Temporal associations between physical activity, mental activity and fatigue dimensions in knee osteoarthritis: An exploratory intensive longitudinal study

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Abstract

Background: Fatigue may include both physical and mental dimensions. Evidence suggests that physical and mental activity may influence fatigue in knee osteoarthritis (OA). However, how physical and mental activities relate to fatigue dimensions in knee OA is unclear.

Purpose: This study estimated intra-day contributions of physical and mental fatigue to general fatigue and evaluated temporal associations between physical activity, mental activity and fatigue dimensions in knee OA.

Methods: An intensive longitudinal study combined with ecological momentary assessment of mental activity intensity and fatigue dimensions was conducted on 23 participants with knee OA. Physical activity was monitored continuously with an accelerometer over seven days.

Results: Physical fatigue contributed 33% more to general fatigue earlier in the day than mental fatigue, and 11% more near the end of the day. Within-day, previous general fatigue significantly and negatively predicted future step counts, light intensity physical activity time and light intensity physical activity + standing time. We found a significant bidirectional association between mental activity and general fatigue, a positive association between mental activity and mental fatigue and a significant negative association between mental fatigue and mental activity.

Conclusions: Within-day general fatigue may be a significant fatigue dimension that reduces physical activity. Conversely there was no evidence that physical activity might contribute to lower scores on any fatigue dimensions in this population. To manage general fatigue, physical and mental fatigue might have to be targeted more precisely at different time of the day.

Keywords: Knee osteoarthritis, General fatigue, Physical fatigue, Mental fatigue, Physical activity, Mental activity

Introduction

Fatigue is an important and prevalent symptom that considerably impacts the lives of individuals with osteoarthritis (OA) [1,2], affecting more than 40% of adults with OA [1,3]. However, fatigue in OA has received limited research attention. Currently no consensus definition of fatigue exists in the OA population. Generally, fatigue is defined as an unpleasant and subjective feeling of tiredness, exhaustion or lack of energy [4]. This may include both physical fatigue (feeling physically tired, weak or heavy) [5] and mental fatigue (feeling mentally tired, confused and unable to concentrate) [5] components that are interconnected yet distinct [6]. Fatigue dimensions may or may not be related to physical activity (PA) [7] and mental activity [8]. Factors such as depression, high pain, poor physical function, low PA levels [9,10] and high mental task demands [11] have been suggested as correlates of greater fatigue in the OA population.

PA is one of the more studied elements. In a population of individuals with OA (hip and knee), momentary fatigue led to subsequent reduction in PA [12,13], while other studies noted that PA may influence and/or reduce fatigue in the general population and in populations with chronic diseases [14–17]. In a recent longitudinal analysis, we found that PA was associated with greater fatigue at two years follow-up in a subgroup of knee OA with pre-existing fatigue (to be submitted). Nonetheless, there is limited longitudinal evidence on the association between PA and fatigue dimensions in rheumatic conditions such as knee OA.

Observational studies using intensive longitudinal methods and ecological momentary assessment (EMA), defined as real-time measurements of experiences or behaviours in a free-living environment [18], have higher ecological validity than traditional longitudinal designs and can better capture participant's daily life [19,20]. Considering the complexity of the relationship between fatigue and PA and their variability over short time periods [12,21,22], an intensive longitudinal assessment approach provides the possibility to study short-term dynamics (i.e., within day or across days) between different PA metrics and fatigue dimensions in knee OA [19]. Importantly, we do not know when a PA measure at one time point may has its maximal effect on fatigue variables at a later time, nor do we know if temporal precedence (fatigue dimensions precede different PA patterns or vice versa) exists between fatigue dimensions and different PA metrics in free-living in knee OA. This dearth of knowledge is an imperative gap for the study of temporal relations between fatigue dimensions and PA metrics that may inform potential causality and possible therapeutics targets.

In addition to PA, mental activity is another factor hypothesised to significantly contribute to fatigue [8]. Limited evidence is available on the influence of mental activity on fatigue in OA [11], although studies suggest that mental activity and PA influence general fatigue [6–8]. As general fatigue may be a result of physical fatigue and/or mental fatigue [23], understanding how general fatigue and its dimensions (i.e., physical and mental fatigue) relate to the daily fluctuation of PA and mental activity may inform fatigue management plans in the knee OA population. To advance the understanding of general fatigue, the present study sought to estimate the contribution of physical fatigue and mental fatigue to general fatigue [24] as well as evaluate temporal associations between objective PA categories (e.g., step counts, PA intensity, and standing time), subjective mental activity intensity, and fatigue using an intensive longitudinal design approach [19] in individuals with knee OA.

Methods

Study design and participants

We conducted an intensive longitudinal study combining EMA of general, physical and mental fatigue with concurrent continuous objective monitoring of PA in people with knee OA for seven days [19,24]. Eligible participants were required to have a self-reported doctor diagnosis of knee OA, be over 50 years old and report pain, aching, stiffness and fatigue on most days of the past three months. Subjects also were able to read and write English and were independently ambulant with or without a walking stick. Exclusion criteria comprised major mental health issues (e.g., schizophrenia), any known medical cause of fatigue (e.g., low haemoglobin or anaemia, thyroid problem), any major chronic conditions other than OA (e.g., multiple sclerosis, stroke, congestive heart failure, cancer, chronic infection), and total knee joint replacement or frequent falls ($\geq$ 2 in the last twelve months).

Study participants were recruited from the general population through advertisement in a national newspaper (Metro Scotland), emails to the university staff of Glasgow Caledonian University, the musculoskeletal database, church newsletters, podiatry clinics and health centres in the Glasgow area. Written informed consent was obtained from all participants, and the study was conducted following the Declaration of Helsinki and approved by Glasgow Caledonian University School of Health and Life Sciences ethics committee (HLS/PSWAHP/17/148).

