Testing an Integrated Behavioural and Biomedical Model of Disability in N-of-1 Studies with Chronic Pain

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Abstract

Background. Previous research has supported an integrated biomedical and behavioural model explaining activity limitations. However, further tests of this model are required at the within-person level, because while it proposes that the constructs are related within individuals, it has primarily been tested between individuals in large group studies. We aimed to test the integrated model at the within-person level. *Method*. Six correlational N-of-1 studies in participants with arthritis, chronic pain and walking limitations. Daily measures of theoretical constructs were collected using a handheld computer (PDA), activity was assessed by self-report and accelerometer, and data analysed using time-series analysis. *Results*. The biomedical model was not supported as pain-impairment did not predict activity, so the integrated model was supported partially. Impairment predicted intention to move around while perceived behavioural control (PBC) and intention predicted activity. PBC did not predict activity limitation in the expected direction. *Conclusions*. The integrated model of disability was partially supported within individuals, especially the behavioural elements. However, results suggest that different elements of the model may drive activity (limitations) for different individuals. The integrated model provides a useful framework for understanding disability and suggests interventions, and the utility of N-of-1 methodology for testing theory is illustrated.

Keywords: disability, ICF, theory of planned behaviour, chronic pain, N-of-1, single-case.

Theories of disability or activity limitation attempt to explain variability in activity, but they have usually been tested as explanations of differences between people (i.e. an individual differences approach), rather than variability within persons. Nevertheless, interventions target within-person processes (e.g. enhancing perceived control to increase activity levels) and therefore it is important to understand the processes involved within individuals. Factors that predict differences between individuals may be different from those predicting behaviour within individuals.

Biomedical and behavioural determinants of disability have been brought together theoretically by Johnston (1996), who proposed that activity limitations could be seen as behaviour (or absence of behaviour) and determined by both biomedical and behavioural factors. Research testing Johnston's integrated model has been mostly at the between-person level using large-group designs, operationalising the biomedical constructs of *impairment* (of body structure and function) from the *International Classification of Functioning, Disability and Health* (ICF; WHO, 2001), with the outcome of *activity limitation* (limitations in the performance of tasks, conceptualised on a continuum from activity to limitation). The ICF, depicted in Figure 1, is a framework of theoretical constructs on which researchers can base causal models, and it permits non-biomedical variables (personal and environmental contextual factors) to influence activity and activity limitations. The integrated model combines these biomedical constructs with constructs from a behavioural model, either social cognitive theory (Bandura, 1986) or the theory of planned behaviour (TPB; Ajzen, 1991). The TPB proposes that intention and perceived behavioural control (PBC) are the proximal determinants of behaviour and the model predicts many forms of behaviour well (Armitage & Conner, 2001).

(Insert Figure 1 about here)

An integrated ICF-TPB model, using proximal predictors from the TPB (intention and

PBC) and measures of impairment, is generally supported in between-person studies. For example, in patients with a neurological disorder, PBC predicted activity (and mediated its relationship with impairment) but intention was not predictive (Schröder et al., 2007). Dixon, Johnston, Rowley and Pollard (2008) used structural equation modelling to compare three models in orthopaedic patients before joint replacement: an integrated ICF-TPB model, a biomedical impairment–activity limitation model and a behavioural TPB model (i.e. cognitions alone as predictors). Impairment was operationalised as pain and activity limitation as walking, as pain has been found to fit the ICF definition of impairment (Pollard, Johnston & Dieppe, 2006). The integrated ICF-TPB model was a better fit to the data and explained more variance than either the biomedical or behavioural model. However, only PBC and not intention mediated significantly.

Recently, in replication studies, similar results have been obtained with the same a priori theoretical and statistical models and a similar population before and one year after joint replacement (Quinn et al., 2012). Indeed the integrated model was an even better fit after surgery and explained more variance than the biomedical or behavioural model. Again, only PBC, and not intention, was predictive. However, these studies analysed data aggregated across many individuals. They indicate *who*, at a point in time, would likely have what level of disability, so they explain differences *between* people. To test the integrated model further, and as a basis for future intervention design, it is necessary to test whether the model allows us to explain *when* individuals will be more or less disabled. Observations within individuals are required to examine this.

