

# **A series of n-of-1 studies examining the interrelationships between social cognitive theory constructs and physical activity behaviour within individuals**

## Abstract

**Objectives:** Research supports the ability of Social Cognitive Theory (SCT) to explain physical activity (PA) behaviour, but most studies have examined this theory between individuals in large group studies. The aim of the present study was to examine the interrelationships between SCT constructs and PA within individuals of varying activity levels. **Design:** correlational n-of-1 studies. **Methods:** Six adults aged 29-65 with varying levels of PA provided daily measures of PA, and completed probe measures over a four-week period of SCT constructs (e.g. barrier self-efficacy, goal setting, planning, social support, outcome expectations, perceived barriers, enjoyment). Data were analysed using cross-correlational time series analysis. **Results:** Cross-correlation analysis showed that at least one SCT construct was associated with PA in five participants, although no individual had the same pattern of associations across the study. On some occasions, SCT constructs predicted subsequent PA, but at other times, PA engagement caused a subsequent change in the SCT construct. There were also examples of PA and SCT constructs being concurrently associated. **Conclusions:** SCT factors are associated with variations in PA behaviour, but the cause and effect of these relationships within individuals is complex.

*Keywords:* n-of-1 methods, physical activity, social cognitions

Social Cognitive Theory (SCT) provides a framework for understanding physical activity (PA) and several studies have demonstrated its utility in explaining PA behaviour (Young et al., 2014; Anderson et al., 2006; Bandura, 1997; 2004; Rovniak, et al., 2002; Ayotte et al., 2010). SCT posits that behaviour is the product of

the interactions between personal factors, behavioural factors, and environmental factors. Central to SCT is the idea that these dynamic and bi-directional interactions will determine an individual's actions (Bandura, 1997; 2004). Core constructs within SCT include self-efficacy (a person's beliefs in their capabilities to change or continuously engage in behaviour), self-regulation (the ability to plan, set goals, and evaluate progress), social support (support from significant others, such as family and friends), outcome expectations (positive or negative outcome beliefs), and perceived barriers (personal and environmental obstacles that a person perceives) (Young et al., 2014; Anderson et al., 2006; Ayotte et al., 2011; Bandura, 1997; 2004).

The majority of studies testing the utility of SCT in predicting PA behaviour are based on between group designs, which can only identify the differences in cognitions and behaviour *between* individuals. However, evidence suggests that the processes that explain the *between-person* variability in cognitions and behaviour may be different from the processes that explain the *within-person* variability (Molenaar & Campbell, 2009; Curran & Bauer, 2011; Johnston & Johnston, 2013; Hobbs et al., 2012; Quinn et al., 2013; McDonald et al., 2017a). Bandura (1997) suggests that cognitions are likely to fluctuate on a momentary basis (e.g., within-day or daily) and may contribute to the intra-individual variations in behaviour. Therefore, investigating the *within-person* variability in cognitions and behaviour may enhance understandings of why individuals are more active on specific days than on other days. Doing so may determine the factors that can aid in the design of individually tailored interventions that take into account the daily motivations and barriers that can impede or facilitate PA engagement (Kwasnicka et al., 2017). For example, an intervention may be effective for the group receiving it, on average, but may not be beneficial for all individuals within that group.

One method that can be used to measure the within-individual changes in cognitions and behaviour is the use of single case n-of-1 designs (Johnston & Johnston, 2013). n-of-1 designs involve repeatedly measuring specific variables *within* an individual over time. Doing so allows for the relationship between predictors and behaviour to be identified at the individual level. n-of-1 designs allow for the examination of whether psychological constructs can account for the variability in behaviour that has already been supported at the between-person level (Johnston & Johnston, 2013). As such, n-of-1 designs have been identified as an important tool for theory testing by the Medical Research Council (MRC) Complex Interventions Guidance (Craig et al., 2008). They have been successfully applied to a wide variety of health-related fields.

A recent systematic review by McDonald et al., (2017a) concluded that n-of-1 methods have been under-used in health psychology, despite evidence that they represent a useful tool with which we can advance theory and develop interventions for individuals. The n-of-1 methodology has several benefits over between-person designs as it can examine within-individual variability in health behaviours over time, test theory within individuals, examine the effectiveness of an intervention within a specific individual, and personalise interventions to the individual (Johnston & Johnston, 2013; McDonald et al., 2017a).

A number of studies have used n-of-1 designs to investigate the daily relationships between social cognitions and PA *within* individuals (e.g. Hobbs et al., 2013; O'Brien et al., 2015; Kwasnicka et al., 2017). However, research investigating the relationships between social cognitions and PA using n-of-1 designs has mainly used constructs from the Theory of Planned Behaviour (TPB, Ajzen, 1991), meaning

that there is a need to determine whether n-of-1 designs can be used to examine the relationship between cognitions and PA using constructs from other established psychological theories such as SCT. The aim of the current study was to examine the interrelationships between SCT constructs and PA *within* a group of individuals of varying activity levels using an observational n-of-1 design. It was hypothesised that social cognitive constructs would be associated with the daily (concurrent and future) variations in PA *within-individuals* over time.

## **Method**

### ***Design***

We employed observational n-of-1 studies of correlational design with daily accelerometer measures of activity for four weeks. We utilised the multiple-probe technique (Horner & Baer, 1978), whereby probe measures of the theoretical constructs were taken using self-report measures on three randomly chosen days per week. Multiple-probe designs are a variation on more typical n-of-1 studies in which daily assessment is replaced by intermittent probes to monitor psychological states (see Horner & Baer, 1978, for a full description of multiple-probe designs). Adopting the multiple-probe approach has the advantage of allowing researchers to utilise traditional psychometric questionnaires, rather than measures relying on one or two items. In addition, the daily burden on participants is reduced.