Study protocol

This intensive longitudinal study was conducted between February 2018 and April 2019 and consisted of two visits to the Glasgow Caledonian University laboratory. During the first visit, twenty-three participants completed sociodemographic and health outcome questionnaires and were trained to use the paper-based EMA diary by completing a mock EMA questionnaire. Participants were encouraged to record fatigue symptoms at defined intervals and when possible use standardised recording times: morning between 9.30-11.00am; afternoon between 2.00-3.30pm and evening between 6.30-8.00pm for seven days. Participants were requested to record any deviations from these standardised times; however, retrospective completions were discouraged.

An activPAL (model, activPAL$_{TM}$3c PAL Technologies Ltd, Glasgow, Scotland, UK) was affixed onto the anterior aspect of each participant's right mid-thigh using Opsite Flexfix© adhesive (10cm x 10cm) after the device had been made waterproof with a small nitrile sleeve and wrapped with a 3M medipore soft cloth hypoallergenic surgical tape (2861, 25mm x 9.14m) [25]. Participants were encouraged to wear the activPAL for 24 hours daily during the entire study period and to continue activities as normal. To record bedtime, waking and napping times, participants were given a sleep logbook. During the second laboratory visit (day 9) the activPAL was removed, and the EMA diaries and sleep logbook were returned.

Assessment of sociodemographic and health outcomes

Sociodemographic data included age, gender, marital status, and disease duration. Height and body mass were recorded using a stadiometer (a ruler and sliding horizontal headpiece that is adjustable to rest on top of the head and used in measuring height) and a weighing scale. The knee injury and osteoarthritis outcome score, a 42-item questionnaire was used to assess knee symptoms in the past month [26,27]. The scores of the five subscales: pain, symptoms, function in daily activity, sport and recreation, and knee-related quality of life were normalized to a scale of 0-100, with 0 representing extreme knee problems and 100 as no knee problem. The knee injury and osteoarthritis outcome score is a highly reliable [26] and valid tool [27] in the knee OA population. General, physical and mental fatigue were measured using a 0-10 numerical rating scale during the first visit. Participants reported average fatigue symptoms over the past seven days with anchors of 0= 'no fatigue' and 10= 'totally fatigued' for each fatigue dimension.

EMA of general fatigue, physical fatigue and mental fatigue

For each EMA fatigue dimension, participants rated current levels of fatigue on a scale anchored as 0= 'no fatigue' and 10= 'totally fatigued' for seven days. The numerical rating scale has been shown to provide valid measurement of subjective feelings such as fatigue [28].

Subjective assessment of mental activity intensity

Participants' current mental activity intensity was reported with a 0-10 numerical rating scale using the question 'how hard is your mental activity right now?' with anchors '0'=no activity and '10'= 'very very hard' at designated times thrice daily for seven days on a paper-based diary.

Assessment of physical activity

Free-living physical activity (PA) was objectively measured with an activPAL tri-axial accelerometer over a 9-day period. The activPAL is a small device (53 X 35 X 7mm) that uses proprietary algorithms to estimate the amount of time spent sitting, standing, stepping, and to classify intensity categories i.e., light intensity physical activity and moderate-to-vigorous physical activity and these estimations have been reported as accurate [29–31]. The activPAL has been validated for use in free-living and laboratory environments and in patient populations, such as knee OA [32]. We included seven days data for analysis to avoid first day reactivity and last day incomplete data. The data were downloaded using the activPAL3$_{TM}$ software (V8.10.8.32). We used the following PA parameters for statistical analyses: step count, standing time, light intensity physical activity time, light intensity physical activity +standing time and moderate-to-vigorous physical activity time per period assessed using the HSC PAL software V1.22. A cadence greater or equal to 100 steps/min was considered as moderate-to-vigorous physical activity while cadence of less than 100 steps/min was considered as light intensity physical activity [33].

Statistical analyses

Data distribution and normality were visually examined using histograms. All fatigue variables were normally distributed. Descriptive statistics include means, standard deviations (SD) and frequencies. Pearson correlation analyses examined the associations between aggregated EMA fatigue symptom variables within day. EMA fatigue, mental activity ratings and physical activity data were graphed for both within and between day intensity and variability.

To estimate the distinct contribution of physical and mental fatigue to general fatigue within day, participants with at least four days continuous physical and mental fatigue data entries (am, noon and pm) were selected for linear regression analysis [34,35]. This analysis assumes that general fatigue is the sum of the reported physical and mental fatigue at each time point. The average of all morning, afternoon and evening physical and mental fatigue for each person were used. Any individuals who reported <1 average rating for either physical or mental fatigue continuously for the seven consecutive days were excluded. The coefficients of physical and mental fatigue were plotted (Figure 2) within day and the ratio of physical fatigue to mental fatigue within day was estimated.

Time series and cross correlation

The temporal associations of different PA parameters, mental activity intensity and fatigue dimensions were assessed with a cross-correlation function (CCF) analysis. CCF quantifies any linear relationship that may exist between successive measurements in two paired and equally spaced time-varying variables [36]. Prior to estimating the CCF, we checked for auto-correlated errors in the data (i.e., non-randomness) using autocorrelation function analysis which involves a time-varying variable (X[t]) correlated against itself [37]. This analysis determined the inter-day dynamics of each fatigue dimension. The absolute value of cross correlation was considered significant if it fell within the 95% confidence interval (CI) of the mean. Autocorrelation function and CCF analyses were performed on data from each subject and then averaged over all subjects. Data were analysed using Microsoft Excel 2019 and IBM SPSS Statistical software (version 23.0).