Single-case or *N-of-1* designs (Hadert & Quinn, 2008) involve a priori hypotheses and regular quantitative measurement of variables in a single individual (e.g. daily), often replicated in several others. The time-series data are usually not aggregated across cases. Experimental N-of-1 designs are useful to test the effects of interventions (see Barlow, Nock

& Hersen, 2009), while correlational N-of-1 designs can be useful test theory (e.g. Crane, Martin, Johnston and Goodwin, 2003; Hobbs, Dixon, Johnston & Howie, 2013; Johnston & Johnston, 2013). In a single-case study testing Johnston's (1996) integrated model in a man with a neurological condition, time-series analysis showed that self-efficacy and PBC (but not impairment) predicted a personally important activity: playing the piano (Schröder et al., 2008). However, the model did not predict walking, and there were inconsistent relationships between impairment and mediating cognitions, indicating a need for further within-person research.

Accordingly, we asked six individuals with chronic pain from arthritis and walking limitations to record data each day. We analysed the data from each single-case study using time-series analysis. An issue with this form of analysis is that daily observations sometimes correlate with those one day, two days, etc. earlier. For example, pain today is likely to be predicted by pain yesterday and the day before but is unlikely to be predicted by pain six months ago. This *autocorrelation* or *serial dependency* violates the assumption of independence of observations used in inferential statistics, so significance values can be misleading unless it is removed statistically. We achieved this by *pre-whitening*, as in Crane et al. (2003) and Hobbs et al. (2013). We operationalised impairment as pain, as in previous studies (Dixon et al., 2008; Quinn et al., 2012) and activity limitation as amount of activity, measured by accelerometer and self-report. From the integrated model, we proposed that:

1. Impairment will predict activity.
2. Intention and PBC will predict activity
3. The integrated model will explain more variance in activity than either the biomedical model (impairment) or the behavioural model (intention and PBC), with the behavioural constructs partially mediating the effects of the biomedical constructs.

Method

Design

N-of-1 studies of correlational design, with twice daily self-report measures of theoretical constructs and accelerometer measures of activity for 60 to 90 days. The research was approved by our university's Psychology Research Ethics Committee and was conducted in accordance with the British Psychological Society's (2009) *Code of Ethics and Conduct*.

Participants

Six women with arthritis and walking limitations took part, recruited by newspaper advertisement (n = 3) or a poster placed at local supermarkets (n = 3). Table 1 summarises their characteristics. Each experienced chronic pain and (apart from participants A and B) joint stiffness, but no other medical condition affected their walking. Four were retired, participant B worked at a sedentary job and C had a physically demanding job (both worked full-time). All the participants were white and born in the UK.

< Insert Table 1 here >

Apparatus

A handheld PDA computer (HP iPAQ hx2100) was used with software which enabled self-rating measures to be presented, and a stylus with thick rubber grip ('Paper Mate PhD Multi™', Sanford L.P., Oak Brook, Illinois). Participants also wore a wrist-mounted accelerometer on their non-writing arm ('Actiband™', Cambridge Neurotechnology, England), with measurement epoch of 60 seconds. The device was small and light (12 grams), waterproof, and had no display or controls. On the wrist it has good interunit reliability and correlates well with oxygen uptake (Rowe, Kemble, Birkenmeyer & Mahar, 2008a, 2008b).

Measures

All self-rating items were presented on the PDA using a 100-point visual analogue scale (VAS). Items were in fixed random order, with the impairment (pain) measure first. TPB items were operationalised according to Ajzen (2002) and Francis et al. (2004); following

piloting of alternative word formats, the wording *move around more than usual today* represented the behaviour, allowing the item and behavioural measure to match in terms of target, action, context and time (TACT), with target and context generalised across all conditions (Francis et al., 2004). Items were reverse-scored where appropriate so that greater scores indicated greater levels of the construct.

