

Running head: An integrated model of walking in osteoarthritis

Using impairment and cognitions to predict walking in osteoarthritis: a series of *n*-of-1 studies with an individually-tailored, data-driven intervention

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### **Acknowledgements**

The authors would like to thank the participants in the study for the time and effort they gave to the project.

## **Statement of Contribution**

### **What is already known on this subject?**

- *N*-of-1 methods have been used to study within-individual predictors of walking in healthy and chronic pain populations
- An integrated biomedical and behavioural model of activity and activity limitations recognises the roles of impairment and psychology (cognitions)
- Interventions modifying cognitions can increase physical activity in people with mobility limitations

### **What does this study add?**

- *N*-of-1 methods are suitable to study within-individual predictors of walking and interventions in osteoarthritis
- An integrated and a psychological model are better predictors of walking in osteoarthritis than a biomedical model
- There was no support for an individually-tailored, data-driven walking intervention

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## **Abstract**

**Objectives.** This study compares the ability of an integrated model of activity and activity limitations, the International Classification of Functioning, Disability and Health (ICF), and the Theory of Planned Behaviour (TPB) to predict walking within individuals with osteoarthritis. The effectiveness of a walking intervention in these individuals is also tested.

**Design.** A series of *n*-of-1 studies with an AB intervention design.

**Methods.** Diary methods were used to study four community-dwelling individuals with osteoarthritis of the knee or hip. Data on impairment symptoms (pain, pain-on-movement and joint stiffness), cognitions (intention, self-efficacy and perceived controllability) and walking (pedometer step count) were collected twice-daily for 12 weeks. At six weeks, an individually-tailored, data-driven walking intervention using action planning or a control cognition manipulation was delivered. Cross-correlations, trends and differences in mean between baseline and intervention phases were tested using simulation modelling analysis, and multiple regression analyses were conducted.

**Results.** Cognitions, intention in particular, were better and more consistent within-individual predictors of walking than impairment. The walking intervention did not increase walking in any of the three participants that received it. Both the integrated model and the TPB, which recognise a role for cognitions in predicting behaviour, accounted for substantially more variance in walking than the biomedical model of the ICF.

**Conclusion.** Despite the lack of evidence for an individually-tailored walking intervention, predictive data suggest that interventions for people with osteoarthritis that address cognitions are likely to be more effective than those that address impairment only. Further within-individual investigation is warranted.

Physical inactivity is a leading cause of death and diseases, including Type II diabetes and coronary heart disease (Kohl et al., 2012; Lee et al., 2012). People with osteoarthritis have higher levels of physical inactivity and lower levels of physical activity than people without osteoarthritis (Dunlop et al., 2011; Stubbs et al., 2013), rendering them at excess risk of diseases linked to physical inactivity. Engaging in more physical activity not only reduces the risk of conditions secondary to osteoarthritis, but is also a recognised core treatment for the management of osteoarthritis, reducing pain, improving function and mobility (Centers for Disease Control and Prevention, 2010; National Institute for Health and Care Excellence, 2014).

There are evidence-based recommendations for the role of structured exercise or physical therapy in the management of osteoarthritis (Hochberg et al., 2012; Roddy et al., 2005; Zhang et al., 2010); however, these interventions are often limited by high attrition, poor adherence and a lack of evidence for effectiveness beyond the short-term (Fransen & McConnell, 2008; Fransen, McConnell, Hernandez-Molina, & Reichenbach, 2014; Jordan, Holden, Mason, & Foster, 2010). In contrast to structured exercise, interventions encouraging more habitual, moderate intensity physical activity like walking may be a promising solution to overcome the limitations to exercise as a therapy and help manage osteoarthritis and secondary diseases (Chang et al., in press; Roddy et al., 2005).

Interventions to promote walking in people with osteoarthritis are complex with potentially multiple interacting components. Guidance on the development of complex interventions identifies an important role for theory (Craig et al., 2008). An integrated theoretical model of activity and activity limitations (Johnston, Bonetti, Pollard, Backman, & Hofston, 2002; Johnston & Dixon, 2013) is available that integrates psychological theory of behaviour, the Theory of Planned Behaviour (TPB:(Ajzen, 1991), with a biomedical model, the International Classification of Functioning, Disability and Health framework for health outcomes

(ICF:(World Health Organization, 2001). The integrated model preserves the direct relationship between impairment and activity found in the ICF, but also incorporates a role for psychology through cognitions (see Figure 1). TPB cognitions, such as intention and perceived behavioural control, act as process variables that mediate the relationship between impairment and activity. In chronic conditions where curative treatment to target impairment is unavailable, limited or costly, the role for cognitions, recognised in the integrated model, is key. Cognitions provide an opportunity to intervene to increase activity and reduce disability without the need to reduce impairment. Experimental evidence has shown that cognitions can be modified to promote physical activity and reduce activity limitations in typically sedentary individuals with chronic conditions including osteoarthritis (Fisher & Johnston, 1996; Lorig, Ritter, Laurent, & Fries, 2004).