Results

Sample characteristics

Of 37 eligible individuals, 14 declined participation and 23 agreed to participate in the study (Figure 1). All 23 participants had valid EMA data but only 22 had valid PA data. Out of a possible 21 EMA data points per person and a total of 483 data entries for the 23 participants, only 15 (3.1%) data entries were missing and 8 individuals had $\leq$3 missing data entries. 468 (96.9%) out of the potential 483 data entries were completed. Average age of study participant was 64.9±7.0 years and 61% were female (Table 1). The study sample reported well-advanced knee OA with time since doctor-diagnosis ranging from three weeks to twenty years. 15 of the 23 participants reported unilateral right knee joint as symptomatic. The average fatigue in the past seven days prior to the start of the EMA study was 6.70±1.69 for general fatigue, 6.61±1.99 for physical fatigue and 5.35±2.69 for mental fatigue. Correlations between aggregated within-day EMA fatigue dimensions (general, physical and mental fatigue) ratings were all significant and showed large effect sizes ($r \geq 0.78$). The within-day correlations between fatigue dimensions were as follow: general and physical fatigue (r= 0.94-0.98), general and mental fatigue (r= 0.78-0.81) and physical and mental fatigue (r= 0.79-0.87).

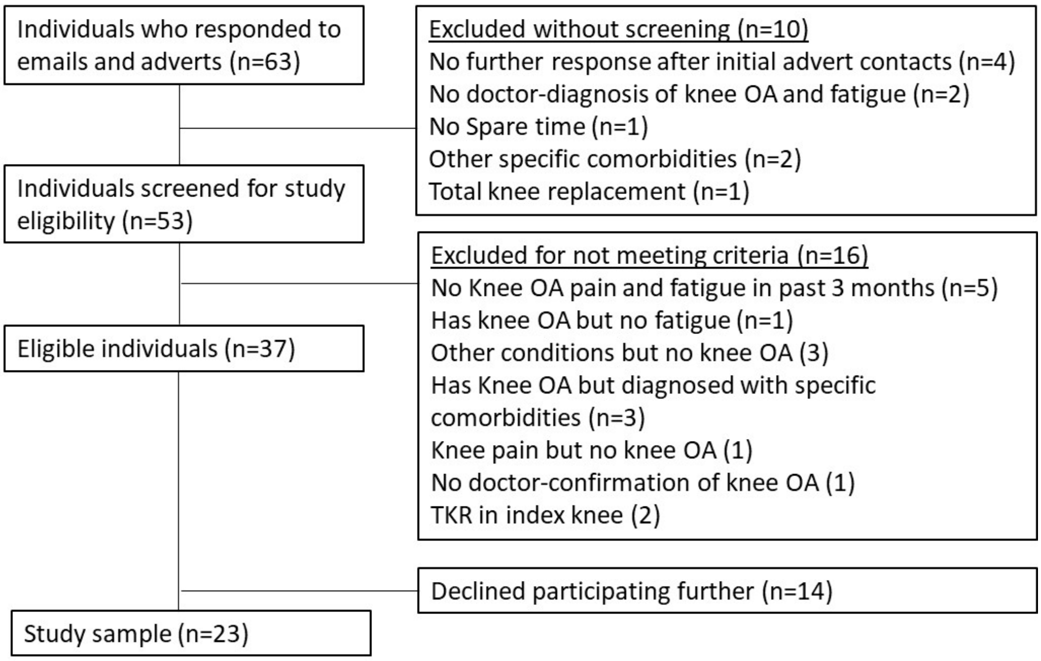

Fig. 1 Flow diagram of participant selection

EMA data

Overall, subjects' average EMA fatigue and mental activity intensity throughout the seven days were relatively low ($\leq$4.0 on the 0-10 scale). Little variation was observed across days and within day for EMA fatigue and mental activity intensity (Supplementary material – figures S1a-d).

Table 1: Baseline characteristics of study participants

Characteristics	Mean (SD)
Number of study participants	23
Age [years]	64.87(6.98)
Sex, male/female [n]	9/14
Marital status, married/others [n]	11/12
BMI [kg/m^2]	32.77(5.75)
Duration of doctor diagnosis	3 weeks – 20 years
Symptomatic index knee, left/right [n]	8/15
KOOS	
KOOS-Pain [0-100]	41.91(16.94)
KOOS-Symptom [0-100]	45.74(15.57)
KOOS-ADLs [0-100]	51.26(18.09)
KOOS-Sports/Rec [0-100]	25.00(16.86)
KOOS-QoL [0-100]	28.22(18.89)
NRS general fatigue [0-10]	
Past 7 days	6.70(1.69)
NRS physical fatigue [0-10]	
Past 7 days	6.61(1.99)
NRS mental fatigue [0-10]	
Past 7 days	5.35(2.69)
Average total steps/day [n=22]	7895.84(3446.15)
Average standing time, min/day [n=22]	245.73(90.46)
Average LIPA time. min/day [n=22]	69.75(26.79)
Average LIPA & standing time, min/day [n=22]	315.49(103.90)
Average MVPA time, min/day [n=22]	27.43(23.48)

Data are mean (SD) or number (n). BMI = Body mass index; kg/m^2= Kilogram/meter square; Nm/kg= newton-meter/kilogram; KOOS = Knee injury and Osteoarthritis Score; ADLs= activities of daily living; Sports/Rec= Sports/Recreational; QoL = Quality of life; NRS=Numerical rating scale; LIPA= light intensity physical activity; MVPA = moderate to vigorous physical activity; minute/day

Physical activity data

Over the seven days, participants' total steps/day averaged 7896±3,446. The study sample averaged 246±90 min/day in standing, 70±27 min/day in light intensity physical activity and 27±24 min/day in moderate-to-vigorous physical activity (Table 1). All PA categories rose from morning to afternoon and decreased in the evening while, across days PA showed little variation (Supplementary material – figures S2a-d).