IMPAIRMENT (ICF): Impairment was operationalised as pain, as in previous studies by Dixon et al. (2008) and Quinn et al. (2012). We selected this selected because pain is a form of impairment according to the ICF (Dreinhöfer et al., 2004), and in addition Pollard et al. (2006), using discriminant content validation methods, had found that items measuring pain from commonly-used health outcome measures were consistently matched by expert judges to the ICF definition of impairment, suggesting that pain is a form of impairment. In the present study it was measured by one item, always prior to measured activity. For A, it was measured at the previous evening's diary entry: 'Overall, how bad was your pain on movement today?', and for other participants at the morning entry: 'Right now, how bad is your pain on movement?'. Both items were anchored by *no pain* and *worst pain imaginable* (Skevington, 1995). Higher scores indicated greater impairment.

ACTIVITY (ICF): Activity was measured using self-report and objective (accelerometer) methods. Consistent with the ICF, activity was conceptualised as being on a continuum with activity limitations i.e. more activity indicates less activity limitation. The accelerometer measured activity throughout the day in counts per 60-second epoch: a higher count indicates greater activity (i.e. a lower level of activity limitation). A daily mean was calculated between the two diary entry times, to allow for variation in the length of measurement each day. When an entry had been missed or the accelerometer not worn, no score could be calculated and was classed as missing data.

Self-reported activity was measured each evening: 'How much have you moved around

today?', with the scale anchored by *less than usual* and *more than usual*. Greater scores indicated more activity and thus lower activity limitation.

PERCEIVED BEHAVIOURAL CONTROL (PBC): All participants completed 2 items measuring PBC at the morning entry, assessing facets of ease/difficulty and controllability (Ajzen, 2002): 'If I wanted to, it would be easy for me to move around more than usual today' and 'I have complete control over whether I move around more than usual today' (Terry & O'Leary, 1995) anchored by *strongly agree* and *strongly disagree*.

INTENTION: All participants completed three items at the morning entry to measure intention: 'Today, I intend to move around…', 'Today, I would like to move around…' and 'Today, it is likely that I will move around…', anchored by *more than usual* and *less than usual* (Conner & Sparks, 1995).

Procedure

A newspaper advertisement and poster at local supermarkets headlined 'Do you suffer from arthritis?' and asked for volunteers who as a result had chronic pain and problems with walking. Volunteers who contacted us, met inclusion criteria and provided informed consent were interviewed to obtain background information. We provided each with an accelerometer, PDA, battery charger and thick-grip stylus. Participants were asked to make diary entries using the PDA twice daily for 60 to 90 days: each morning shortly after waking, and again at bedtime. To do so, they used the stylus to tap a button on the PDA screen labelled *make morning entry* or *make evening entry*. They also were asked to wear the accelerometer all day, every day, on the wrist of their non-writing hand. We scheduled regular meetings to download data and check each participant's well-being and that everything was in order.

Analysis

Correlational time-series analysis was conducted, with accelerometer data recorded between the morning and evening diary entries being analysed.

Missing data: We carried out multiple imputation using the *Amelia II* computer program (version 1.6.4; Honaker, King & Blackwell, 2013), which is designed to accurately impute time-series data. Five imputed datasets were created for each participant, with composite scales were imputed to minimise the number of imputed values due to the short nature of the original data. Imputed data were transferred to SPSS 17.0 for analysis, which was set to treat the five imputed datasets per participant as multiply imputed data and to automatically calculate pooled statistical coefficients and *p*-values. SPSS 17.0 is able to do this for means, standard error, Pearson correlation co-efficients and associated *p*-values, and in multiple regression, values of B and standard error and associated *p*-values, and others. For statistics in our analysis that SPSS 17.0 does not provide pooled coefficients for (i.e. adjusted R^2 and associated *p*-values) the mean of each statistic produced from the five datasets was taken.