Figure 1 about here

To date the integrated model has been tested using group-based designs identifying differences in activity limitations and walking *between* individuals with disabling chronic conditions including osteoarthritis (Dixon, Johnston, Rowley, & Pollard, 2008; Quinn et al., 2012), chronic pain (Dixon, Johnston, Elliott, & Hannaford, 2012) and chronic idiopathic axonal polyneuropathy (Schroder et al., 2007). However, the majority of psychological theories posit within-individual processes and therefore the importance of testing whether a model or theory can account for differences in behaviour *within* an individual, is paramount (Curran & Bauer, 2011; Johnston & Johnston, 2013). *N-of-1* designs are longitudinal, within-participant study designs, which are a recognised tool to test health behaviour models, theory and interventions within individuals (Craig et al., 2008). The design has specifically been deemed a viable method for the study of physical activity (Gorczyński, 2012).

Within the field of physical activity research, *n*-of-1 designs have been used to predict walking in healthy individuals (Hobbs, Dixon, Johnston, & Howie, 2013) and physical activity in people with chronic pain (Quinn, Johnston, & Johnston, 2013). In addition, the suitability of *n*-of-1 randomised controlled trials to test behavioural walking interventions has been explored (Sniehotta, Presseau, Hobbs, & Araujo-Soares, 2012). In pursuit of personalised medicine, *n*-of-1 designs are ideal to test individualised data-driven interventions within individuals, data from which can be used to inform the design of trials of stratified interventions (Lillie et al., 2011).

This study tests whether the integrated model is a better predictor of walking in individuals with osteoarthritis than the ICF or TPB alone. Specifically, we examined whether milder impairment (operationalised as symptomatic joint pain, joint stiffness and pain-on-movement) as set out in the ICF (Cieza et al., 2004; Dreinhofer et al., 2004) and stronger control cognitions (operationalised as perceived controllability and self-efficacy, the subcomponents of perceived behavioural control from the TPB) predicted objectively measured walking. Secondly, we test whether an individually-tailored, data-driven behavioural intervention can increase walking in these individuals.

## **Materials and Methods**

### **Participants**

Participants were recruited via adverts placed in local community facilities including the library, post office and church. The inclusion criterion was having knee or hip osteoarthritis that had been clinically confirmed by a health professional. Exclusion criteria were inflammatory arthritis, knee or hip replacement of the arthritic joint, acute knee or hip surgery or injury in the past 3 months, or potential health risk from doing physical activity (Thomas, Reading, & Shephard, 1992). Five people responded to the advert, were screened against the

inclusion and exclusion criteria and invited to take part. Four individuals (80%) accepted the invitation: participant A – male, 48 years old, knee osteoarthritis diagnosed 3 years previously; participant B – male, 59 years old, hip osteoarthritis diagnosed 2 years previously; participant C – female, 67 years old, knee osteoarthritis diagnosed 1 year previously; participant D - female, 60 years old, knee osteoarthritis diagnosed 3 years previously. Participants were informed that they would complete a diary for 12 weeks and that at six weeks they would receive an individually-tailored intervention to help them increase their walking and improve their mobility. Participants were remunerated for their time with £50 on study completion.

## **Measures**

Twice a day for a period of 12 weeks, participants completed a diary using a handheld personal digital assistant device (Hewlett Packard iPAQ 214). The device was programmed using the software ‘Pocket Questionnaire v1.2’ (University of Aberdeen Data Management Team 2006) and diary data were downloaded from the device using the Pocket Questionnaire software. With the exception of the objectively measures walking data, all measures were self-reported using a visual analogue scale (VAS) with scale anchors appropriate to each diary item (see below for details). Participants tapped the screen with a stylus at the appropriate point on the VAS between the two scale anchors. A higher score indicated greater impairment, higher intention, greater self-efficacy and higher perceived controllability. The VAS was recorded by the software as a numerical value between 0-100.

### *Walking*

Walking was assessed objectively by pedometer (Omron HJ-113) and participants entered their step count at each diary entry.<sup>1</sup>

### *Impairment*

Joint pain and pain-on-movement were measured by two items: ‘How would you describe your pain right now?’ and ‘How would you describe your pain when you move right now?’, the VAS was anchored with *no pain* and *extreme pain*. Joint stiffness was assessed with one item: ‘How would you describe your joint stiffness right now?’, anchored with *no stiffness* and *extreme stiffness*.

### *Theory of planned behaviour cognitions*

The proximal predictors of behaviour posited by the TPB were measured by standard single items. Intention was assessed with the item: ‘To what extent do you intend to walk more than usual between now and the next time you fill in the diary?’, anchored with *no intention* and *definitely intend*. Self-efficacy was assessed by the item: ‘How confident are you that you can walk more than usual between now and the next time you fill in the diary?’, anchored with *not at all confident* and *extremely confident*. Perceived controllability was measured with ‘How much do control do you have over walking more than usual between now and the next time you fill in the diary?’, anchored with *no control* and *complete control*.