Within-day estimation of physical fatigue and mental fatigue contributions to general fatigue

Physical fatigue contributed nearly a third more than mental fatigue to general fatigue at the beginning of the day, but physical fatigue gradually decreased and contributed approximately 11% more than mental fatigue toward the end of the day (figure 2). However, mental fatigue rose throughout the day. The ratio of physical fatigue to mental fatigue decreased from morning [1.44] to evening [1.14] (figure 3).

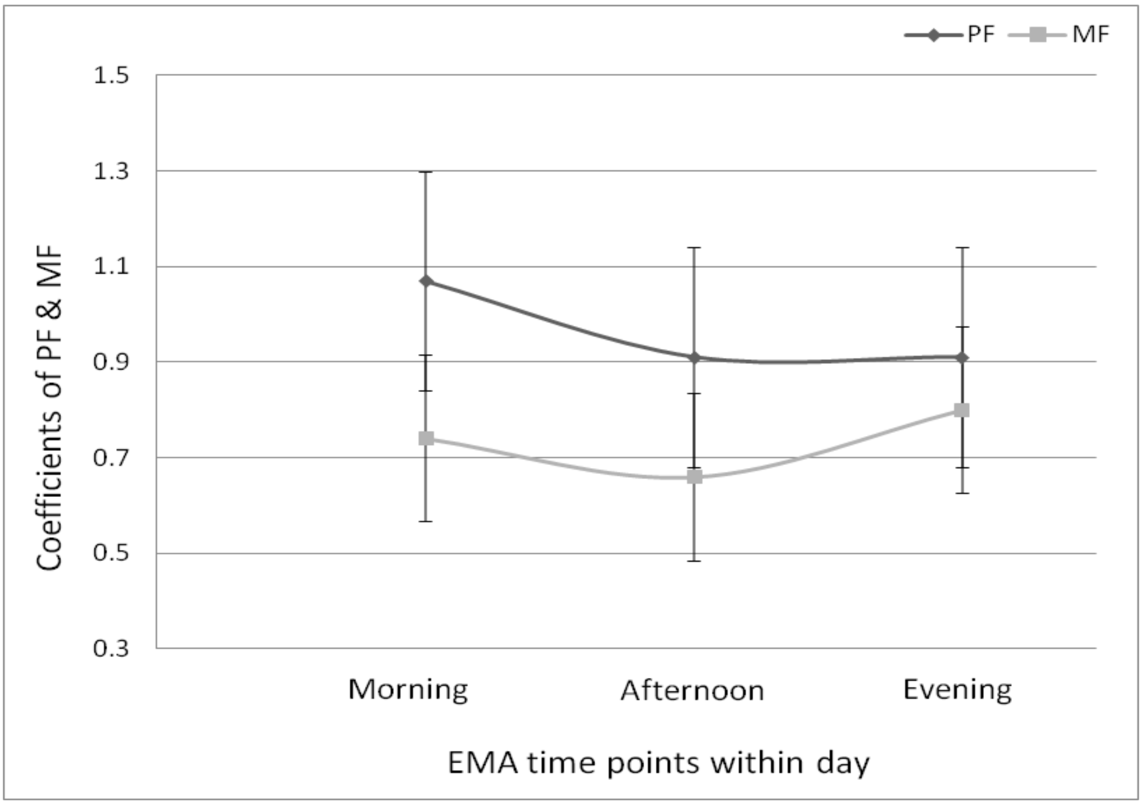

Fig. 2 Contributions of physical fatigue and mental fatigue to general fatigue within day. PF, physical fatigue; MF, mental fatigue; EMA, ecological momentary assessment