### ***Participants***

Six participants (2 males and 4 females) were recruited from the area surrounding a Scottish University through email, flyers, and word of mouth. The

sample size is in line with recommendations for n-of-1 designs (Duan, Kravitz, & Schmid, 2013), in which the number of observations and not the number of participants determines study power. The inclusion criteria stated that each participant must be between the ages of 18-65 years, of reasonably good health, and could be regularly active or currently inactive. The sample included two inactive, two minimally active, and two currently active participants based on their scores on a PA questionnaire (IPAQ; Craig et al., 2003). All participants were of Scottish nationality and included community residents, university staff, and students. The age range of participants was 29 to 65 years. Each participant was remunerated (£50) and provided informed consent.

### ***Apparatus***

PA was assessed using the ActiGraph GT3X accelerometer (ActiGraph GT3X; ActiGraph LLC, Pensacola, FL, USA). The accelerometer was given to participants with instructions that it should be worn on the waistband using the elastic belt provided. Research has demonstrated that the Actigraph accelerometers are highly accurate (98%) in recording steps taken by participants at various walking speeds (Le Masurier & Tudor-Locke, 2003).

### ***Measures***

#### *Socio-demographic information and general health*

Information on participant's age, gender, nationality, educational achievements, and employment status was collected. General health and ability to take part in the study were assessed at baseline using a 16-item Physical Activity Readiness Questionnaire (PAR-Q: Thomas et al., 1992).

### *Physical activity status*

Current PA status was assessed at baseline using the International Physical Activity Questionnaire (IPAQ-SF; Craig et al., 2003). The IPAQ is a nine-item self-report instrument that assesses the amount of time spent sitting, walking, and taking part in moderate and vigorous intensity PA over the last seven days (Craig et al., 2003; Van Poppel et al., 2010). The IPAQ categorises PA into three different intensity levels (inactive, minimally active, and currently active). The IPAQ is a valid and reliable measure of PA (Booth et al., 2003).

### *Self-efficacy*

Self-efficacy was measured using the 9-item Self-efficacy for Exercise (SEE) Scale to assess participants' confidence in overcoming barriers associated with PA (Resnick & Louise, 2000). Each item started with the statement "how confident are you that you could exercise for 20 minutes 3 times per week if..." anchored by (1) *not very confident* and (10) *very confident*. Possible barriers included "weather", "feeling stressed", and "being too busy". The measure has demonstrated good internal reliability and validity in previous studies (Resnick & Louise, 2000).

### *Outcome expectations*

Outcome expectations were measured using the 12-item Benefits of Physical Activity Scale to assess the participants' expectations in engaging in PA (Rogers et al., 2005). Participants responded to statements such as "if I participate in regular exercise, then I will...feel more attractive/improve my self-esteem/improve my muscle tone" etc. Each item was anchored by (1) *not likely/important* and (5) *very*

*likely/important*. Previous research has demonstrated high internal reliability for the measure (Ayotte et al., 2010).

### *Social support*

Social Support was measured across two components, friends and family, using the 13-item Social Support for Exercise Survey to assess the amount of support for exercising that an individual receives from friends and family members (Sallis et al., 1987). Participants responded to statements such as “my friends/family have...exercised with me/ discussed exercise with me/ criticised me for exercising” etc. Each item was anchored by (1) *none* and (5) *very often*. Research has demonstrated acceptable reliability and validity for the measure (Sallis et al., 1987).

### *Self-regulation*

Two measures were used to assess self-regulatory strategy use; the Exercise Planning and Scheduling Scale (EPS) and the Exercise Goal-Setting Scale (EGS) (Rovniak et al., 2002). These measures consist of 10-items to assess participants’ ability to plan, schedule, and set exercise goals in relation to physical activity. Participants rated statements such as “I schedule exercise at specific times per week” and “I have developed a series of steps for reaching my exercise goals”. Each item was anchored by (1) *does not describe me* and (10) *completely describes me*. Previous research has demonstrated the reliability and validity for these scales (Ayotte et al., 2010).

### *Enjoyment*

The 18-item Physical Activity Enjoyment Scale (PACES) was used to measure how much enjoyment participants gain from being physically active (Kendzierski &

DeCarlo, 1991). Participants rated statements on a 7-point scale ranging from “I enjoy it” vs. “I hate it”/ “it interests me” vs. “it bores me”/ “it is tiring” vs. “it is energising”, etc. Studies have demonstrated the internal consistency (Kendzierski & DeCarlo, 1991) and validity of the scale (Felton et al., 2000).

#### *Perceived barriers to exercise*

The Perceived Barriers to Exercise (PBE) scale assessed the personal and environmental barriers an individual perceives in relation to PA engagement (Salmon et al., 2003). Participants were asked to rate how specific barriers would interfere with their engagement of PA (e.g. cost, weather, physical safety, etc.) anchored by (1) *is not a barrier* and (10) *very much a barrier*. Research has shown that the PBE is a valid and reliable measure (Salmon et al., 2003).

#### *Physical activity behaviour*

A composite measure of PA was derived from accelerometer step-counts and self-report diary measures of non-ambulatory PA. It has been suggested that utilising a composite PA measure, employing both objective and self-report data, is a useful way of measuring PA behaviour as it may overcome the limitations of using each method in isolation (e.g. Haskell, 2012). The accelerometer measured activity (step counts) throughout the day in counts per 60-s epoch. Steps were chosen in order for “step equivalents” to be added to participants’ overall step count if/when they took part in any structured PA that could not be accurately measured by the accelerometer (e.g. swimming/ weight lifting/ cycling/ etc.). The accelerometer was worn on seven consecutive days per week (including weekends) for approximately four weeks (28-31 days). Participants were instructed that if they missed a day (e.g. forgot to put the accelerometer on), they should not count that day as a data point. It was also made explicit to participants that they should refrain from wearing the accelerometer only

when they think they will be active, as this would not accurately measure their normal daily activity patterns.