## **Walking Intervention**

The interventions were data-driven and designed to increase walking. For each participant, baseline data were analysed to identify the cognitions that were significantly correlated with walking reported at the next diary entry, approximately 12 hours later. Each participant then

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<sup>1</sup>Self-reported walking, and cognitions and self-reported behaviour of an individualised non-walking behaviour were also recorded; these data are not reported here.

received an intervention using either action planning or a control cognition manipulation accordingly. For example, if intention was significantly correlated with walking, the participant received the action planning intervention; if perceived controllability was significantly correlated with walking, the participant received the perceived controllability intervention; and if self-efficacy was significantly correlated with walking, the participant received the self-efficacy intervention. When both intention and perceived controllability or both intention and self-efficacy were significantly correlated with walking, the participant received either the perceived controllability or self-efficacy intervention respectively. Delivering the intervention which targeted one of the subcomponents of perceived behavioural control maximised the opportunities for intervention success either directly impacting on behaviour or via intention (see Figure 1),

*Perceived controllability or self-efficacy intervention.* The content of the intervention was based on a previously successful experimental manipulation of control beliefs (Fisher & Johnston, 1996). The following instructions were given to the participant (wording was adapted for the perceived controllability (or self-efficacy) interventions, respectively):

*‘One of the things that influences whether you as individual walk is your sense of control (confidence) over walking. The more control you believe you have (confident you feel), the better you will succeed at walking. Please tell me about three occasions when you felt in control of (confident about) walking. It may help you to visualize the occasions.’*

Participants wrote down the descriptions to use as reminders of feeling this way.

*Action planning intervention.* Participants were told that one of the things that influenced whether they walked was their intention, and that specifying the day of the week, time of the day and length of time that they intended to walk in a plan would help them to walk more (Sniehotta, Scholz, & Schwarzer, 2006; Sniehotta, Schwarzer, Scholz, & Schuz, 2005). A previous study with a similar personalised intervention showed positive effects on physical

activity (Michie, Johnston, Cockcroft, Ellinghouse, & Gooch, 1995). Participants were asked to complete a written version of their plan and to use it as a reminder of what they planned to do.

## **Procedure**

Participants were provided with a pedometer, a diary device and instructions on how to operate them. With the researcher, participants completed a practice diary entry to ensure comprehension. Device alarms prompted each participant to complete the diary at two agreed time points each day (approximately 12 hours apart). Participants were advised to miss the diary entry if they were not able to complete it within one hour of the original alarm. At six weeks, baseline data were downloaded from the devices and analysed. Each participant then received the data-driven intervention at home. The intervention was delivered by the researcher and lasted between 10 and 15 minutes.

## **Analyses**

Data for each participant were analysed separately using the open source statistical package R, v.2.15.2. Simulation modelling analysis for time series data (Borckardt et al., 2008) was used. Missing data were imputed using the package “norm” and a suitable transformation for those variables which were not normally distributed. For each variable, a number of autoregressive models of different orders were fitted with the simplest autoregressive model that had a satisfactory goodness of fit selected for each variable. In some cases this was simply a random white noise model. 10,000 simulations were then generated based on the same autoregressive model. By comparing the simulated datastreams with the observed datastreams, an estimation of how likely observed patterns were to arise by chance was obtained. This process allowed for analyses which took into account the non-independent,

correlated nature of the data. Three tests were applied to these simulations: a test for significant cross-correlations between variables, a test for a significant change in mean from the baseline to the intervention phase, and a test for a significant trend across the whole study period.

In addition, multiple regressions were conducted testing three different models for each participant: the TPB, the ICF and the integrated model. The aim was to see how well each of these models predicted step count at the next time point; for instance, the regression testing the ICF model included joint pain, pain-on-movement and joint stiffness at time 0 as predictors, and steps at time 1 as the response variable.

## **Ethics**

This study was approved by the [BLINDED] Ethics Committee, which conforms to the ethical standards of the British Psychological Society.

## **Results**

### **Descriptive data**

Adherence to diary completion was high. The lowest rate of adherence was 89.5% (participant C) and the highest was 99.8% (participant B). The descriptive data for impairment symptoms, cognitions and walking for each participant over the 12-week study period are shown in Table 1. Between and within-participant variability was evident in all measures.

Table 1 about here

### **Predicting walking during baseline phase**

Overall, cognitions served as better predictors of walking than impairment and intention was the most consistent predictor of walking (Table 2). The same pattern of association between intention and walking was observed for all four participants; stronger intention now was associated with higher step count approximately 12 hours later (i.e., at the next diary entry) whilst, in contrast, weaker intention now was associated with higher concurrent step count and higher step count approximately 24 hours later (i.e., two diary entries later).