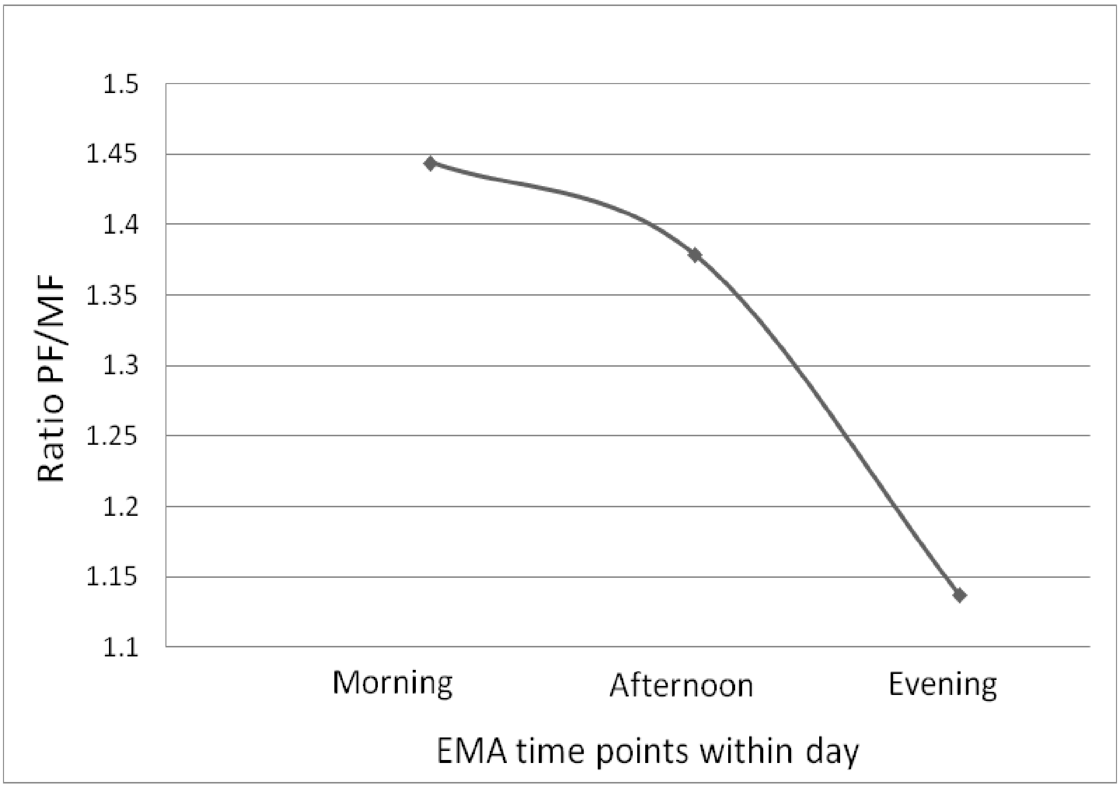

Fig. 3 The ratio of physical fatigue to mental fatigue within day. PF, physical fatigue; MF, mental fatigue; EMA, ecological momentary assessment

Within-day temporal associations of PA categories, mental activity intensity and fatigue

Within day, previous general fatigue negatively predicted future step count (r= -0.62; 95% confidence interval (CI) [-0.99, -0.25]), light intensity physical activity time (r= -0.62; 95% CI [-0.99, -0.25]) and light intensity physical activity + standing time (r= -0.43; 95% CI [-0.85, -0.01]; Table 2). Bidirectional associations were found for general fatigue and mental activity intensity (r= 0.43; 95% CI: 0.01, 0.85); r= -0.43; 95% CI: -0.85, -0.01). Mental activity intensity was positively associated with concurrent mental fatigue levels (r= 0.34; 95% CI: 0.01, 0.67). Within day, previous mental fatigue correlated negatively with subsequent mental activity intensity (r= -0.43; 95% CI: -0.85, -0.01). Neither the different PA categories nor mental activity intensity were associated with physical fatigue or vice versa.

Table 2: Cross-correlation of fatigue dimensions, PA intensity categories and MA intensity within day (Intra-day analysis)*

n=22		General fatigue	Physical fatigue	Mental fatigue
Steps/day	Steps/day concurrent with symptom report	-0.19(-0.52, 0.13)	-0.16(-0.47, 0.14)	-0.11(-0.42, 0.19)
	Morning and afternoon steps on afternoon and evening symptoms	0.05(-0.51, 0.42)	-0.14(-0.60, 0.32)	0.33(-0.11, 0.77)
	Morning and afternoon symptoms on afternoon and evening steps	-0.62(-0.99, -0.25)†	-0.33(-0.77, 0.11)	-0.24(-0.69, 0.21)
MVPA time	MVPA time concurrent with symptom report	-0.15(-0.47,0.16)	-0.20(-0.47,0.06)	-0.18(-0.48, 0.13)
	Morning and afternoon MVPA time on afternoon and evening symptoms	-0.24(-0.69, 0.21)	-0.14(-0.60, 0.32)	0.14(-0.32,0.60)
	Morning and afternoon symptoms on afternoon and evening MVPA time	-0.24(-0.69, 0.21)	0.05(-0.42, 0.51)	-0.05(-0.51, 0.42)
LIPA + standing time	LIPA & standing time concurrent with symptom report	-0.18(-0.55,0.19)	-0.15(-0.51, 0.21)	-0.03(-0.38, 0.32)
	Morning and afternoon LIPA + standing time on afternoon and evening symptoms	0.24(-0.21, 0.69)	0.14(-0.32, 0.60)	0.05(-0.42, 0.51)
	Morning and afternoon symptoms on afternoon and evening LIPA + standing time	-0.43(-0.85, -0.01)†	-0.33(-0.77, 0.11)	-0.05 (-0.51, 0.42)
LIPA time	LIPA time concurrent with symptom report	-0.10(-0.44, 0.25)	-0.12(-0.45, 0.20)	0.03(-0.32, 0.37)
	Morning and afternoon LIPA time on afternoon and evening symptoms	0.14(-0.32,0.60)	0.24(-0.21, 0.69)	0.14(-0.31, 0.60)
	Morning and afternoon symptoms on afternoon and evening LIPA time	-0.62(-0.99, -0.25)†	-0.33(-0.77, 0.11)	-0.24(-0.69, 0.21)
Standing time	Standing time concurrent with	-0.27(-0.62, 0.09)	-0.23(-0.60, 0.14)	-0.13(-0.47, 0.21)

	symptom report			
	Morning and afternoon standing time on afternoon and evening symptom	0.05(-0.42, 0.51)	-0.05(-0.51, 0.42)	0.24(-0.21, 0.69)
	Morning and afternoon symptoms on afternoon and evening standing time	-0.33(-0.77, 0.11)	-0.24(-0.69, 0.21)	0.05(-0.42, 0.51)
Mental activity intensity	Mental activity intensity concurrent with symptom report	0.22(-0.13, 0.57)	0.28 (-0.03, 0.60)	0.34(0.01, 0.67)†
	Morning and afternoon mental activity intensity on afternoon and evening symptoms	0.43(0.01, 0.85)†	0.33 (-0.11, 0.77)	0.05 (-0.42, 0.51)
	Morning and afternoon symptoms on afternoon and evening mental activity intensity	-0.43(-0.85, -0.01)†	-0.33(-0.77, 0.11)	-0.43(-0.85, -0.01)†

*Values are cross correlation coefficients with 95% confidence interval (CI)

†$p<0.05$

Between-day temporal associations of different PA categories, mental activity intensity and fatigue dimensions

Autocorrelation analysis

The autocorrelation of fatigue symptoms (general, physical and mental fatigue) [figures 5a-c] showed that general fatigue and physical fatigue the day before was associated with decreased general fatigue and physical fatigue next day only. However, previous day mental fatigue was associated with reduced mental fatigue subsequently for three days.