Participants were instructed to complete log-books of times when they put on or removed the accelerometers each day, and also if they participated in any non-ambulatory PA (e.g. structured sport or exercise). The instructions for the log-book asked participants to 'record any structured sport or exercise performed in the log book each night' with response options for 'type of activity', 'time of activity', 'length of activity', and 'intensity (low/medium/high)'. Any structured sport or exercise data was then converted into "step equivalents" using the activity's specific MET (metabolic equivalent of task) level (Ainsworth et al., 2000; Miller et al., 2006). These step equivalents were then combined with the raw step-counts to give an overall estimation of PA (measured in steps per day).

### ***Procedure***

Participants provided background information about themselves and completed baseline measures of the PAR-Q and IPAQ-SF, as well as measures of social cognitive constructs. They were then given an accelerometer and a PA log-book and asked to wear the accelerometer each day ( $\geq 10$  hours/day) for a period of four-weeks and record any daily structured sport/exercise that they took part in. Participants were also instructed to complete a series of probe measures relating to the social cognitive constructs on approximately three random days each week over the course of the four-week period (14 data points in total including baseline). The days that participants received the questionnaires were determined using an internet based list randomizer. The questionnaires were completed in paper format or online using a web-based survey platform according to personal preference and internet accessibility. Weekly

accelerometer data was also downloaded to ensure the device was recording properly. Ethical approval was obtained from the University ethics committee prior to testing.

### ***Statistical Analysis***

Data were analysed separately for each participant and correlational time-series analysis was conducted from diary entries and accelerometer data. As the current study used a random schedule to collect social cognitions on indiscriminate days across the duration of the study, there were days where data were not collected (e.g. missing data). A large body of research argues that ignoring missing values and only analysing observed data can result in bias, loss of statistical power, and may threaten the validity of statistical inferences (Fichman & Cummings, 2003).

Therefore, in order to handle missing data within the current study, a Multiple Imputation (MI) procedure (Rubin, 1987) was used to replace missing values. Simulation studies have demonstrated that MI can be effective in datasets where there are 50-80% missing values (Acock, 2005; Shafer & Graham, 2002). Within the current study, missing data for each participant ranged from 51.7% to 56.3%.

MI was carried out using the Amelia II computer program (version 1.7.4). This program performs multiple imputations by using a bootstrapping algorithm to simulate the missing cases, and is designed specifically for time-series data (Honaker & King, 2010). Amelia II produced 10 imputed datasets with each missing case imputed. Based on the imputation procedures created by Acock (2005), and Shafer & Graham (2002) 10 imputations were carried out for each data set with the mean of each statistic being utilised as the final data set and thus assuring 95% confidence in the data's imputation. In line with Naughton & Johnston (2014), each variable was examined using autocorrelograms. Where a significant autocorrelation

was present, this was accounted for using the standard “pre-whitening” (see Hobbs et al., 2013 and Crane et al., 2003 for detail of the pre-whitening procedure).

Following pre-whitening, SCT constructs were then cross-correlated with physical activity separately for each participant. The association between SCT constructs and physical activity was indicated by the correlation coefficient functions at each time lag. A lag of zero indicated that cognitions and behaviour were concurrently related (cognitions were associated with behaviour on the same day), a negative lag between SCT constructs and physical activity indicates that cognitions preceded behaviour, whereas a positive lag indicated that behaviour preceded cognitions. A positive lag of four for example, would indicate a significant association between PA and the social cognitive construct four days following PA engagement, whereas a negative lag of two would indicate a significant association between PA and the social cognitive construct two days prior to PA engagement. Only cross-correlations of  $\geq 0.4$  that exceeded 95% CIs were considered significant predictors in an effort to ensure that identified correlations were meaningful (following the procedure of Hobbs et al., 2013).

## **Results**

Participant characteristics are shown in Table 1. In addition, descriptive statistics for each variable are presented in Table 2. Statistics for each variable are presented as means and standard error as the measure of variance.

Insert Tables 1 & 2 here

*Compliance with study protocol*

All participants completed diary questionnaires on 100% of all possible occasions (13 random probes, excluding baseline). Time plots for cognitions and PA were visually inspected prior to imputation for each participant. Variance was evident for each variable over the timeframe, with the exception of goal setting for participant 4 who scored “1” at each data point across the study. This variable was therefore not included in the final analysis for this individual. Inspection of the data revealed that no individual had the same data pattern over time with regards to cognitions and PA measurements.

### *The relationship between SCT constructs and physical activity*

Table 3 displays the relationships between SCT constructs and PA for each participant. The interrelationships between SCT constructs and PA were examined in each of the six participants. Variability in step counts was evident for all participants and the pattern of behaviours (magnitude of peaks and troughs) was also unique to each individual. In total, 52 separate relationships between SCT constructs and PA were examined. All relationships demonstrated variability over time, 15 of which reached the criterion for significance of prediction (cross-correlations of  $\geq 0.4$  that exceeded 95% CIs).

Insert Table 3 here

### *Participant 1 (male, inactive)*

Due to the low PA levels that were self-reported on the IPAQ this participant was categorised as “inactive”. The participant accumulated a relatively low number of steps/day (< 8000) over the course of the study ( $M = 5075$ ,  $SD = 875.41$ ). A breakdown of step counts found that this participant had 26 days of low PA activity (<8000 steps/day) and only two days of high PA activity (>12,500 steps/day) throughout the

observation period. The cross-correlation analysis for participant 1 revealed that goal setting was significantly associated with higher levels of PA ( $r = 0.42$ ) and predicted behaviour in the days *prior* to engaging in the PA (lag = -4). Additionally, there were also significant associations between PA and barrier self-efficacy ( $r = 0.45$ , lag 4), social support (friends) ( $r = 0.46$ , lag 2), and perceived barriers ( $r = 0.42$ , lag 4). However, these constructs were associated with PA in the days *following* PA engagement (i.e. a positive lag), suggesting that PA engagement resulted in a change in these SCT factors.