Other variables were also predictive of walking. For participant A greater self-efficacy now predicted higher step count 12 hours later. Pain was predictive for participant B; there was a concurrent positive relationship between pain-on-movement and step count. For participant D, stiffness and self-efficacy were predictive; less stiffness predicted higher step count 24 hours later and stronger self-efficacy predicted higher step count concurrently and 24 hours later. All impairment and cognition variables were predictive for participant C, however the manner of the relationships varied. The same general relationship between each impairment symptom and walking was observed; the concurrent relationship between impairment and step count, and the relationship between impairment and step count 24 hours later were positive, i.e. worse symptoms were associated with higher step count. In contrast, worse symptoms now were associated with lower step count 12 hours later. As with intention, stronger self-efficacy now predicted higher step count 12 hours later whilst higher step count now predicted a weaker self-efficacy. In this case, stronger self-efficacy now also predicted higher step count 24 hours later. The direction of these relationships was reversed for perceived controllability which showed a negative relationship with step count 12 and 24 hours later and a positive concurrent relationship.

Table 2 about here

### **Data-driven interventions**

The final row of Table 2 shows the walking intervention delivered to each participant, determined by the predictors of walking at the next diary entry evident in baseline data. For participant A, both intention and self-efficacy were significantly correlated with step count 12 hours later thus the self-efficacy intervention was delivered. Intention was significantly correlated with steps for both participant B and D so these participants received the action planning intervention. Participant B did not fully engage with the intervention, however, as he declined to make a plan. Hence, he only received feedback that his intention predicted walking and that making a plan would help him walk more. Participant C did not receive a walking intervention as she did not want to walk more than she currently did. Instead, she received an action planning intervention to increase a non-walking behaviour, data on which are not reported in this paper, and therefore intervention data for participant C are not presented.

### **Predicting walking during intervention phase**

As found at baseline, intention was the most consistent predictor of walking during the intervention phase (Table 3). The previous pattern of association between intention and walking was observed in the data from all three participants, weaker intention now was associated with higher concurrent step count and higher step count approximately 24 hours later whilst stronger intention now was associated with higher step count approximately 12 hours later. In addition during this phase, pain-on-movement was associated with higher concurrent step count for all participants.

Table 3 about here

For participants A and D, new relationships emerged during the intervention phase that were not identified at baseline. Both control cognitions were predictive of step count; however, their predictive pattern varied. For participant A, stronger perceived controllability and weaker self-efficacy now were associated with higher concurrent step count, whilst for participant D, stronger perceived controllability and weaker self-efficacy now were associated with lower step count 12 hours later. In addition, the concurrent relationship between self-efficacy and step count was positive at baseline but negative during the intervention phase. As identified at baseline, in general, cognitions served as better predictors of walking than impairment; however, during the intervention phase pain-on-movement also served as a relatively good predictor.

### **Testing the effect of the intervention on impairment, cognition and walking**

Figure 2 displays the serial data for step count and either intention or self-efficacy, depending on whether the participant received an action planning or self-efficacy intervention respectively, for each participant across the study period.

Figure 2 about here

Tests were conducted for significant differences in mean values between the baseline and intervention phases accounting for serial correlation (Table 4). Significant increases in perceived controllability and self-efficacy were found for participant A, who received the self-efficacy intervention; however there was no significant increase in step count.

Nevertheless, both joint pain and joint stiffness significantly decreased from baseline to intervention. There was no change in walking from baseline to intervention for participants B and D, both of whom received the action planning intervention. Significant decreases in

cognitions were seen however, with perceived controllability decreasing for participant B and intention for participant D. Moreover, a significant decrease in joint pain was identified for participant D; yet, interestingly it was coupled with a significant increase in joint stiffness.

Table 4 about here

### **Trend analyses across the study period**

Increasing or decreasing trends in each variable were explored across the study period (Table 5). For participants A and B the trends found almost exactly matched the results of the tests for significant differences in mean values between baseline and intervention phases. From week 0 to week 12, perceived controllability trended upwards whilst pain and stiffness trended downwards for participant A, and perceived controllability trended downwards for participant B. The only difference between mean difference and trend analyses was that a significant change in self-efficacy for participant A was found between baseline and intervention phases, but there was no significant trend in self-efficacy across the whole study period. For participant D, the trend analyses identified an increase in stiffness and a decrease in intention from week 0 to week 12, which matches the pattern of mean differences identified in these variables; however, no trend in pain was found despite the previously reported significant mean decrease in pain from baseline to intervention. For participant C, there was a decreasing trend in pain, pain-on-movement and stiffness over the study period.

Table 5 about here

### **The ability of the TPB, ICF and the integrated model to predict walking across the study period**

The multiple regression analyses are presented in Table 6. With the exception of participant A for whom the ICF did not predict walking, each of the three models, the TPB, the ICF and the integrated model, significantly predicted walking 12 hours later in all participants. The ICF, however, accounted for the least amount of variance in walking, explaining less than a quarter of the variance that the other models explained. When compared to the TPB, the integrated model accounted for marginally more variance in walking in all participants.