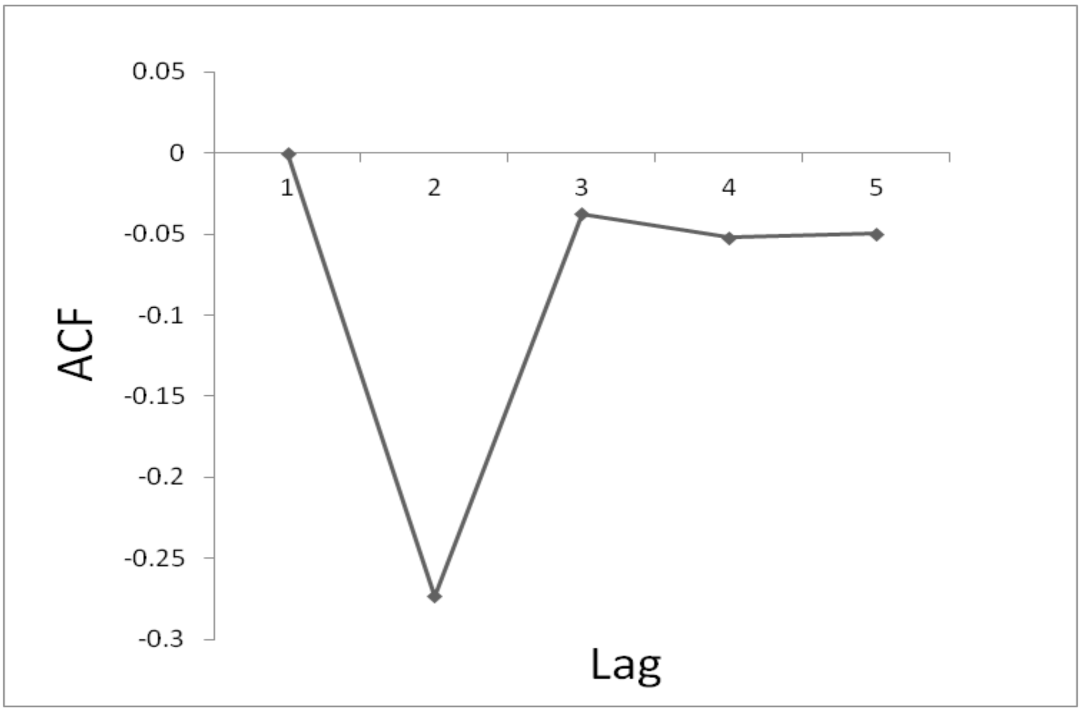

Fig. 4 Autocorrelation plot of general fatigue between days. ACF, autocorrelation

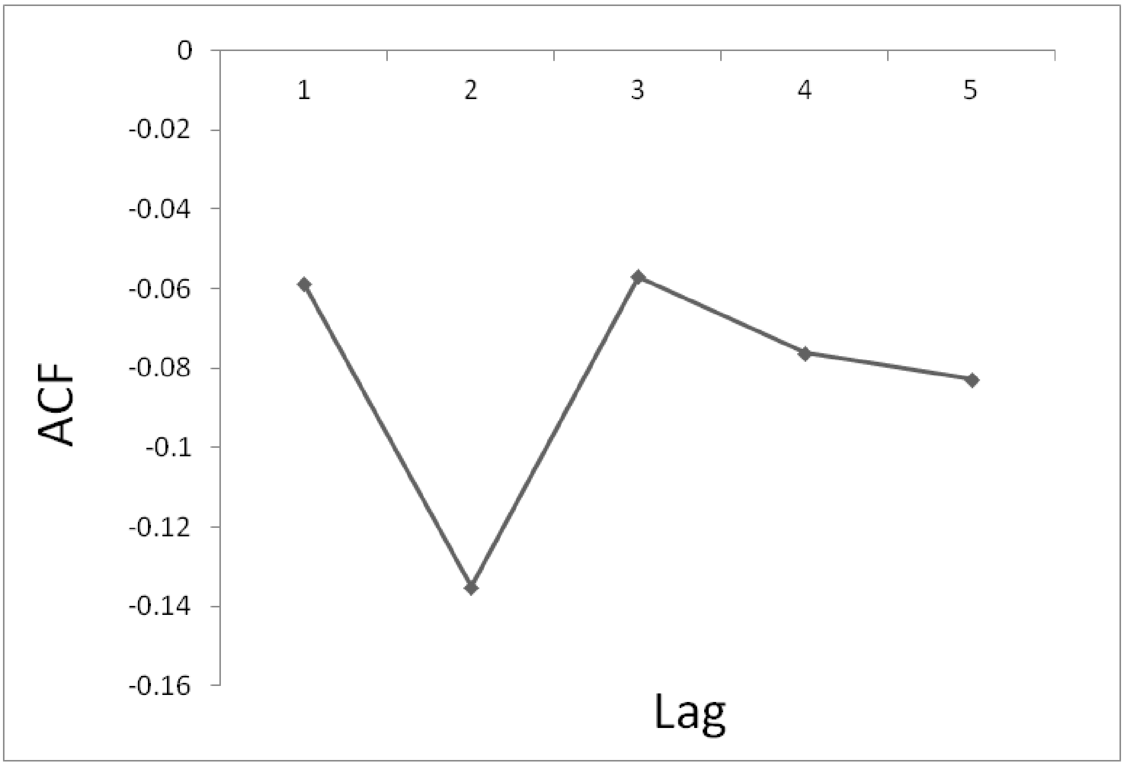

Fig. 5 Autocorrelation plot of physical fatigue between days. ACF, autocorrelation

