a training session (E: +10.4%; V: +17.8%; C: + 6.2%) but results were not significant and for arousal and calmness effect sizes were low. However, for valence we found a marginally significant effect with a high effect size. We assume that participation in a training session positively influenced acute valence of the *EG* participants. Morris and Salmon (1994) also provided evidence for positive changes in mood directly after running training. In line with the present study, Simons and Birkimer (1988) were unable to detect significant effects on tiredness. In contrast, Maroulakis and Zervas (1993) detected significant improvements in mood in all dimensions they investigated. Kanning et al. (2012) showed that daily life physical activity led to higher valence and energetic arousal in students immediately after the activity.

The heterogeneous mood effects pre to post-exercise of T1 (compared to T1–T3) possibly illustrate an interesting characteristic of inactive people. Acute exercise may lead to a decrease in mood at the beginning of an intervention and to an increase during the course of an intervention. For inactive people even moderate intensity endurance training leads to uncommonly high physiological efforts. An increased value of energetic arousal and a decreased value of calmness seem to support this assumption. Thus, inactive people may perceive exercise more aversive during the first sessions of an endurance intervention. The tendency of increased mood values of all three dimensions across the whole intervention period (T1–T3), indicates that in contrast to earlier findings (Steinberg et al., 1998), acute mood effects of acute exercise training differ from acute mood effects of regular exercise training. One can assume that if somebody is used to the physiological strain, regular exercise can rather positively influence acute calmness, energetic arousal and valence.

MEDIUM TERM EFFECTS OF REGULAR EXERCISE

No medium term effects of regular aerobic endurance training on mood could be observed in the present study. The results are not in line with earlier studies in youths at risk (Lubans et al., 2012) and untrained men (Rimmele et al., 2007) showing that exercise and an active lifestyle, respectively led to benefits in psychological well-being.

The significant decrease of compliance at T3 illustrated that the criterion of at least six data entries per time of measurement was not achieved by several participants. Due to the low baseline endurance capacity of participants, endurance improvements could already be expected at T2 (after 6 weeks) (Hohmann et al., 2007). In addition, there were no important differences between T2 and T3. Thus, for the descriptive analyses of medium term effects of regular endurance training on mood, the data of T2 and T3 were combined. The results showing no medium term effects of regular exercise on mood during the first 8 weeks of training in the present study have to be interpreted with caution. Intra-individual progress over the course of the study could not be considered because average values were calculated based on available data entries. In addition, the sample size was not big enough because of the high number of missing data.

However, seven participants (3 *EG*, 4 *CG*) had at least eight data entries for each time of measurement. The descriptive analyses do not suggest meaningful changes in mood from T0 to T4.

Our study confirms results from Alfermann et al. (1993) and Moses et al. (1989). They could not find positive changes in habitual well-being as a result of regular physical activity and exercise.

In line with the results of the present study Steinberg et al. (1998) found decreased mood values over the course of the study while acute positive effects of exercise on mood were present. The findings underline that acute mood effects due to acute exercise have to be differentiated from a general mood enhancement through regular exercise. Alfermann et al. (1993) assumed that an intervention period of approximately half a year is not sufficient to influence global and enduring mental constructs. Berger and Motl (2000) point out that private and professional circumstances possibly have a greater influence than exercise intervention programs. Schlicht and Brand (2007) describe habitual mood as a very stable construct with limited ability to be changed. The young adults of the present sample faced the new situation of the apprenticeship may have had a greater influence on general mood in daily life compared to the positive influence of the regular endurance training.

According to Tellegen et al. (1988) genetic dispositions are one possible explanation. People tend toward a level of well-being that is typical for them, which is changed only briefly and within a more or less narrow corridor, even in the case of exposure to extreme events (Tellegen et al., 1988; Schlicht and Brand, 2007).

AEROBIC EXERCISE CAPACITY

The significant improvement of the diagnostic parameters of the progressive treadmill test from pre to post-exercise intervention showed that the endurance training achieved the pursued results. We achieved a good commitment of the participants to the regularly offered training sessions with an average participation of 14.25 ± 4.33 of a maximum 20 possible training sessions.