Table 6 about here

## **Discussion**

This study used an *n*-of-1 design to test the ability of an integrated model of activity and activity limitations to predict objectively measured walking in individuals with osteoarthritis. The effectiveness of an individually-tailored, data-driven walking intervention was also tested. Within-participant analyses were used to identify whether an individual was more likely to walk when impairment symptoms are milder and cognitions are more positive towards walking than at other times. During the intervention phase in particular, the impairment symptom of pain-on-movement was a good predictor of walking in all participants, providing evidence for a direct relationship between impairment and activity as proposed by the ICF. In addition, the regression analyses revealed that the ICF could significantly explain walking in three of four participants albeit only explaining between 2% and 10% of variance.

Intention was a proximal predictor of walking for all participants during the baseline and intervention phases; participants were more likely to have walked more when they had reported a stronger intention to walk in the previous diary entry. Control cognitions (perceived controllability and self-efficacy) were generally less predictive of walking and

when a predictive relationship was identified it was more variable both within and between participants.

The direction of the significant relationships between intention or self-efficacy and walking at baseline and intervention differed depending on the temporal lag of the relationship. In all cases, stronger intention and self-efficacy now predicted more steps 12 hours later; whereas, in all but one case, at times when the individual recorded having walked more steps they also concurrently reported weaker intention and less confidence about walking within the next 12 hours. This suggests that for individuals with osteoarthritis, walking may be a finite behaviour and walking more than usual may be difficult to sustain over a 24 hour period. The TPB predicts that stronger intention and self-efficacy will result in more activity, whereas the current finding suggests that more walking can also result in weaker cognitions. A negative relationship between self-efficacy and walking is counter to self-efficacy theory, which would predict that a successful mastery experience performing a behaviour would increase, not decrease, self-efficacy to perform the behaviour (Bandura, 1977). However, studies within learning literature have similarly identified a negative relationship between self-efficacy and task performance at the within-individual level and have suggested that personal goals and goal level (difficulty) may help to explain the finding (Vancouver & Kendall, 2006; Vancouver, Thompson, & Williams, 2001). It is possible that individuals with osteoarthritis, for whom walking can be difficult and painful, may on occasion possess the goal to control pain rather than to be active. They may feel that after having walked more than usual, they are not confident of their ability to walk much more because their current goal is to control pain by *not* being active (Quinn et al., 2013). This may also result in a weaker intention to walk. Measures of self-efficacy to control pain and goals in future *n*-of-1 studies of individuals with mobility problems would permit further investigation of possible explanations for the identified negative relationship between self-efficacy and walking.

The walking intervention was ineffective for all three participants that received it. Participant A received the intervention designed to increase self-efficacy and despite a significant increase in self-efficacy between the baseline and intervention phases no positive effects on walking were observed. Enhancing self-efficacy is a key element of many effective arthritis self-management programmes, which have demonstrated increases in physical activity, reductions in pain and the adoption of more effective pain coping strategies (Bruno, Cummins, Gaudiano, Stoos, & Blanpied, 2006; Marks, Allegrante, & Lorig, 2005). A significant decrease in joint pain from baseline to intervention was observed in this participant suggesting that even though the intervention did not increase walking, it may have had a positive impact on pain. However, a decreasing trend in pain was observed across the entire study period, which may also explain the significant mean difference from baseline to intervention. The cause of this trend and other trends identified in participants' data are unclear. Trends may be unrelated to the intervention and instead reflect fluctuations in impairment symptoms or cognitions over time related to the trajectory of the health condition, environmental factors such as changes in the weather or a reaction to taking part in a study that prompted regular self-monitoring through the diary. For example, data from participant C reveal decreasing trends in all impairment symptoms, yet this participant chose not to receive the walking intervention. The inability to shed light on the reason(s) for the identified trends is a limitation of this study, which future studies should address using mixed-methods to elicit information from participants about their perceptions of changes in variables over time, either in the form of real-time noting of events in the diary or retrospectively probing in an interview at the end of the study.

The action planning intervention was ineffective in promoting walking in both of the two participants that received it. An overview of the planning intervention literature concluded that planning interventions are effective in promoting health behaviours (Hagger &

Luszczynska, 2014); however, this conclusion is based on literature dominated by group-based design studies investigating between rather than within-individual intervention effects. The lack of effect of action planning for participant B can perhaps be explained by the fact that they refused to make a plan. Evidence from action planning studies has indicated that participants who actually make an action plan are more likely to perform the target behaviour than participants who do not (Michie, Dormandy, & Marteau, 2004; Rutter, Steadman, & Quine, 2006). Nonetheless, our exploration of the effectiveness of action planning interventions within-individuals is original and therefore, before drawing conclusions about why the intervention was ineffective in the current study, the finding first needs to be replicated.