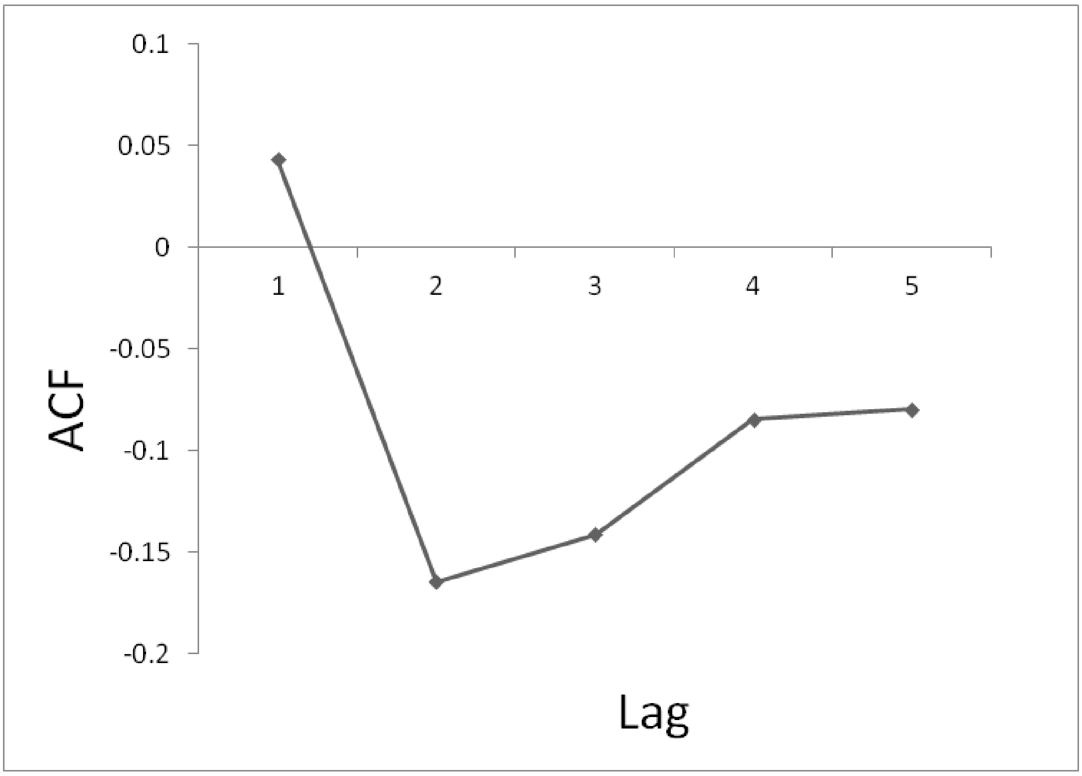

Fig. 6 Autocorrelation plot of mental fatigue between days. ACF, autocorrelation

Cross-correlation analysis

Compared to within-day cross-correlation analyses, the between days analyses showed very small associations between PA categories and fatigue dimensions and most of the absolute values were not within the 95% confidence interval of the mean (data not shown). However, mental activity intensity and fatigue dimensions showed a positive concurrent association as follows: [general fatigue: (r= 0.40; 95% CI: 0.22, 0.58); physical fatigue: (r=0.35; 95% CI: 0.15, 0.55) & mental fatigue: (r=0.56; 95% CI: 0.41, 0.71)].

Discussion

General fatigue is a multifaceted problem that encompasses both physical and mental dimensions [23]. In our study, general, physical and mental fatigue were strongly inter-correlated and the contribution of physical and mental fatigue to general fatigue varied throughout the day. The contribution of physical fatigue to general fatigue was three times greater than mental fatigue, but mental fatigue became increasingly prominent throughout the day. Furthermore, physical fatigue to mental fatigue ratios declined throughout the day. These findings highlight the strong inter-connectedness across fatigue dimensions but also point to the potential importance of delineating fatigue dimensions within-day. Our findings may also imply that when assessing general fatigue, it may be necessary to also assess both physical fatigue and mental fatigue separately as different interventions may impact one or both fatigue dimensions differently. Further, considering the potential evidence on biochemical differences between mental fatigue and physical fatigue in the general population [38], future studies might want to advance or validate our findings by further exploring fatigue dimensions in a larger population of knee OA.

Fatigue dimensions and PA categories

This study showed that previous general fatigue is associated with reduced levels of PA (step counts, light intensity physical activity + standing time and light intensity physical activity time) at later times in the day. Interestingly, general fatigue was the only construct of fatigue that significantly predicted later PA in this study. High general fatigue may indicate reduced energy to expend which may have a negative impact on future PA. Counter-intuitively, individuals who are generally fatigued may assume that resting would improve general fatigue, however this process may have detrimental effects on a population such as those with knee OA who already have unhealthy low levels of PA [39,40]. Given that our observed effect sizes were moderate [41], the negative associations observed between general fatigue and PA categories may highlight the need for better management of general fatigue symptoms in knee OA with the goal of improving PA engagement and overall quality of life. More so, this moderate effect size is comparable or higher than most correlates of PA [42] - acting to reduce general fatigue could have a clinically significant impact on PA and general health. In particular the dose response between PA and health shows significant benefits for health with relatively small increases in PA for those starting from a low level [43].