#### *Participant 2 (female, minimally active)*

Based on the IPAQ responses this participant was classified as being “minimally active”. Analysis of the accelerometer data revealed that participant 2 also accumulated a relatively low average number of steps/day (< 8000) across the course of the study ( $M = 5946$ ,  $SD = 892.13$ ). A breakdown of step counts found that participant 2 had three days of high activity (> 12,500 steps/day) and three days of moderate activity (8-12,500 steps/day) over the course of the observation period. However, this person also spent 22 days where they were relatively inactive (< 8000 steps/day), indicating that they have an irregular pattern of PA behaviour. The cross-correlation analysis revealed that several social cognitive constructs were significantly associated with higher levels of PA behaviour within this participant across the study. For example, there were significant associations with daily PA and social support (family) ( $r = 0.91$ ), social support (friends) ( $r = -0.60$ ), outcome expectations ( $r = 0.55$ ), perceived barriers ( $r = 0.47$ ), exercise planning ( $r = 0.45$ ), and barrier self-efficacy ( $r = 0.45$ ). Additionally, the majority of these constructs, e.g. barrier self-efficacy, outcome expectations, exercise planning, social support (friends) and social support (family) were concurrently associated with PA behaviour (lag = 0), meaning that they were

related to PA on the same day. Additionally, perceived barriers was associated with PA three days *prior* to engaging in the behaviour (lag = -3), suggesting that having a greater perception of PA barriers in the days leading up to a period of activity was associated with higher levels of PA behaviour for this individual.

*Participant 3 (female, active)*

The IPAQ responses for this individual indicated that they were “currently active”. The data from the accelerometers revealed that participant 3 was moderately active over the course of the study (8-12,500 steps/day) ( $M = 10,564$  steps/day,  $SD = 552.24$ ) (Tudor-Locke & Bassett, 2004). There were 13 days spent in moderate activity levels (8-12,500 steps/day) and nine days where high levels of PA were achieved (>12,500 steps/day), with six days spent in low levels of activity (<8000 steps/day) across the study. Cross-correlation analysis revealed that daily social support (friends) was negatively associated with PA over the course of the study ( $r = -0.43$ ). Furthermore, social support from friends also preceded PA (lag = -2), indicating that having lower perceptions of social support from friends in the days *prior* to being active resulted in higher levels of activity two days later for this individual.

*Participant 4 (female, inactive)*

Participant 4 was categorized as being “inactive” based on the self-report PA questionnaire (IPAQ). Accelerometer data also revealed that this participant had a relatively low level of PA (< 8000 steps/day) across the duration of the study ( $M = 5578$  steps/day,  $SD = 534.13$ ). Inspection of this individual’s daily activity patterns revealed that there were 26 days spent in low levels of activity (<8000 steps/day) and five days

spent in either moderate (8-12,500 steps/day) or high levels (>12,500 steps/day) of activity across the study (two days and three days, respectively). Cross-correlation analysis for this participant revealed that none of the SCT constructs were associated with PA behaviour over time. However, it should be noted that this individual consistently reported setting no PA goals (i.e. a score of 1 for goal setting) over the course of the four-week period. As such, goal setting was not included in the cross correlational analysis for this participant.

*Participant 5 (male, active)*

The fifth participant's IPAQ self-report indicated that they were "currently active". This participant was also moderately active (8-12,500 steps/day) over the course of the study based on their accelerometer data ( $M = 11,033$  steps/day,  $SD = 1053$ ). Although there were 11 days when PA was high for this participant (> 12,500 steps/day), they had ten days where their activity patterns substantially reduced to below recommended levels (< 8000 steps/day). The remaining eight days were spent in periods of moderate activity levels (8-12,500 steps/day). The cross-correlation analysis for this participant revealed that daily outcome expectations ( $r = 0.55$ ), enjoyment ( $r = 0.43$ ) and goal setting ( $r = -0.4$ ) were significantly associated with daily PA behaviour. Outcome expectations and goal setting were associated with PA concurrently (e.g. on the same day) (lag = 0). It also emerged that PA preceded exercise enjoyment (lag = 4), indicating that taking part in PA predicted an increase in enjoyment 4 days later.

*Participant 6 (female, minimally active)*

Participant 6 was categorised as being "minimally active" based on their scores for the self-report PA questionnaire (IPAQ). Participant 6 accumulated a relatively low

average number of steps/day (<8000) over the course of the study ( $M = 5536$  steps/day,  $SD = 319.07$ ). There were only two days when this individual achieved moderate levels of PA (8-12,500 steps/day), with most time (26 days) being spent in low levels of PA (<8000 steps/day). There was no point in the study when this individual achieved high levels of PA (>12,500 steps/day). Cross-correlation analysis revealed that higher levels of daily enjoyment ( $r = 0.56$ ) was associated with higher levels of daily PA for this participant. Enjoyment was associated with PA concurrently (lag = 0), indicating that higher levels of enjoyment was associated with higher levels of PA on the same day.

## **Discussion**

The present study found that SCT constructs were associated with PA behaviour in five out of six participants. However, no individual within the study had an identical pattern of cognitions and behaviour across the four-week period. In addition, while we found that on some occasions, for some participants, the SCT constructs predicted subsequent PA behaviour, there were other occasions where PA behaviour and SCT constructs were concurrently related, and other instances where PA engagement predicted a change in the SCT construct. Indeed, the majority of the associations between SCT constructs and PA were either concurrent or positive lags suggesting that in most cases performance of physical activity may have caused a change in the SCT construct rather than the reverse. These findings highlight the importance of reciprocal bi-directional relationships between SCT constructs and PA. Indeed, Weinstein (2007) has previously highlighted the potential effects of behaviour on cognitive constructs, particularly for on-going behaviours, such as physical activity.