The current findings show that the TPB and the integrated models were able to explain considerably more variance in walking than the ICF. Findings from the chronic pain literature are in line with this. Dixon et al (2012) similarly found the TPB to be a better predictor of walking than the ICF in a group-based study and Quinn et al (2013) found that the TPB better predicted activity measured by accelerometry than the ICF in an *n-of-1* study. Specifically, in the current study, the ICF explained less than 10% of the variance in walking in each participant, whereas the TPB and the integrated models were able to explain considerably more amounts of variance, accounting for between 46% and 66% of variance in walking. Moreover, the amount of variance explained by the TPB and the integrated model was extremely comparable with the integrated model only marginally explaining more variance. The univariate analyses showed that even though cognitions, in particular intention, were consistently the best predictors of walking, the impairment symptom of pain-on-movement was also a good predictor during the intervention phase explaining at least 20% of variance in walking. Adding impairment to the TPB, as is the case in the integrated model, may not provide a unique, substantial contribution to explaining behaviour if it acts indirectly via one

or other of the cognitions. Future work is needed to explore potentially mediating relationships.

A strength of this study was the use of an objective measure of walking. The variance in objectively measured walking explained by the TPB in the participants in this study is greater than has been reported previously in TPB studies of objectively measured physical activity (McEachan, Conner, Taylor, & Lawton, 2011). However, the dominance of group-based studies of the TPB in the literature, on which previous findings are primarily based, means that there is a lack of data on the predictive ability of the TPB at the within-individual level from which to compare. However, the *n*-of-1 study by Quinn et al (2013) did report that 32% of the variance in activity could be explained by the TPB in one of the studied participants. A potential limitation of the current study is the use of single item measures of the TPB variables, which may be less sensitive reducing statistical power. Single items were used to reduce participant burden and the likelihood of poor study compliance. In comparison to multiple item measures, which are more commonly used in TPB studies, single item measures may contain more measurement error making them susceptible to attenuation effects. However, if more measurement error did exist in the single items used then this would mean that the identified relationships were in fact underestimated.

The variability and complexity of the within-individual relationships between impairments, cognitions and walking in individuals with activity limitations are evident in these data, which were collected using an *n*-of-1 design. Group-based designs can mask individual differences in the predictive utility of theoretical models, which may contribute to the small or modest effect sizes that are typically seen from interventions to improve mobility disability (Baker, Atlantis, & Fiatarone Singh, 2007; Keysor & Brems, 2011). The novelty of this study was that it used an *n*-of-1 design to test the utility of different models to explain walking in people with osteoarthritis and, in turn, to inform the design of an individually-

tailored, data-driven intervention. In general, cognitions, primarily intention, were more consistent and better predictors of walking than impairments. These findings lend support for the TPB, either alone or as part of the integrated model, as a predictive model of walking in osteoarthritis, highlighting the need for effective behaviour change interventions that target cognitive predictors. Future work is needed to ascertain whether the between and within-individual predictors of walking of people with impairments are the same and to consider these findings in the design, development and evaluation of future interventions.

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Table 1. Descriptive statistics for impairment, cognitions and walking (steps) for each participant across the 12-week study period.

	Pain	Pain-on- movement	Stiffness	Intention	PC	SE	Steps
<b>Participant A (n=169)</b>							
Mean (SD)	55.8 (16.6)	57.9 (16.6)	57.2 (16.6)	31.9 (23.1)	85.6 (11.9)	57.1 (16.3)	2349 (2498)
AR(1)	0.31	0.44	0.36	-0.35	0.00	0.34	-0.42
AR(2)	0.00	0.00	0.00	0.31	0.00	0.00	0.43
<b>Participant B (n=168)</b>							
Mean (SD)	28.2 (9.4)	25.5 (9.6)	37.2 (10.9)	24.2 (16.1)	69.9 (7.8)	62.8 (8.7)	4369 (4103)
AR(1)	0.32	0.29	0.20	-0.34	0.38	0.41	-0.35
AR(2)	0.00	0.00	0.00	0.00	0.00	0.00	0.33
<b>Participant C (n=179)</b>							
Mean (SD)	32.1 (9.7)	34.0 (9.9)	46.0 (14.6)	39.8 (31.6)	94.9 (6.0)	38.0 (14.9)	1741 (1900)
AR(1)	0.00	0.00	0.00	-0.07	0.00	-0.37	-0.29
AR(2)	0.00	0.00	0.00	0.50	0.00	0.00	0.46

AR(3) <sup>1</sup>	0.00	0.00	0.00	-0.28	0.00	0.00	0.00
<b>Participant D (n=161)</b>							
Mean (SD)	27.4 (14.5)	26.2 (14.3)	32.3 (15.7)	31.6 (27.0)	71.6 (16.1)	73.5 (10.7)	3664 (3825)
AR(1)	0.37	0.34	0.33	-0.23	0.00	0.35	-0.57
AR(2)	0.00	0.00	0.00	0.45	0.00	0.00	0.00

Impairments and cognitions were measured on VAS from 1-100; a higher score = worse impairment and stronger cognitions. Walking was measured objectively by pedometer. Mean number of steps = mean number at each diary entry; doubling this value provides an estimate of the mean number of steps per day.

