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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

Abstract

Objectives. First, 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. Second, the effectiveness of a walking intervention in these individuals is determined.

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 lower-limb osteoarthritis. Data on impairment symptoms (pain, pain-on-movement and joint stiffness), cognitions (intention, self-efficacy and perceived controllability) and walking (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. Simulation modelling analysis examined cross-correlations and differences in baseline and intervention phase means. Post hoc mediation analyses examined theoretical relationships and multiple regression analyses compared theoretical models.

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 receiving it. The integrated model and the TPB, which recognise a predictive role for cognitions, were significant predictors of walking variance in all participants, whilst the biomedical ICF model was only predictive for one participant.

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, including testing mediational relationships, 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., 2008); 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) adopts the conceptualisation of disability as behaviour and 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, 2001). Within the disability literature, a deficit model is commonly employed which studies an individual's *limitation* to perform a behaviour; however, a model which studies an individual's *actual performance* of a behaviour is also feasible. Therefore, compatible with the conceptualisation of disability as behaviour is the possibility to investigate disability associated with osteoarthritis by measuring the performance of PA behaviour.

The integrated model preserves the direct relationship between impairment and activity (or activity limitation) 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 (Gorczynski, 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. This approach mirrors the movement towards personalised medicine (Dallery & Raiff, 2014; Lillie et al., 2011) and has been used by the Arthritis Self-Management Programme, where an individual's self-efficacy score is used to guide the design of an action plan in order to maximise effectiveness (Bodenheimer, Lorig, Holman, & Grumbach, 2002).

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. Second, 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 self-reporting 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). Diaries were completed at the following times: participant A - 10:00 and 18:00; participant B - 09:00 and 17:00; participant

C - 09:00 and 19:00; and participant D – 09:00 and 17:00. 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 measured 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. 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.[1]

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*. A higher score indicated greater impairment.

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

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

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*. A higher score indicated higher intention, greater self-efficacy and higher perceived controllability.

Walking Intervention

The interventions were data-driven and designed to increase walking. For each participant, baseline data (weeks 0-6) were analysed to identify the cognitions that were significantly correlated with walking reported at the next diary entry, approximately eight hours later. Each participant then 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. The rationale behind this was to maximise opportunity for intervention success and utilise all potentially causal pathways specified in the integrated model (see Figure 1); manipulating a control cognition that was already significantly correlated with behaviour, could potentially further increase walking directly but it could also potentially increase walking indirectly via strengthening intention.

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. 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 programme R, v.2.15.2. Missing data were imputed using the package "norm" and a suitable transformation for those variables which were not normally distributed. Auto-correlation refers to the correlation found within one measure across time (for example, the correlation between joint stiffness now and joint stiffness at the next diary entry). Because auto-correlation is often found within daily sequential measures the standard assumption that observations are independent cannot be applied. This means that any auto-correlation found in daily sequential measures must be accounted for in any analysis.

Auto-regression models can be used to account for the autocorrelation found within a measure. These are essentially regression models of relationships within variables across time. For example, an autoregressive model of order one uses the value of a measure at one time point (lag 0) to predict the value of that same measure at the next time point (lag 1). In turn an autoregressive model of order two uses the values of a measure at lag 0, and lag 1 to predict the value of that measure at lag 2 (for instance, joint stiffness in the morning and joint stiffness in the afternoon as predictors of joint stiffness the next morning).

The "stats" package was used to conduct simulation modelling analysis for time series data (Borckardt et al., 2008). This procedure involved (i) finding the correlation between lagged data series by computing the autocorrelation function, (ii) selecting the simplest auto-regressive model which could account for any significant auto-correlations which were found, (iii) simulating 10,000 data series based on the same auto-regressive model, and (iv) counting how many simulated data series displayed more significant lagged cross-correlations between impairment and cognitions, and walking (steps) during the baseline (0-6

weeks) and intervention (6-12 weeks) phases, than those seen in observed data series. This count provided an empirical p-value.

In addition, multiple regressions were conducted using the "stats" package. The auto-correlation present in each data series was accounted for through a process known as "pre-whitening". The residuals of the same auto-regression models applied above provided pre-whitened data series, with significant auto-regressive relationships filtered out. These pre-whitened data were used to test 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 lag 0 as predictors, and steps at lag 1 as the response variable. Analysis of variance tested for a significant difference between the TPB and integrated models.