These findings suggest that individuals make daily decisions, adopt daily attitudes, and hold daily beliefs about engaging in PA that can influence their current and future behaviour. In addition, the findings show that their current behaviour can influence future cognitions. These variations in cognition and behaviour may not be detected when using *between-group* designs and as such demonstrates a potential limitation of such designs. Similar findings have been reported in other n-of-1 studies. For example, Hobbs et al. (2013) demonstrated that individuals were more likely to be physically active on days when they had more positive attitudes, higher perceived behavioural control, and stronger behavioural intentions. In addition, O'Brien et al. (2015) found that individuals with lower-limb osteoarthritis were more likely to have higher levels of PA (e.g. increased walking) on days when they had stronger cognitions (e.g. attitudes, perceived behavioural control, and intentions) towards the behaviour. Furthermore, Kwasnicka et al., (2017) identified that daily fluctuations in self-reported adherence to a weight loss maintenance plan were significantly associated with maintenance motivation and satisfaction with outcomes, self-regulation, habit, and stable environment.

Within the current study, on some occasions, specific social cognitions predicted PA in the opposite direction than expected (i.e. negatively). For example, the most consistent social cognitive construct that was associated with PA was social support (friends). However, on several occasions, this construct was negatively associated with behaviour, suggesting that *lower* levels of support from friends was associated with *higher* levels of PA. This potentially highlights a unique difference when investigating the *within-individual* variations in behaviour when compared to studies that use *between-group* designs. Previous research has demonstrated that negative relationships between cognitions and behaviour often occur when using

longitudinal *within-subject* designs rather than between-group designs (e.g., Richard, Diefendorff, & Martin, 2006; Schmidt & DeShon, 2009, Vancouver & Kendall, 2006). Social support from friends was associated with behaviour across all activity groups (e.g. inactive, minimally active, and currently active participants). Bandura (1997) argues that social support is a key factor that can influence PA behaviour, and previous investigations also demonstrated that individuals who have greater levels of support from friends are more likely to be physically active (Blanchard, McGannon, Spence et al., 2005; Eyster et al., 1999). However, the findings from the current study revealed that on some occasions, social support from friends was negatively related to PA behaviour. Empirical studies investigating the influence of social support on PA have generally been inconsistent in determining whether social support is an important factor for PA engagement and maintenance (Eyster et al., 1999). Many studies suggest that a reason for the inconsistent findings is that social support can vary with age, gender, and the type of exercise that is performed (Eyster et al., 1999). From the current findings, however, a further reason why these inconsistencies may occur is that the cognitions that explain the *between-subject* processes may be different from those that explain the *within-individual* processes. Although having a supportive network of friends for being active may be important for an individual overall, there may be specific occasions when a lack of social support can encourage greater PA engagement, or when PA engagement can lead to lower social support. It may be that someone engaging in PA has to reduce their social interaction with friends in order to do so, thus resulting in a lower level of social support from these friends which may explain why lower levels of social support from friends may be associated with greater PA.

Whilst the findings provide some support for SCT in explaining PA *within* individuals, no participant had the same pattern of relationships between SCT

constructs and PA behaviour across the study. Similarly, a recent study by McDonald et al. (2017b) also reports no consistent pattern of predictors of physical activity across individuals during the retirement transition within a series of n-of-1 studies. This suggests that individually tailored interventions that consider the unique needs, characteristics, and behaviour patterns of the individual may be more effective than a “one-size-fits-all” approach with regards to increasing PA behaviour (Noar et al., 2007; Ryan & Lauver, 2002). The current study provides further evidence that investigating the *within-individual* variations in cognitions and behaviour may provide important information that can guide interventions aimed at increasing PA behaviour. For example, examination of the data for participant 1 (inactive) demonstrates that exercise goal setting predicted subsequent PA behavior. Whereas, for participant 2, who was minimally active perceiving greater barriers was the factor that predicted subsequent PA. Therefore, although these individuals both have low levels of PA behaviour, they would benefit from differently focussed behaviour change interventions.

There are several limitations that should be acknowledged. First, the questionnaires that were used were not specifically designed for time-series research, and may not be sensitive to the daily *within-individual* variability in cognitions and behaviour. Second, whilst individuals of varying activity patterns were recruited specifically for this investigation, the difference in actual steps/day measured by the accelerometers was relatively small between individuals categorized as “inactive” and “minimally active” (based on the self-report PA questionnaire). Categorising participants by their scores on self-report questionnaires in this way may not accurately reflect their true PA level over a longer period. Third, whilst the variable (random) methods used in the current study to collect data over the four-week period

was implemented to reduce participant burden, the intensive nature of collecting data in this way may have resulted in participants altering their behaviour to some extent as a result of constant observation. In addition, we did not account for weekday vs weekend days within the analyses. It is possible that some of the variability in participants' PA levels could be explained to some extent by being more (or less) active on weekend days vs weekdays. Finally, the use of probe measures (rather than daily measures) of the predictor variables may be seen as a limitation. Adopting this approach had the advantage of allowing us to utilise traditional psychometric questionnaires, rather than measures relying on one or two items. However, the disadvantage of this is that we were not able to capture day-to-day fluctuations in cognitions. The fact that this approach also resulted in a large amount of missing data, which required extensive use of imputation, can also be regarded as a limitation. Future research should therefore adapt the measures utilised here to reduce them to one or two items and administer them daily to examine further the utility of SCT in explaining PA within individuals. The type of design that we adopted also makes it difficult to deconstruct the influence that cognitions have on subsequent behaviour, and the influence of behaviour on subsequent cognitions.

Overall, these findings suggest that constructs derived from SCT are associated with PA within individuals over time. However, the vast majority of associations were either concurrent or positive lags suggesting that in most cases performance of physical activity may have caused a change in the SCT construct rather than the other way around. These bi-directional relationships indicate that while SCT constructs can predict physical activity engagement, physical activity engagement can also lead to changes in SCT constructs. The nature of these bi-directional relationships warrants further investigation. These findings highlight that

tailored PA interventions at the individual level may be more effective than a “one-size-fits-all” approach with regards to increasing PA behaviour.