PC = Perceived Controllability; SE = Self-Efficacy; Steps = pedometer step count; AR(1) = first order autoregressive term; AR(2) = second order autoregressive term; AR(3) = third order autoregressive term

<sup>1</sup>AR(2) model did not have a sufficient goodness of fit for intention for participant C therefore an AR(3) model was specified.

Table 2. Lagged cross-correlations between impairment and cognitions, and walking (steps) during the baseline phase (0-6 weeks), accounting for serial correlation

Variable	Participant A			Participant B			Participant C			Participant D		
	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0
<b>Lagged cross-correlation with step count</b>												
Pain	-0.06	-0.04	0.13	-0.05	-0.02	0.02	0.23*	-0.26*	0.27**	-0.12	0.08	-0.07
Pain-on-movement	0.02	-0.04	0.14	-0.03	-0.04	0.22*	0.41***	-0.39***	0.48***	-0.08	-0.03	-0.07
Stiffness	-0.18	0.15	-0.13	-0.15	0.18	0.06	0.48***	-0.40***	0.51***	-0.23*	0.09	-0.18
Intention	-0.62***	0.84***	-0.68***	-0.46***	0.71***	-0.40***	-0.65***	0.75***	-0.69***	-0.59***	0.79***	-0.58**
PC	-0.05	-0.11	0.17	-0.08	0.14	-0.17	-0.55***	-0.38***	0.29**	0.21	-0.12	0.10
SE	0.13	0.27*	-0.18	0.05	-0.05	-0.12	0.27*	0.69***	-0.67***	0.26*	-0.04	0.25*
<b>Intervention</b>	SE			Action Planning			None			Action Planning		

PC = Perceived Controllability; SE = Self-Efficacy; CCF -2 = cross-correlation function between each listed variable reported now and step count recorded approximately 24 hours later (i.e., two diary entries later); CCF -1 = cross-correlation function between each listed variable

reported now and step count recorded approximately 12 hours later (i.e., one diary entry later); CCF 0 = cross-correlation function between each listed variable and step count recorded at the same time point. \*  $P \leq 0.05$ ; \*\*  $P \leq 0.01$ ; \*\*\*  $P \leq 0.001$

Table 3. Lagged cross-correlations between impairment and cognitions, and walking (steps) during the intervention phase (6-12 weeks), accounting for serial correlation

Variable	Participant A			Participant B			Participant D		
	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0
<b>Lagged cross-correlation with step count</b>									
Pain	0.16	-0.16	0.20	0.01	-0.03	0.10	-0.11	-0.04	0.16
Pain-on-movement	0.13	-0.10	0.24*	0.16	-0.11	0.25*	-0.11	-0.12	0.23*
Stiffness	0.13	0.11	0.15	-0.01	0.11	0.01	-0.15	-0.02	0.19
Intention	-0.56**	0.81***	-0.59**	-0.40***	0.70***	-0.47***	-0.50***	0.69***	-0.52***
PC	-0.16	0.13	0.24*	0.10	0.16	-0.20	-0.02	-0.21*	0.12
SE	-0.14	0.27*	-0.27*	-0.10	-0.05	-0.03	0.19	0.22*	-0.21*

Participant C did not receive a walking intervention so intervention data are not reported.

PC = Perceived Controllability; SE = Self-Efficacy; Steps = pedometer step count; CCF -2 = cross-correlation function between each listed variable reported now and step count recorded approximately 24 hours later (i.e., two diary entries later); CCF -1 = cross-correlation function between each listed variable reported now and step count recorded approximately 12 hours later (i.e., one diary entry later); CCF 0 = cross-correlation function between each listed variable and step count recorded at the same time point. \*  $P \leq 0.05$ ; \*\*  $P \leq 0.01$ ; \*\*\*  $P \leq 0.001$

Table 4. Tests for significant difference in mean values of variables between baseline and intervention phases, accounting for serial correlation

	Pain	Pain-on-movement	Stiffness	Intention	PC	SE	Steps
<b>Participant A</b>							
Baseline Mean (SD)	59.0 (16.7)	60.4 (18.0)	62.8 (17.5)	32.2 (24.7)	82.2 (15.8)	54.6 (19.5)	2157 (2176)
Intervention Mean (SD)	52.6 (14.2)	56.3 (13.7)	52.1 (14.0)	31.3 (21.6)	89.2 (3.00)	59.6 (12.2)	2540 (2775)
Int.Cor	-0.21	-0.13	-0.32	-0.02	0.30	0.15	0.077
Pr(>r)	0.008**	0.096	0.000***	0.740	0.000***	0.050*	0.119
<b>Participant B</b>							
Baseline Mean (SD)	28.2 (8.6)	24.7 (9.4)	37.4 (10.8)	25.3 (16.0)	72.0 (6.0)	64.1 (7.3)	4485 (4278)
Intervention Mean (SD)	28.2 (10.2)	26.3 (9.8)	39.0 (11.2)	23.4 (16.1)	67.5 (8.3)	61.7 (9.6)	4271 (3967)
Int.Cor	0.00	0.09	0.07	-0.06	-0.30	-0.14	-0.03
Pr(>r)	0.971	0.272	0.366	0.426	0.000***	0.072	0.676
<b>Participant D</b>							
Baseline Mean (SD)	30.5 (15.5)	28.4 (14.8)	27.3 (13.1)	37.1 (25.1)	72.1 (15.8)	74.2 (12.2)	3357 (3441)
Intervention Mean (SD)	25.1 (13.3)	24.3 (13.7)	36.7 (16.3)	27.4 (27.8)	71.4 (16.6)	73.0 (9.4)	3930 (4133)