Autocorrelation and pre-whitening: Following imputation, variables were examined using autocorrelograms in SPSS and if significant autocorrelation was found, pre-whitening was performed using the procedure used by Crane et al. (2003) and Hobbs et al. (2013). First, plots of partial autocorrelation were examined to determine the significant order of autocorrelation (e.g. first order, where today's observation is dependent on that of yesterday, second order where the dependence is on the observation two days previously, etc.). A new variable was then created, lagged by the appropriate number of days. For example, a first-order autocorrelation function would involve producing a new time series with a lag of one day relative to the original. This lagged variable was regressed onto the original series; the unstandardised residuals became the new pre-whitened variable, which was checked to confirm absence of autocorrelation. This procedure enables the use of inferential statistics as the assumption of independence of data points is no longer violated.

Tests of hypotheses: Correlational analysis (Pearson's *r*) was performed separately for each participant. For A, the measure of pain the previous day was correlated with activity and

other variables the next day, while for other participants pain the same morning was correlated with activity during that day. Multiple regression was also conducted where more than one predictor had a *p* value of .15 or below; hierarchical multiple regression was used to test the predictive power of the integrated model against the biomedical and behavioural model. Full results of the multiple regression analyses are in the supplementary online archive. To test for mediation, we planned to conduct multiple mediation analysis if Baron and Kenny's (1986) conditions were met, using bootstrapping with 5000 resamples as recommended by Preacher and Hayes (2008).

Results

Descriptive statistics (untransformed) for each variable are presented in Table 2, including means of each variable and standard error as the measure of variance in the multiply-imputed data, as in Hobbs et al. (2013). Full tables of intercorrelations and time-series charts of raw data are displayed in the supplemental online archive. The next section presents details of transformations, including pre-whitening, and scale reliabilities. The final section presents tests of each hypothesis using the pre-whitened data, with statistics reported for each participant. All analyses (except for scale reliability) used multiply-imputed data.

<Insert Table 2 here>

Transformations and Pre-Whitening

Autocorrelation was found in the variables and participants indicated in Table 2, and was followed by the pre-whitening procedure described above. Subsequent autocorrelograms confirmed the absence of autocorrelation. Using the Kolmogorov-Smirnov test no variable was found to deviate significantly from normality except for B's intention and self-reported activity variables, which showed kurtosis; no transformations were successful in rendering them normal.

Scale reliability

Internal consistency (Cronbach's alpha) for each multi-item scale and participant is shown in Table 2. Because only composite scales were imputed, alpha values relate to original, unimputed data only. For each multi-item scale (i.e. PBC and intention), alpha was calculated using untransformed data individually for each participant, with each day of data as one data point. For intention, internal consistency was generally good as alpha exceeded .6 for all except D (whose alpha was close to this value). For PBC, alpha exceeded .6 for all except A and C. To maintain equivalent scales for all participants to allow comparisons between them, no changes were made to the scales.

Does impairment predict activity? (biomedical model - hypothesis one)

According to the biomedical model, impairment should predict subsequent activity (limitation). As Table 3 illustrates, this was not the case. Therefore the hypothesis that impairment predicts activity (limitation) receives little support.

< Insert Table 3 here >

Do intention and PBC predict activity (limitation)? (behavioural model - hypothesis two)

According to the TPB, daily activity (limitation) should be predicted by intention and PBC on that day. As Table 4 shows, with the behavioural measures, intention predicted accelerometer-measured activity in one case (Participant A) and self-report activity for all except D. However, results for PBC were unexpected. PBC significantly predicted in the expected direction only for participant F (accelerometer measure only), and predicted activity negatively for participant A (both activity measures) and C (accelerometer measure).