## References

Acock, A. C. (2005). Working with missing values. *Journal of Marriage and family*, 67(4), 1012-1028. doi: 10.1111/j.1741-3737.2005.00191.x

Ainsworth, B. E., Haskell, W. L., Whitt, M. C., Irwin, M. L., Swartz, A. M., Strath, S. J., O'Brien, W.L., Bassett, D.R., Schmitz, K.H., Emplaincourt, P.O. & Jacobs, D. R. (2000). Compendium of physical activities: an update of activity codes and MET intensities. *Medicine and Science in Sports and Exercise*, 32, S498-504. Retrieved from <http://www.acsm.org/public-information/acsm-journals/medicine-science-in-sports-exercise>

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179-211. doi: 10.1016/0749-5978(91)90020-T

Anderson, E. S., Wojcik, J. R., Winett, R. A., & Williams, D. M. (2006). Social-cognitive determinants of physical activity: The influence of social support, self-efficacy, outcome expectations, and self-regulation among participants in a church-based health promotion study. *Health Psychology*, 25, 510-520. doi: 10.1037/0278-6133.25.4.510

Ayotte, B. J., Margrett, J. A., & Hicks-Patrick, J. (2010). Physical activity in middle-aged and young-old adults: The roles of self-efficacy, barriers, outcome expectancies, self-regulatory behaviors and social support. *Journal of Health Psychology*, 15, 173-185. doi: 10.1177/1359105309342283

- Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York: Freeman.
- Bandura, A. (2004). Health promotion by social cognitive means. *Health Education & Behavior*, 31, 143-164. doi: 10.1177/1090198104263660
- Blanchard, C. M., McGannon, K. R., Spence, J. C., Rhodes, R. E., Nehl, E., Baker, F., & Bostwick, J. (2005). Social ecological correlates of physical activity in normal weight, overweight, and obese individuals. *International Journal of Obesity*, 29(6), 720-726. doi: 10.1038/sj.ijo.0802927
- Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P (2003). International PA questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, 195, 3508-1381. doi: 10.1249/01.mss.0000078924.61453.fb
- Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J.F. & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*, 35(8), 1381-1395. doi: 10.1249/01.MSS.0000078924.61453.FB
- Craig, P., Dieppe, P., Macintyre, S., Michie, S., Nazareth, I., & Petticrew, M. (2008). Developing and evaluating complex interventions: the new Medical Research Council guidance. *BMJ*, 337, a1655. doi: 10.1136/bmj.a1655
- Crane, C., Martin, M., Johnston, D., & Goodwin, G. M. (2003). Does depression influence symptom severity in irritable bowel syndrome? Case study of a patient with irritable bowel syndrome and bipolar disorder. *Psychosomatic*

*Medicine*, 65(5), 919-923. Retrieved from

<http://journals.lww.com/psychosomaticmedicine/pages/default.aspx>

Curran, P. J., & Bauer, D. J. (2011). The disaggregation of within-person and between-person effects in longitudinal models of change. *Annual Review of Psychology*, 62, 583-619. doi: 10.1146/annurev.psych.093008.100356

Duan, N., Kravitz, R.L. & Schmid, C.H. (2013). Single-patient (n-of-1) trials: a pragmatic clinical decision methodology for patient-centered comparative effectiveness research. *Journal of Clinical Epidemiology*, 66, 21-8. doi: 10.1016/j.jclinepi.2013.04.006

Eyler, A. A., Brownson, R. C., Donatelle, R. J., King, A. C., Brown, D., & Sallis, J. F. (1999). Physical activity social support and middle-and older-aged minority women: results from a US survey. *Social Science & Medicine*, 49(6), 781-789. Retrieved from <https://www.journals.elsevier.com/social-science-and-medicine>

Felton, G. M., Ott, A., & Jeter, C. (2000). Physical activity stages of change in African American women: implications for nurse practitioners. *Nurse Practitioner Forum*, 11, 116-23. Retrieved from <https://europepmc.org/abstract/med/11220052>

Fichman, M., & Cummings, J. N. (2003). Multiple imputation for missing data: Making the most of what you know. *Organizational Research Methods*, 6(3), 282-308. Retrieved from <http://journals.sagepub.com/home/orm>

Haskell, W. L. (2012). Physical activity by self-report: a brief history and future issues. *Journal of Physical Activity and Health*, 9, S5-10. Retrieved from <https://journals.humankinetics.com>

- Hobbs, N., Dixon, D., Johnston, M., & Howie, K. (2013). Can the theory of planned behaviour predict the physical activity behaviour of individuals? *Psychology & Health, 28*(3), 234-249. doi: 10.1080/08870446.2012.716838
- Honaker, J., & King, G. (2010). What to do about missing values in time-series cross-section data. *American Journal of Political Science, 54*(2), 561-581. doi: 10.1111/j.1540-5907.2010.00447.x
- Horner, R. D., & Baer, D. M. (1978). Multiple-probe technique: a variation of the multiple baseline. *Journal of Applied Behavior Analysis, 11*, 189-196.  
Retrieved from [http://onlinelibrary.wiley.com/journal/10.1002/\(ISSN\)1938-3703](http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1938-3703)
- Johnston, D. W., & Johnston, M. (2013). Useful theories should apply to individuals. *British Journal of Health Psychology, 18*(3), 469-473. doi: 10.1111/bjhp.12049
- Kendzierski, D., & DeCarlo, K. J. (1991). Physical activity enjoyment scale: Two validation studies. *Journal of Sport and Exercise Psychology, 13*(1), 50-64.  
doi: 10.1123/jsep.13.1.50
- Kwasnicka, D., Dombrowski, S. U., White, M. & Sniehotta, F. F. (2017). N-of-1 study of weight loss maintenance assessing predictors of physical activity, adherence to weight loss plan and weight change. *Psychology & Health, 32*, 686-708. doi: 10.1080/08870446.2017.1293057
- Le Masurier, G. C., & Tudor-Locke, C. (2003). Comparison of pedometer and accelerometer accuracy under controlled conditions. *Medicine and Science in Sports and Exercise, 35*(5), 867-871.  
doi:10.1249/01.MSS.0000064996.63632.10