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 very high and missing data were randomly distributed within a data series. Participant A completed the diary on 97.7% of all possible occasions and the maximum number of missing data in a given data series was 6 (4.8% of all possible observations). Participant B completed the diary on 100% of all possible occasions and the maximum number of missing data was 2 (2.4% of observations). Participant C completed the diary on 97.6% of all possible occasions and the maximum number of missing data was 4

(4.9% of observations). Participant D completed the diary on 100% of all possible occasions and the maximum number of missing data was 2 (2.8% of observations). In all cases the maximum number of missing data was seen in the walking data series.

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 at the next diary entry whilst, in contrast, weaker intention now was associated with higher concurrent step count and higher step count two diary entries later.

Other variables were also predictive of walking. For participant A greater self-efficacy now predicted higher step count at the next diary entry. 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 two diary entries later and stronger self-efficacy predicted higher step count concurrently and two diary entries 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 two diary entries later were positive, i.e. worse symptoms were

associated with higher step count. In contrast, worse symptoms now were associated with lower step count at the next diary entry. As with intention, stronger self-efficacy now predicted higher step count at the next diary entry whilst higher step count now predicted a weaker self-efficacy. In this case, stronger self-efficacy now also predicted higher step count two diary entries later. The direction of these relationships was reversed for perceived controllability which showed a negative relationship with step count one and two diary entries 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 at the next diary entry 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 two diary entries later whilst stronger intention now was associated with higher step count approximately at the next diary entry. 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 at the next diary entry. 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.

Supplementary File A reports the method and findings of post hoc mediation analyses examining whether any of the cognitions mediated walking, or whether walking mediated any of the cognitions, for each participant[2].

[2] For all participants, the relationship between step count at lag0 and step count at lag1 was mediated by at least one cognition. Intention partially mediated walking in all participants. Self-efficacy partially mediated walking in participant C only. Perceived controllability was not a significant mediator of walking in any participant.

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

Table 5 about here

For each of the four participants the relationship between intention at lag0 and intention at lag1 was mediated by step count (fully mediated for all except for participant C). In addition, self-efficacy was partially mediated by walking for participant A and fully mediated by walking for participant C. Perceived controllability was only tested for participant C, as the autoregressive model was not significant for the other participants. In this instance perceived controllability was not significantly mediated by walking.

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 5. Regression coefficients are reported in Supplementary File B. The TPB and the integrated model predicted walking at the next diary entry in all participants. The ICF, however, only predicted walking in participant D explaining less than half of the variance that the other models explained. The integrated model accounted for significantly more variance in walking than the TPB for participant D ($F(3,153)=5.19$, $p=0.002$) only; there was no significant difference in variance explained for participant A ($p=0.636$), B ($p=0.083$) or C ($p=0.841$).

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 at the next diary entry; 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 before the next diary entry. 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.

Post hoc analyses revealed that walking fully mediated the relationship between current intention and intention at the next diary entry for three participants, and partially mediated the relationship for the other participant. Walking fully mediated self-efficacy in one case and partially mediated self-efficacy in another case. 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.

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. Our exploration of the effectiveness of action planning interventions within-individuals is original and, therefore, replication is needed. It may be the case that a motivational intervention, designed to strengthen intentions by targeting the antecedents of intention for example, may be more effective than action planning. The lack of success of the interventions

used in this study may be a result of the minimal nature of the interventions, such that more intensive interventions may be more successful. The interventions used in this study were chosen, in part, for their simplicity and ease of delivery by a person requiring only minimal training, and also because they have previously met with some success in healthy individuals (Hobbs, 2010). That said, we acknowledge that the pragmatic decision to use action planning rather than targeting beliefs to increase intention, resulted in the match between theory and intervention being less than perfect.

The lack of effect of action planning for participant B can, however, 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).