Int.Cor	-0.19	-0.14	0.30	-0.18	-0.02	-0.06	0.08
Pr(>r)	0.020*	0.069	0.000***	0.028*	0.779	0.479	0.350

Participant C did not receive a walking intervention so intervention data are not reported.

PC = Perceived Controllability; SE = Self-Efficacy; Steps = pedometer step count; Int.Cor = observed correlation between the variable and the baseline/intervention phase; Pr(>r) = probability of this correlation arising by chance for a time series with the observed autocorrelation profile.

\*  $P \leq 0.05$ ; \*\*  $P \leq 0.01$ ; \*\*\*  $P \leq 0.001$

Table 5. Tests for significant trend in variables across the whole study period (0-12 weeks), accounting for serial correlation

	Pain	Pain-on-movement	Stiffness	Intention	PC	SE	Steps
<b>Participant A</b>							
Drift (SE)	-0.09 (0.03)	-0.05 (0.04)	-0.12 (0.03)	-0.03 (0.03)	0.07 (0.02)	0.05 (0.04)	3.95 (2.20)
t-statistic	-3.01	-1.24	-3.97	-0.99	4.13	1.28	1.79
p.value	0.003**	0.217	0.000***	0.325	0.000***	0.201	0.075
<b>Participant B</b>							
Drift (SE)	-0.01 (0.02)	-0.00 (0.02)	-0.00 (0.02)	-0.02 (0.02)	-0.06 (0.02)	-0.01 (0.02)	-7.77 (4.89)
t-statistic	-0.73	-0.06	-0.20	-1.06	-3.57	-0.26	-1.59
p.value	0.466	0.949	0.845	0.291	0.000***	0.796	0.114
<b>Participant C</b>							
Drift (SE)	-0.04 (0.01)	-0.05 (0.01)	-0.08 (0.02)	0.06 (0.03)	-0.02 (0.01)	-0.01 (0.01)	-2.32 (2.38)
t-statistic	-2.79	-3.65	-3.89	1.64	-1.81	-0.35	-0.98
p.value	0.006**	0.000***	0.000***	0.103	0.072	0.724	0.329
<b>Participant D</b>							

Drift (SE)	-0.05 (0.03)	-0.04 (0.03)	0.10 (0.03)	-0.10 (0.04)	-0.01 (0.03)	-0.01 (0.03)	4.58 (3.36)
t-statistic	-1.32	-1.29	2.97	-2.51	-0.41	-0.35	1.36
p.value	0.189	0.199	0.003**	0.013*	0.685	0.723	0.175

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PC = Perceived Controllability; SE = Self-Efficacy; Steps = pedometer step count; Drift = slope of fitted line after accounting for serial correlation; p.value= probability of this slope arising by chance for a time series with the observed autocorrelation profile.

\*  $P \leq 0.05$ ; \*\*  $P \leq 0.01$ ; \*\*\*  $P \leq 0.001$

Table 6. Multiple regression analyses comparing the ability of the integrated model, ICF and TPB to predict walking (steps) at the next diary entry

	Integrated	ICF	TPB
<b>Participant A</b>			
R <sup>2</sup>	0.656	0.022	0.650
F-statistic (DF)	51.19 (6,161)	1.21 (3,164)	101.6 (3,164)
p.value	0.000***	0.309	0.000***
<b>Participant B</b>			
R <sup>2</sup>	0.567	0.054	0.541
F-statistic (DF)	34.9 (6,160)	3.10 (3,163)	64.11 (3,163)
p.value	0.000***	0.028*	0.000***
<b>Participant C</b>			
R <sup>2</sup>	0.464	0.102	0.462
F-statistic (DF)	24.63 (6,171)	6.59 (3,174)	49.87 (3,174)
p.value	0.000***	0.000***	0.000***
<b>Participant D</b>			
R <sup>2</sup>	0.535	0.066	0.478
F-statistic (DF)	29.35 (6,153)	3.65 (3,156)	47.68 (3,156)
p.value	0.000***	0.014*	0.000***

\*  $P \leq 0.05$ ; \*\*\*  $P \leq 0.001$

Figure captions

Figure 1: The integrated model: the Theory of Planned Behaviour integrated into the International Classification of Functioning, Disability and Health

Figure 2: Time plots of step count and either intention (0=no intention, 100= definitely intend) or self-efficacy (0=not at all confident, 100=extremely confident) for the three participants that received a walking intervention