In comparison to the within-day associations, there were no significant temporal associations between fatigue dimensions and PA categories in this sample across consecutive days. This suggests that fatigue dimensions were not particularly influenced by time spent in different PA categories or step counts from the previous day or vice versa. Perhaps this lack of between-days effect may be due to low levels of PA observed. Quasi-experimental and randomised controlled trial studies may be needed to evaluate the effectiveness of both acute and chronic PA interventions on fatigue dimensions in the knee OA population.

Fatigue dimensions and mental activity

Our finding of significant bidirectional associations between general fatigue and mental activity intensity within day suggests the potential presence of a mutually reinforcing link between these two factors in knee OA. It has been posited that exerting cognitive control as usually required in mental activity performance requires energy and effort [44] which may lead to greater general fatigue. As a result of this potential rise in general fatigue, individuals may subsequently reduce task engagement i.e., decrease physical activity participation, and this may further escalate general fatigue. Also, having pre-existing general fatigue may necessitate increased motivation in order to exert higher mental control for mental activity.

We also found a positive concurrent association between mental activity intensity and mental fatigue within-day and between days. In addition, a greater level of previous mental fatigue was associated with subsequent lower mental activity intensity within day. This highlights the potential negative role of higher mental exertion on mental fatigue and vice versa in this population. The likely influence of previous mental fatigue on subsequent mental activity intensity may reduce important work-related or leisure cognitive performance. Thus participation in fatigue-inducing physical, mental and functional activities may affect motivation and task self-efficacy, thus leading to impaired abilities to engage in adequate levels of physical activities [45,46]. A recent systematic review and meta-analysis concluded that cognitive effort rather than duration of cognitive task may be more important with regards to eliciting negative carryover effects associated with mental activity [47].

However, it is uncertain if the reduced levels of mental performance associated with mental fatigue are due to progressive decline of the mental resources (i.e., attention, memory) or an insufficient recruitment of unaltered cognitive processes, caused by a loss of motivation [48]. Thus, further research may be required to establish which domain of mental activity influences mental fatigue or explore the mechanism of actions between mental fatigue and mental activity exertion in knee OA. As this study was performed in free-living environments, we were unable to manipulate the potential influence of physical and mental activity interactions on fatigue. Future experimental studies might examine the role of dual tasking on fatigue and its dimensions.

Fatigue dimensions between days

Our findings showed that mental fatigue was temporally associated with subsequent levels of mental fatigue for more than three days, suggesting that the effects of mental fatigue linger with significant carry over effects observed over three days. However, physical and general fatigue were only temporally associated for one day, which suggest that the carry over effects of these two fatigue dimensions are shorter when compared to mental fatigue. These findings highlight the importance of fatigue variability [21] and the potential dynamic day-to-day nature of different fatigue dimensions in the knee OA population. Interestingly these carry-over effects observed for fatigue dimensions were potentially informative, perhaps indicating that effective management of different fatigue dimensions could lead to subsequent decrements in fatigue across days with positive carry over effects perhaps lasting longer for mental fatigue.

Clinical relevance

In terms of clinical relevance, our findings may have several implications. First, our findings of varied contributions of within-day physical and mental fatigue to general fatigue may help clinicians or researchers to explore or design targeted within-day therapeutic modalities, which might be effective in reducing physical and mental fatigue within-day. Further, to effectively manage general fatigue in knee OA, different components of general fatigue may require potential targeting at different times within days. Thus, clinicians or patients may need to focus on reducing physical fatigue at the beginning of the day and target decreasing mental fatigue during the latter part of the day. Secondly, the significant negative effect sizes observed for within-day general fatigue and subsequent physical activity may further suggest the need for individualised within-day treatment plans for general fatigue. Thirdly, the probable detrimental and mutually reinforcing relationship observed between higher intensity mental activity and increased general fatigue could play an important role in declining activity participation in this population. These findings may align with previous research in OA that found decreased mental endurance and greater mental fatigability within-day and across days following a lab-based cognitive task [11]. Mental activity may be an important factor to consider in the management and design of fatigue interventions. Thus, clinicians and researchers could include assessment of different mental activity domains and fatigue dimensions since both factors may likely impact activity performance negatively in daily life.

Limitations and strengths

The important limitations of this study include the relatively small sample size power; however, this was an exploratory study that requires replication. That said, the momentary fatigue symptoms of our participants were similar to those of larger OA samples [13,49]. Second, self-selection bias may have limited generalizability given that 38% of our initial sample who did not participate may have had significant and perhaps higher levels of fatigue. Third, very few participants reported completing symptom entries out with the specified time blocks and actual compliance could not be ascertained. The use of mobile or electronic devices for capturing momentary fatigue dimensions would be advisable. The subjective measurements of mental activity intensity and mental fatigue may be overlapping constructs which limits clear interpretation. Also, our self–reported doctor diagnosis of knee OA were not validated with knee OA radiographical results. A strength of our study was the recruitment of OA participants from the general community as well as the ecological validity of this study, as study participants were assessed in their own environment. In addition, the use of objective PA measurement prevents reactivity or recall bias. Also, the inclusion of different PA parameters rather than a single metric of PA and different fatigue dimensions builds on previous evidence on PA and fatigue.

Conclusion

This study suggests varying contribution of physical and mental fatigue to general fatigue throughout the day and persistent effects of mental fatigue over several days. Within-day general fatigue may be a significant fatigue dimension that reduces PA. Also, general and mental fatigue may be important fatigue components that influence mental activity intensity. It may be necessary to consider precisely targeted within-day general fatigue and mental fatigue management to increase functional PA and mental activity levels in knee OA.

Supplemental Material

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