- McDonald, S., Quinn, F., Vieira, R., O'Brien, N., White, M., Johnston, D. & Sniehotta, F. F. (2017a). The state of the art and future opportunities for using longitudinal N-of-1 methods in health behaviour research: A systematic literature review. *Health Psychology Review*, doi: 10.1080/17437199.2017.1316672
- McDonald, S., Vieira, R., Godfrey, A., O'Brien, N., White, M. & Sniehotta, F.F. (2017b). Changes in physical activity during the retirement transition: a series of novel n-of-1 natural experiments. *International Journal of Behavioral Nutrition and Physical Activity*, 14, 167. doi: 10.1186/s12966-017-0623-7
- Miller, R., Brown, W., & Tudor-Locke, C. (2006). But what about swimming and cycling? How to “count” non-ambulatory activity when using pedometers to assess physical activity. *Journal of Physical Activity and Health*, 3, 257-266. doi: 10.1123/jpah.3.3.257
- Molenaar, P. C., & Campbell, C. G. (2009). The new person-specific paradigm in psychology. *Current Directions in Psychological Science*, 18(2), 112-117. doi: 10.1111/j.1467-8721.2009.01619.x
- Naughton, F., & Johnston, D. (2014). A starter kit for undertaking n-of-1 trials. *The European Health Psychologist*, 16(5), 196-205. Retrieved from <https://ehps.net/ehp/index.php/contents/article/download/ehp.v16.i5.p196/12>
- Noar, S. M., Benac, C. N., & Harris, M. S. (2007). Does tailoring matter? Meta-analytic review of tailored print health behavior change interventions. *Psychological Bulletin*, 133(4), 673. doi: 10.1037/0033-2909.133.4.673

- O'Brien, N., Philpott-Morgan, S., & Dixon, D. (2016). Using impairment and cognitions to predict walking in osteoarthritis: A series of n-of-1 studies with an individually tailored, data-driven intervention. *British Journal of Health Psychology, 21*(1), 52-70. doi: 10.1111/bjhp.12153
- Quinn, F., Johnston, M., & Johnston, D. W. (2013). Testing an integrated behavioural and biomedical model of disability in N-of-1 studies with chronic pain. *Psychology & Health, 28*(12), 1391-1406. doi: 10.1080/08870446.2013.814773
- Resnick, B., & Jenkins, L. S. (2000). Testing the reliability and validity of the self-efficacy for exercise scale. *Nursing Research, 49*, 154-9. doi: 10.1097/00006199-200005000-00007
- Richard, E. M., Diefendorff, J. M., & Martin, J. H. (2006). Revisiting the within-person self-efficacy and performance relation. *Human Performance, 19*(1), 67-87. doi: 10.1207/s15327043hup1901\_4
- Rogers, L. Q., Shah, P., Dunnington, G., Greive, A., Shanmugham, A., Dawson, B., & Courneya, K. S. (2005). Social cognitive theory and physical activity during breast cancer treatment. *Oncology Nursing Forum, 32*, 807-15. doi: 10.1188/05.ONF.807-815
- Rovniak, L. S., Anderson, E. S., Winett, R. A., & Stephens, R. S. (2002). Social cognitive determinants of physical activity in young adults: A prospective structural equation analysis. *Annals of Behavioral Medicine, 24*, 149-156. Retrieved from <http://www.springer.com/medicine/journal/12160>

- Rubin, D. B. (1987). The calculation of posterior distributions by data augmentation: Comment: A noniterative sampling/importance resampling alternative to the data augmentation algorithm for creating a few imputations when fractions of missing information are modest: The SIR algorithm. *Journal of the American Statistical Association*, 82(398), 543-546. Retrieved from <http://www.tandfonline.com/toc/uasa20/current>
- Ryan, P., & Lauver, D. R. (2002). The efficacy of tailored interventions. *Journal of Nursing Scholarship*, 34(4), 331-337. Retrieved from [http://onlinelibrary.wiley.com/journal/10.1111/\(ISSN\)1547-5069](http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1547-5069)
- Sallis, J. F., Grossman, R. M., Pinski, R. B., Patterson, T. L., & Nader, P. R. (1987). The development of scales to measure social support for diet and exercise behaviors. *Preventive Medicine*, 16(6), 825-836. Retrieved from <https://www.journals.elsevier.com/preventive-medicine/>
- Salmon, J., Owen, N., Crawford, D., Bauman, A., & Sallis, J. F. (2003). Physical activity and sedentary behavior: a population-based study of barriers, enjoyment, and preference. *Health Psychology*, 22(2), 178. Retrieved from <http://www.apa.org/pubs/journals/hea/>
- Schafer, J. L., & Graham, J. W. (2002). Missing data: our view of the state of the art. *Psychological Methods*, 7(2), 147. <http://www.apa.org/pubs/journals/met/>
- Schmidt, A. M., & DeShon, R. P. (2009). Prior performance and goal progress as moderators of the relationship between self-efficacy and performance. *Human Performance*, 22(3), 191-203. doi: 10.1080/08959280902970377