The current findings show that the TPB and the integrated models were consistently able to explain walking whereas the ICF could only explain walking in one participant. 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 TPB and the integrated models accounted for between 7% and 35% of variance in walking. In the case of participant D, the ICF was predictive explaining 7% of the variance in walking. The integrated model was also found to significantly explain more variance than the TPB in this participant. 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 always

provide a unique, substantial contribution to explaining behaviour if it acts indirectly via one or other of the cognitions. In such a situation it could be suggested that the TPB alone is just as useful as the integrated model and may be preferred due to its more parsimonious nature. The limited incremental value of the integrated model beyond the TPB might be due to the possibility that cognitions are temporally unstable within the daily time period used in this study. In contrast, impairment might not vary much over a short time period limiting the ability of impairment to predict walking. Over longer time periods, however, impairment might be more predictive of walking. Future work is needed to explore additional temporal and 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 with 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. Simulation modelling analysis was the analysis of choice to investigate these high-frequency, within-individual processes in potentially autocorrelated data. 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 & Brembs, 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
Participant A (n=169)							
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
Participant B (n=168)							
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
Participant C (n=179)							
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)[1]	0.00	0.00	0.00	-0.28	0.00	0.00	0.00
Participant D (n=161)							
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

[1]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

	Participant A			Participant B			Participant C			Participant D		
Variable	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0
						Lagged cross-correlation with step count						
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***	-.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*
Intervention		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 two diary entries later (i.e., two diary entries later); CCF -1 = cross-correlation function between each listed

variable reported now and step count recorded approximately at the next diary entry (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

	Participant A			Participant B			Participant D		
Variable	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0	CCF -2	CCF -1	CCF 0
				Lagged cross-correlation with step count					
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 two diary entries later (i.e., two diary entries later); CCF -1 = cross-correlation function between each listed variable reported now and step count recorded approximately at the next diary entry (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
Participant A							
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
Participant 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
Participant D							
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. Multiple regression analyses comparing the ability of the integrated model, ICF and TPB to predict walking (steps) at the next diary entry

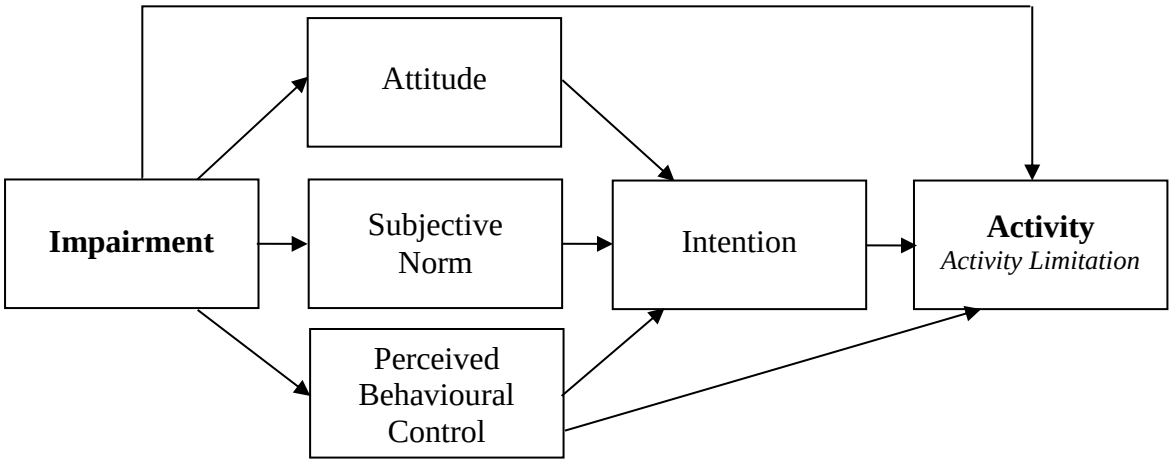
	Integrated	ICF	TPB
Participant A			
R^2	0.353	0.016	0.346
F-statistic (DF)	13.91 (3.153)	0.86 (3,156)	27.48 (3,156)
p.value	0.000***	0.462	0.000***
Participant B			
R^2	0.337	0.035	0.308
F-statistic (DF)	13.53 (6,160)	1.96 (3,163)	23.22 (3,163)
p.value	0.000***	0.122	0.000***
Participant C			
R^2	0.071	0.005	0.067
F-statistic (DF)	2.19 (6,171)	0.32 (3,174)	4.156 (3,174)
p.value	0.046*	0.814	0.007**
Participant D			
R^2	0.238	0.073	0.161
F-statistic (DF)	7.98 (6,153)	4.11 (3,156)	9.97 (3,156)
p.value	0.000***	0.008**	0.000***