<Insert Table 4 here>

Multiple regression was performed where at least two predictors had a *p* value of .15 or above; this was the case with participant A (both activity measures), C (self-reported activity only) and F (accelerometer measure only). Full results of these analyses can be found in the supplementary online archive; we report values for B and its standard error rather than β, because these statistics are pooled automatically by SPSS. For participant A, with accelerometer-measured activity, the equation was significant (adjusted R^2 = .33, p<.01) with intention (B = .94, SEB = .31, p = .01) and PBC (B = -1.02, SEB = .41, p = .02) predicting significantly. For self-reported activity, the equation was significant (adjusted R^2 = .51, p<.001), with intention predicting significantly (B = .75, SEB = .13, p < .001) and PBC closely approaching significance (B = -.36, SEB = .18, p = .05). For participant C, predicting self-reported activity, the equation was significant (adjusted R^2 = .13, p<.01); intention contributed significantly (B = .45, SEB = .16, p <. 01) but PBC did not (B = -.24, SEB = .15,

p = .11). For participant F, predicting accelerometer-measured activity, the equation was just significant (adjusted R^2 = .07, p = .045); however neither variable contributed significantly to the equation.

Thus, although impairment did not reliably predict activity, intention did in at least some cases, while PBC's relationship with behaviour was not always as expected.

Does the integrated model explain more variance in activity than either the biomedical or behavioural models? (Hypothesis three)

If the integrated model explains more variance than each of the separate models, then in hierarchical multiple regression, adding behavioural constructs to the biomedical (impairment) should produce a significant increase in variance explained – and vice versa.

<Insert Table 5 here>

Table 5 shows variance in activity (adjusted R^2) accounted for by the biomedical model (impairment), by the behavioural model (intention and PBC), and change in variance accounted for on entering the constructs of the other model. Adding intention and PBC to impairment accounted for significant additional variance in nearly all participants. However, with TPB variables already in the equation, impairment did not account for significant additional variance. Thus, this hypothesis was partially supported; the integrated model accounts for more variance by adding behavioural constructs to impairment, but there is no greater variance explained by adding impairment to the behavioural constructs.

Does impairment predict intention and PBC? A proposition of the integrated model is that the experience of impairment has an impact on intention and PBC (mediated by attitudes and subjective norm for intention), so impairment should predict these variables. This appears to generally be the case in these data (see Table 3). Overall pain the previous day trended toward predicting PBC for participant A but narrowly missed significance (r = -.28, p = .07), while morning pain predicted PBC and intention for participants B, C, D and F. Thus the

hypothesis that impairment predicts intention and PBC generally receives support, as predicted by theory.

Is the relationship between impairment and activity partially mediated by intention and PBC? A condition required for mediation is that the predictor variable correlates significantly with the outcome variable (Baron & Kenny, 1986). However, these criteria were not met because impairment did not predict activity in any case.

Discussion

We conducted six N-of-1 studies with hypotheses derived from the integrated model of disability (Johnston, 1996), using daily measures to collect correlational data. We first tested the biomedical model, hypothesising that impairment (operationalised as pain) would predict activity – but surprisingly this was not supported for any participant. Second, we tested the behavioural model, hypothesising that intention and PBC would predict activity; this was generally supported for intention, but sometimes not in the predicted direction for PBC; these relationships were stronger for self-report than for objectively-measured activity. Third, the behavioural model accounted for additional variance over and above the biomedical model for five of our six participants, on both behaviour measures but especially for the self-report data, but adding impairment to the behavioural models did not account for significantly more variance. This suggests the biomedical model was not necessary to explain activity (limitations) in these within-person data. Fourth we hypothesised that impairment should predict intention and PBC and we found this to generally be the case. Fifth, since the biomedical model was not supported it was not possible for behavioural variables to mediate the effects of impairment on activity.

In summary, pain-impairment predicted intention and PBC, and one or both of these two constructs predicted activity in several cases, particularly for self-report measures. However, we found little evidence of a direct relationship between impairment and activity – a

cornerstone of the biomedical model. Therefore, our findings mainly support the behavioural element of the integrated model. The conceptualisation of disability as behaviour is generally supported by the predictive relationship with intention and PBC, so the psychological component of the model is supported in these within-participant studies, even though the biomedical component is not. In any case, while not always predictive, the behavioural variables nearly always provided a better account of behaviour here than pain-impairment. As the integrated approach represents an interdisciplinary model, these findings raise the question whether a behavioural model would be sufficient within individuals, at least for those who participated here. This position is supported by the finding that impairment does not account for significant additional variance over and above behavioural variables.