- Spence, J. C., Burgess, J. A., Cutumisu, N., Lee, J. G., Moylan, B., Taylor, L., & Witcher, C. S. (2006). Self-efficacy and physical activity: A quantitative review. *Journal of Sport & Exercise Psychology, 28*, s172-s173. Retrieved from <http://journals.humankinetics.com/journal/jsep>
- Thomas, S., Reading, J., & Shephard, R. J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Canadian Journal of Sport Sciences, 17*, 338-45. Retrieved from <https://www.ncbi.nlm.nih.gov/labs/journals/can-j-sport-sci/>
- Tudor-Locke, C., & Bassett, D. R. (2004). How many steps/day are enough? Preliminary pedometer indices for public health. *Sports Medicine, 34*(1), 1-8. Retrieved from <https://link.springer.com/journal/40279>
- van Poppel, M. N., Chinapaw, M. J., Mokkink, L. B., Van Mechelen, W., & Terwee, C. B. (2010). Physical activity questionnaires for adults: a systematic review of measurement properties. *Sports Medicine, 40*(7), 565-600. doi: 10.2165/11531930-000000000-00000
- Vancouver, J. B., & Kendall, L. N. (2006). When self-efficacy negatively relates to motivation and performance in a learning context. *Journal of Applied Psychology, 91*(5), 1146. doi: 10.1037/0021-9010.91.5.1146
- Weinstein, N. D. (2007). Misleading tests of health behavior theories. *Annals of Behavioral Medicine, 33*(1), 1-10. doi: 10.1207/s15324796abm3301\_1
- Young, M. D., Plotnikoff, R. C., Collins, C. E., Callister, R., & Morgan, P. J. (2014). Social cognitive theory and physical activity: a systematic review and meta-analysis. *Obesity Reviews, 15*(12), 983-995. doi: 10.1111/obr.12225

Table 1: Participant characteristics.

Participant	Age	Description	Days of data available (% missing)		Total days of measurement
			Social cognitive variables	Accelerometers	
1	65	Inactive, retired	14 (51.7)	28 (0)	28
2	40	Minimally active, full-time student	14 (51.7)	28 (0)	28
3	64	Currently active, part-time employment	14 (51.7)	28 (0)	28
4	30	Inactive, full-time employment	14 (56.3)	31 (0)	31
5	31	Currently active, full time employment	14 (53.3)	29 (0)	29
6	29	Minimally active, full-time student	14 (51.7)	28 (0)	28

Table 2: Descriptive data for SCT constructs and PA measures for each participant.

Variable	P1		P2		P3		P4		P5		P6	
	<i>M</i>	SE	<i>M</i>	SE	<i>M</i>	SE	<i>M</i>	SE	<i>M</i>	SE	<i>M</i>	SE
Barrier self-efficacy	3.83	0.18	5.83	0.17	3.18	0.33	2.7	0.16	7.81	0.12	1.92	0.19
Outcome expectations	162.17	9.69	265.86	4.56	120.3	7.41	102.86	3.66	211.61	5.43	195.95	11.58
Planning	1.99	0.08	3.12	0.09	1.81	0.05	2.21	0.02	2.82	0.1	1.33	0.07
Goal setting	1.15	0.09	3.97	0.04	1.1	0.06	Na	Na	1.97	0.12	1.51	0.1
Social support (family)	1.72	0.06	1.93	0.09	3.2	0.04	1.92	0.03	2.12	0.05	2.41	0.25
Social support (friends)	1.63	0.01	3.23	0.14	3.12	0.05	2.13	0.05	2.17	0.04	1.983	0.19
Enjoyment	73.38	1.25	111.21	1.88	99.84	1.71	46.68	1.05	96.08	1.59	105.57	1.55
Perceived Barriers	2.59	0.04	1.94	0.05	2	0.09	1.48	0.01	2.23	0.04	2.12	0.02
PA (accelerometers)	5075	875.41	5946	892.13	10,564	552.24	5578	534.13	11,033	1053	5536	319.07

Table 3: Cross-correlations and time lags between SCT constructs and PA.

SCT constructs cross-correlation (standard error) and time lag								
Participant	BSE	OE	EXPLAN	EXGOAL	SSFAM	SSFRI	ENJOY	PBARR
1 (Inact)	0.45 (0.2) lag 4*	-0.31 (0.21) lag-5	0.33 (0.2) lag 4	0.42 (0.2) lag -4*	-0.14 (0.21) lag -5	0.46 (0.20) lag 2*	0.21 (0.19) lag 0	0.42 (0.2) lag 4*
2 (Min act)	0.45 (0.19) lag 0*	0.55 (0.19) lag 0*	0.45 (0.19) lag 0*	0.31 (0.2) lag -4	0.91 (0.19) lag 0*	-0.60 (0.19) lag 0*	0.25 (0.2) lag 2	0.47 (0.2) lag -3*
3 (Cur act)	-0.33 (0.2) lag 1	-0.29 (0.2) lag 1	-0.28 (0.2) lag 1	-0.31 (0.19) lag 0	0.20 (0.2) lag -2	-0.43 (0.2) lag -2*	0.39 (0.2) lag 3	-0.31 (0.2) lag 3
4 (Inact)	0.19 (0.18) lag -1	0.22 (0.18) lag -1	0.26 (0.19) lag -2	NA	-0.14 (0.18) lag 0	0.15 (0.19) lag 3	0.22 (0.19) lag 2	-0.19 (0.18) lag 0
5 (Cur act)	-0.30 (0.19) lag 0	0.55 (0.19) lag 0*	0.19 (0.2) lag 4	-0.4 (0.19) lag 0*	0.32 (0.19) lag 1	0.32 (0.19) lag 1	0.43 (0.2) lag 4*	0.24 (0.2) lag 4
6 (Min act)	-0.37 (0.2) lag 0	-0.30 (0.2) lag 0	0.30 (0.22) lag 5	-0.31 (0.21) lag 2	-0.35 (0.22) lag 4	-0.21 (0.21) lag 1	0.56 (0.2) lag 0*	0.36 (0.2) lag 0

Notes: When cross-correlations were identified at more than one time lag only the highest correlation is reported.

\*Significant cross-correlation ( $\geq 0.40$  ( $\pm$ ) and exceeding 95% CI).

Non-significant: Correlation did not reach 95% CI.

NA: Variable was not included in analysis

(Inact) = Inactive, (Min act) = Minimally Active, (Cur Act) = Currently Active.

BSE: Barrier self-efficacy; OE: Outcome expectations; EXPLAN: Exercise planning; EXGOAL: Exercise goal setting; SSFAM: Social support (family); SSFRI: Social support (friends); ENJOY: Enjoyment; PBARR: Perceived barriers.