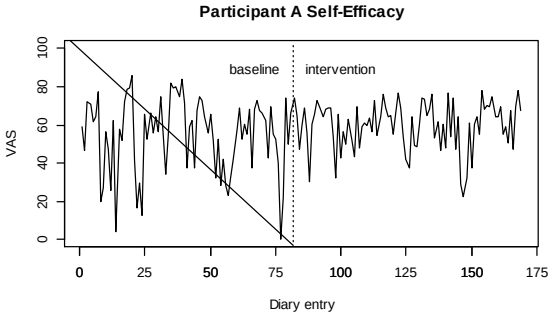
* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$

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


Attitude
Impairment
Subjective Norm
Intention
Activity
Activity Limitation
Perceived Behavioural Control


Participant A Self-Efficacy
baseline
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VAS
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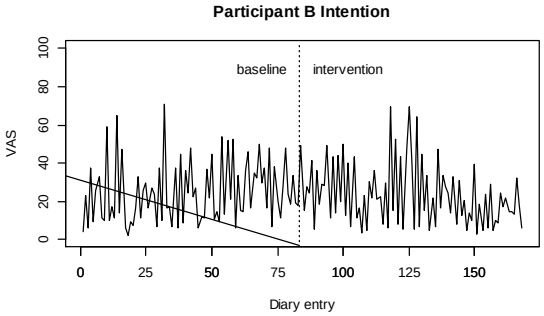
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baseline
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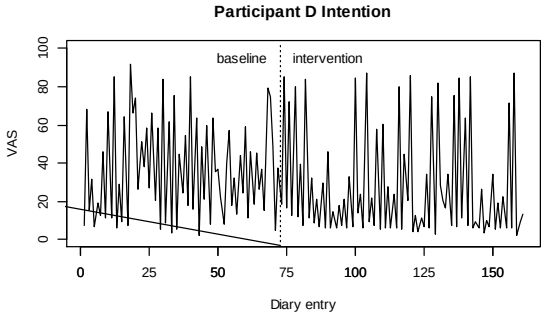
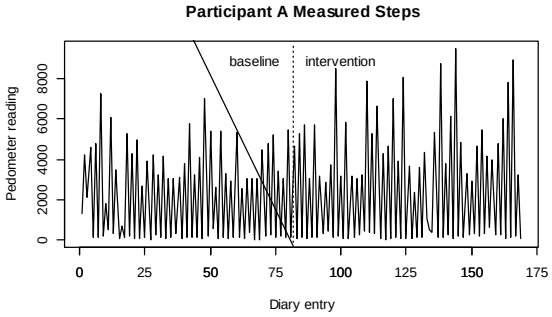
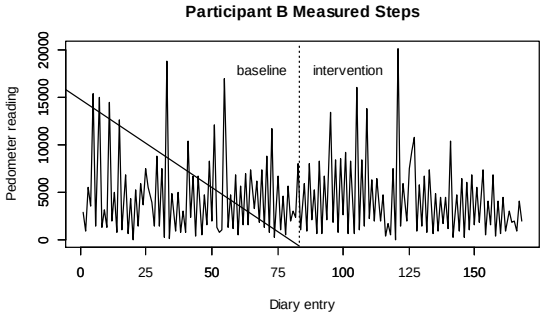
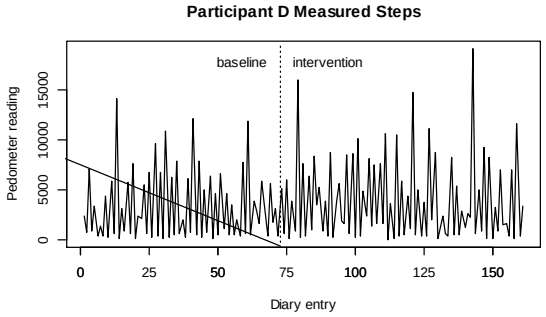

Participant D Intention
baseline
intervention
VAS
Diary entry


Participant A Measured Steps
baseline
intervention
Pedometer reading
Diary entry


Participant B Measured Steps
baseline
intervention
Pedometer reading
Diary entry


Participant D Measured Steps
baseline
intervention
Pedometer reading
Diary entry