A common finding in large-group, between-person research is that PBC but not intention predicts activity limitation (Schröder et al., 2007; Dixon et al., 2008; Quinn et al., 2012). However, recently intention has been shown to predict activity (but not activity limitation; see below) in a study of over 600 adults living in the community (Dixon, Johnston, Elliott & Hannaford, 2012). This finding is similar to those obtained here, and is in line with TPB predictions; thus support exists for both intention and PBC elements of the model, if not always in the same studies. Ajzen (1991) proposed that TPB constructs vary in the strength of their contribution to behaviour depending on the nature of the population and the behaviour: It may be that this is the case not just for different populations and behaviours, but for different individuals as well. Although not addressed explicitly by Ajzen, this is in accordance with the spirit of the theory. Consider two individuals abstaining from an action: one may have high intention but low PBC for the behaviour, and another high PBC but low intention. This may indicate a need for tailored intervention; for example, N-of-1 methods have established which variables predict behaviour in individuals before tailoring intervention to those constructs (Hobbs, 2010).

The findings with PBC in our N-of-1 studies here are quite different from the results of the group studies, which were consistently in line with TPB predictions. This is a puzzling result. However, negative relationships have been found between self-efficacy and behaviour, usually in multilevel data including within-subjects measures of task performance (for review, see Vancouver, More & Yoder, 2008), and self-efficacy closely resembles PBC (Ajzen, 2002). It may be that on days when a participant experiences high levels of control, they may choose to avoid activity rather than choosing to do more and perhaps exacerbate pain.

Previous group studies also found that impairment predicted activity limitation, unlike the findings in these single-case studies. It is possible that impairment is less predictive of variations in activity levels within an individual than between individuals because there is less variance in impairment and activity limitations within individuals. People with long-term conditions, like the participants in the present study, may have established a restricted range of activity that is compatible with their personal tolerance of impairment and their motivation to be active. Therefore, impairment may determine the absolute range of activities one can physically perform, while within that range (which may or may not be accurately known to the individual), psychological variables may better account for everyday levels of behaviour. One might still expect to find a relationship between impairment and activity limitations in between-person analyses, because individuals with the greatest impairment are the ones with the most restricted range of activity. Nevertheless, the behavioural variables did predict activity suggesting that there is sufficient variability in activity levels; and standard deviations for pain suggest that this also showed considerable day-to-day variation.

In Dixon et al.'s (2012) group study and Schröder's (2008) N-of-1 study, impairment only predicted activity limitation, and not activity behaviour per se. The present study assessed activity rather than activity limitations and this may account for the weak predictions from impairment. It would appear that impairment is more important in predicting activity

limitations than activity behaviour. Further, since measures of activity and of activity limitations appear to produce very different patterns of results, it casts doubt on the ICF proposition that activity and activity limitations lie on a continuum (WHO, 2001). These findings may be due to measurement artefact, or may reflect a major difference in conceptualisation. While activity refers to the performance of behaviour, activity limitation requires comparison of activity with a standard.

Strengths and limitations

N-of-1 methodology allows us to examine the applicability of theory at the within-person level which has already been supported at the between-person level. To do this, we collected objective data on activity, although technical and scheduling issues lead to loss of some days of data. Our data do not rely solely on self-reports which are more vulnerable to bias. While our findings are similar for objective and self-report measures, effects are stronger for self-report as is commonly found. Also, unlike many studies in the field of chronic pain, we did not recruit participants from those actively seeking treatment specifically for their pain, although most were receiving outpatient treatment for arthritis.

However, there are limitations in the study. Only one form of impairment was measured – pain – while arthritis involves a range of changes to body structure and function, such as those in the ICF core set for osteoarthritis (Dreinhöfer et al., 2004). Indeed, participants also reported joint stiffness, swelling, and fatigue. However, Dixon et al. (2012) found support for the integrated model using general measures of impairment from the SF-36 as well as for pain impairment. In addition, Schröder et al.'s (2007) findings supported the integrated model with muscle strength and sensory function as impairment. Secondly, statistical power was limited, so some correlations of reasonable magnitude may not have reached statistical significance. The possibility of Type 2 error indicates a need for longer single-case studies to acquire more data points, and more reliable data collection methods to decrease missing data.