PHYSICAL ACTIVITY BEHAVIOR

The objective activity monitoring during the whole study revealed several important aspects considering physical activity in both groups. The monitoring of the physical activity behavior of apprentices showed that they rarely pursue any moderate or intense exercise and that their daily routine primarily consists of low intensity activities or sedentary behavior.

During the intervention period, total activity intensity significantly differed between experimental and control group. The increase from 0 to 1% in the highest activity intensity level during the intervention period can be explained by the running training, as jogging episodes reveal a value of about 1000 mg/min (Kanning et al., 2012). Due to the decrease to 0.2% of time spent in this activity intensity level post the intervention, one can assume that no further increase in the highest activity intensity level besides jogging occurred. In addition, we could show that activity behavior of both groups did not change significantly pre to post-intervention period. This is displayed by the time spent in all other intensity levels which did not change in either *EG* or *CG*. During exercise programs one often faces the problem that the control group starts to become more active during the intervention period due to motivational reasons although they are not supposed to. Activity monitoring offers the potential to control for the activity of the control group.

Based on the results we assume that *EG* participants' daily life physical activity behavior did not impact the results of the exercise intervention. Mean activity intensity was higher post the intervention period in the *EG* (not significant) which may be an indicator that the intervention led to a higher daily physical activity level of the participants of the experimental group. To answer this question, future studies could add an assessment of physical activity few more weeks after the end of an exercise intervention.

AMBULATORY ASSESSMENT OF MOOD STATES AND PHYSICAL ACTIVITY BEHAVIOR

The compliance with accelerometers showed acceptable results. The participants did not feel disturbed by the sensor at any time. They sometimes forgot to put on the sensor in the morning and therefore the activity throughout the whole day could not be determined. For future studies a more interactive activity sensor emitting an acoustic signal or sending a message to a mobile phone if the sensor does not record activity, may limit this problem. This study showed that ambulatory activity monitoring helps to control physical activity behavior of control and experimental group during randomized controlled trials.

The assessment of subjective data via electronic diaries requires a certain self-discipline and willingness to answer the queries. Apparently it did not apply for the participants of the present study. Only a few participants accurately completed the data acquisition via the electronic diaries. Therefore, the question rises whether this approach of data acquisition is suitable for apprentices. Due to the decreasing data entries from T0 to T4, it seemed that the participants felt an increasing disinterest over the course of the study.

To adequately illustrate mood in daily life, more frequent mood assessments have to be conducted. Since mood is a very instable construct, single occasion questionnaires are not appropriate methods to address this issue. Ambulatory assessment offers a great potential to assess mood states across various situations and get more insights in the process of mood changes over time. Furthermore, recall bias can be reduced because data are collected when events actually happen. However, based on the poor compliance to mood assessments in this pilot study, more appropriate strategies have to be generated in future studies to address the question concerning repeated mood assessment via electronic diaries in this target group.

By installing a mobile phone application, participants would not have to carry an additional device (PDA) during the daily routine. Questions on current mood state could be asked relatively inconspicuously in this way.

Improvements of psychological wellbeing have been discussed in the context of health and adherence to physical activity. Positive mood values influence psychological health as an important part of general health of a person. People tend to choose and repeat behaviors they perceive as pleasant (Baumeister et al., 2007). The role of mood in decision making may also apply for exercise and thus positive effects of exercise on mood may enhance adherence to physical activity and exercise (Ekkekakis et al., 2011). The transition from school to an apprenticeship implicates life style changes in young people. Therefore, interventions to promote an active lifestyle may improve adherence to physical activity and serve as an important health preventive contribution.

Future studies should focus on the interaction between acute and medium term effects of exercise and mood in everyday life. Associations between daily life physical activity behavior and mood should be considered. Future studies should further investigate how acute mood effects differ between the beginning and the course of an endurance intervention in inactive people. To account for the characteristics of mood, more frequent measures are meaningful. Strategies to capture enough data to highlight intra-individual trends in effects of regular exercise on mood have yet to be determined.

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