Thirdly, participants may have only low-pain activity behaviours in their repertoire, with data limited to natural variation in levels of impairment and activity. Although all measures showed considerable variance, it may be less than that of individuals with no limitations. That intention predicted self-report behaviour more often than objectively-measured behaviour raises the possibility that this results from common method error, confounding of the measures or response bias. For example, participants may have recalled more of the activity they intended to do rather than what they actually did. Fourthly, internal consistency was low for the PBC scale for participants A and C, and this may have affected their results. For example, the unexpected negative correlations between PBC and activity may be a spurious product of issues with the measurement scale. These results should be treated with caution until they are replicated in future research.

Finally, the integrated model makes causal propositions which cannot be adequately tested in a correlational design. While measures of our causal variables preceded measures of the activity (limitation) consequences, adequate testing of these causal hypotheses requires an experimental design such as that used by Fisher and Johnston (1996). When they manipulated control cognitions, activity changed as proposed by the integrated model, but further experimental designs are necessary to test causality. Manipulating theoretical mediators and controlling for impairment should demonstrate whether changes in psychological variables can alter activity limitation without change in impairment.

Conclusions

These results emphasise the need to investigate theoretical models within individuals as well as between individuals, not simply because within-person models are necessary for intervention, but also because the processes which explain within-person variation may be different from those that explain between-person variation. Indeed, our findings suggest that while biomedical and behavioural factors are important in predicting differences in activity

levels between people, day to day variability for an individual may be driven more by behavioural factors. Further, the processes may be different for different individuals and the integrated model (supported by the findings here) suggests that while intentions may be the key driver of activities for one person, other cognitions about activity may be more important for another. Our findings also support the concept of disability as behaviour, and that the integrated model is applicable at the within-person level – although the constructs which correlate (and direction of effects) may differ. These findings also highlight the utility of N-of-1 methodology to test theory, allowing theories which were created to explain individual behaviour to be tested within individuals.

Although further research is required, our findings suggest that the integrated model may provide a useful interdisciplinary foundation for understanding disability associated with chronic illness. It offers a framework for organising scientific insights – from the biomedical and behavioural sciences – into the differing and destructive impact of long-term limiting conditions on the activities of living. When organised together, these insights may illuminate more powerful ways to minimise disability and maximise functioning.

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	Age	Diagnosis	Years since onset	Pain locations	Mean pain[a]	Days of data available (% missing) AM	PM	Accelerometer	Total days
A	64	Osteoarthritis	30	Spine, knees, hands, feet, ankles	40	63 (0%)	62 (2%)	44 (30%)	63[c]
B	59	Osteoarthritis	10 to 15	Knees	54	70 (7%)	63 (16%)	53 (29%)	75
C	50	Osteoarthritis	10	Knees	49	68 (3%)	66 (6%)	65 (7%)	70
D	60	Osteoarthritis	5	Hip, toes	32	77 (4%)	76 (5%)	72 (10%)	80
E	43	Ankylosing spondylitis	'Several years'	Hip, knees, neck, spine, elbows, wrists	47	43 (17%)	43 (17%)	51 (2%)	52
F	62	Rheumatoid arthritis	16	Feet, neck, shoulders, wrists, hands	65	59 (3%)	59 (3%)	51 (16%)	61

Table 1. *Participant Characteristics. Note.* [a] Mean overall daily pain was measured at the end of each day at the evening entry during the study period, for all participants (this is a separate measure to the morning pain used for analyses for participants B to F), and measured on a 100-point VAS; higher scores indicate worse pain. [b] Days of data for morning entry/evening entry/accelerometer. Scheduling issues resulted in less accelerometer data than diary data for Participants A and B. [c] Truncated at 44 days as up to this time complete accelerometer data were available

Variable	A		B		C		D		E		F	
	M (α)	*SE*	*M* (α)	*SE*	*M* (α)	*SE*	*M* (α)	*SE*	*M* (α)	*SE*	*M* (α)	*SE*
Impairment (pain)	35.8_1 [a]	2.4[a]	47.6	1.6	35.6	1.4	20.93_1	1.2	38.2	1.6	66.5	1.8
Activity (accelerometer)	80.9	4.6	167.0	6.3	129.1	3.8	149.8_1	4.4	190.9_1	13.3	106.0_1	3.4
Activity (self-report activity)	54.6	2.4	50.0	1.3	51.9_1	2.6	41.3	1.9	60.7_1	1.9	42.7_1	2.4
Intention	59.4	2.0	47.6	1.1	44.5	1.7	55.7_1	1.0	57.9	1.4	48.8_1	2.0
	(.85)		(.86)		(.67)		(.58)		(.79)		(.90)	
PBC	55.2_1	1.6	48.8	1.4	47.2	2.0	64.0	1.5	43.5	1.6	34.5	2.0
	(.37)		(.64)		(.33)		(.68)		(.77)		(.87)	

Table 2. *Means, standard error and presence of autocorrelation (subscript indicates lag for significant autocorrelations) for each variable and Cronbach's alpha for intention and PBC for each participant (Cronbach's alpha coefficients appear in parentheses).* Note. A lag of 1 indicates that there is a significant correlation in the time series between a measure and the same measure one day previously. All variables are measured on 100-point scales, except for the accelerometer measure. [a] Pain was measured as an overall daily rating for Participant A and in the morning for all other participants.

Participant	Activity		Behavioural Variables	
	Accelerometer	Self-Report Activity	Intention	PBC
A	.12	.19	-.04	-.28†
B	.15	-.09	-.23*	-.60**
C	.08	.09	-.32*	-.32*
D	.24	.20	-.33**	-.42**
E	.04	.06	.19	-.25
F	-.23	-.04	-.46**	-.77**

Table 3: *Pearson correlation coefficients between pain impairment (pain the previous day for Participant A, and morning pain for all others), the activity variables and TPB variables.*

Note. * $p<.05$, ** $p<.01$, † = $p<.07$

Participant	Activity (Accelerometer)		Activity (Self-Report)	
	Intention	PBC	Intention	PBC
A	.51**	-.45**	.70**	-.42**
B	.29†	.03	.62**	.16
C	.09	-.35**	.34**	-.23
D	-.10	-.18	.18	-.01
E	.15	-.17	.61**	-.05
F	.23	.30*	.32*	.16

Table 4: *Pearson correlation coefficients between TPB variables and activity limitation.*

Note. * = $p<.05$, **=$p<.01$, † = $p<.07$.

Participant	Impairment (adj. R^2)		Change in adj. R^2 on adding intention and PBC		Intention and PBC (adj. R^2)		Change in adj. R^2 on adding impairment	
	A	SR	A	SR	A	SR	A	SR
A	-.01	.01	.32**	.51**	.32**	.51**	-.02	.03
B	.01	.00	.08*	.38**	.07	.38**	.03	.00
C	.01	.00	.10*	.15**	.10	.13**	-.01	.01
D	.04	.03	.00	.05	.00	.00	.03	.07*
E	-.02	-.02	.03	.37**	.01	.36**	-.02	-.01
F	.04	-.02	.02	.11*	.07	.07	-.02	.02

Table 5. *Variance accounted for in accelerometer (A) and self-report (SR) measures of activity by impairment and TPB variables, and change in variance accounted for when entering the other into the equation. Pain was measured in the morning, except for A for whom it was measured the previous evening. Note.* Order of measures of activity limitation is accelerometer-measured activity/ self-reported activity. A = accelerometer, SR = self-report, * = $p<.05$, ** = $p<.01$.

Figure 1. Schematic representation of the *International Classification of Functioning, Disability and Health* (*ICF*; World Health Organization, 2001), with disability versions of the central constructs in italics. From *International Classification of Functioning, Disability and Health* (p.18) by World Health Organization, 2001, Geneva, Switzerland.