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The Transtheoretical model's processes of change in the heart of a physical activity intervention : a series of n-of-1

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Highlights

- This Processes of Change-personalized Transtheoretical model-based intervention constitutes a replicable intervention
- A personalized TTM-based intervention using processes of change levels was tested
- This intervention increased physical activity levels for most participants

Abstract

The objectives were a) to test whether a Processes of Change (POC)-personalized Transtheoretical model (TTM)-based intervention could increase physical activity (PA) among inactive adults, and b) to examine whether the intervention increased the level of TTM theoretical constructs. The following hypotheses were formulated: 1) PA levels will be significantly higher during and after the intervention in comparison to baseline measures; 2) the level of targeted POCs will significantly increase during the intervention; 3) non targeted POCs will stay stable, and 4) self-efficacy and decisional balance levels will significantly increase during the intervention. A series of N-of-1 with A (1 to 2-week)-B(10-week)-A'(2-week) design were conducted with 12 inactive adults. Behavioral counselors used behavior change techniques to target TTM constructs and supervise PA. Interventions were individualized based on the 5 POCs with the lowest pre-intervention level. Device-based and subjective PA along with TTM measures were collected weekly online. PA data were analyzed with piecewise linear models. A visual analysis was run to examine the TTM constructs. Device, self-reported and TTM data were available for five, seven and five participants, respectively. A significant self-reported PA increase for six participants was found during the phase B and A2. A significant device-measured PA increase was observed in two participants during the study. A substantial increase of targeted POC from baseline for all participants with available data was observed. This study provides the first evidence of behavioral and psychological effects of a POC-personalized TTM-based intervention in inactive adults.

Key words: Single case experimental study; accelerometry, processes of change; behavior change techniques; self-efficacy

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Introduction

Physical inactivity is a risk factor for cardiovascular, metabolic diseases, cancers (Lee et al., 2012) and mental health disorders (Bernard et al., 2018) and its worldwide prevalence was estimated at 27.5% in 2016 (Guthold et al., 2018). In Canada and the US, recent estimates suggest that 84% and 45% of adults, respectively, do not comply with physical activity (PA) national recommendations (Craig *et al.*, 2020), which constitutes a public health challenge.

Among the different potential interventions to improve PA, a previous meta-analysis showed that motivational theory-based interventions were effective (Gourlan et al., 2016). This meta-analysis also underlined that interventions based on a single theory were more effective than those using a combination of theories and that none of the included motivational theories were found to have a larger effect size (Gourlan et al., 2016). Among the most used theories in PA promotion, the transtheoretical model (TTM) has been widely considered to tailor PA interventions. The TTM is based on four core constructs being stages of change, decisional balance, self-efficacy, and processes of change (POCs).

The five stages of change are the most descriptive part of the TTM ("where" individuals are in their readiness to change). These stages are *precontemplation* (not ready, not intending to change), *contemplation* (getting ready, intention to change within the next 6-months), *preparation* (ready, intentions to change within the next month), *action* (new behavior initiated for less than 6 months), and *maintenance* (behavior sustained for more than 6 months) (Prochaska et al., 1994).

Decisional balance is the perception of advantage and disadvantages (pros *vs.* cons) to adopt or cease a behavior (Janis & Mann, 1977). Self-efficacy refers to "the belief in their own ability to organize and perform the behavior despite setbacks and barriers" (p. 141) (Bandura, 1986).

Finally, the ten POCs are the strategies used to achieve the desired behavior change and include five experiential POCs (perceptions and experiences that the individual has of himself and his environment in relation to the behavior) and five behavioral POCs (concrete strategies carried to modify the environment to facilitate behavior change) (Romain et al., 2018b). The five experiential POC are: *Consciousness raising* being defined by the efforts in searching information on the behavior to change, *Dramatic relief* represents the affective aspects of behavior change, *Environmental reevaluation* involves a positive or negative effect of behavior on the social and physical environment of individuals, *Self-reevaluation* is cognitive or emotional appraisal of the behavior's impact, and *Social liberation* being the recognition that current social norms encourage individuals to change their behavior. The five behavioral POC are: *Counterconditioning* being the substitution of the unhealthy behavior by an healthier one, *Helping relationships* defined as the support of a significant other to change the behavior, *Reinforcement management* is defined as the use of reinforcements and rewards to consolidate healthy behavior, *Self-liberation* is committing to change and believing in self's

ability to carry out the commitment made, and *Stimulus control* involves modifying the environment to trigger healthy behavior (Prochaska et al., 1994).

Despite being widely used, the TTM still remains poorly implemented and the reproducibility of TTM based intervention is very low (Bernard et al., 2021). Based on studies examining the addictive behaviors, experiential and behavioral POC act sequentially, with experiential POC used in the early stages and behavioral POC in the later stages (action and maintenance). Notwithstanding, this sequential order was not found for physical activity, experiential and behavioral POC acting in tandem, with the use of both increasing across stages and physical activity amount (for review see Romain et al., 2018b).

In terms of PA promotion, previous meta-analyses showed that TTM-based interventions increased PA in adults (Gourlan et al., 2016; Romain et al., 2018a). Moreover, these meta-analyses revealed that the most important TTM constructs to target in interventions are self-efficacy and POC (Romain et al., 2018a). These findings were confirmed in another study showing that the temporal sequence between the different TTM constructs was driven by the POC (Nigg et al., 2019) and that changes in the latter lead to change self-efficacy, decisional balance, then stage of change.

A personalized Transtheoretical-based intervention based on processes of change

If TTM-based interventions are effective, their effect could be enhanced by overtaking the "one-size-fit-all" approach in behavior change interventions (Johnston & Johnston, 2013, Romain et al., 2018b). Hence, the current research challenge is to personalize TTM interventions by a) using its constructs, b) providing its mechanisms and related behavior change techniques, c) improving the fidelity in reporting (Bernard 2016, 2021, Michie et al. 2011; Sheeran et al., 2017). One strategy to personalize TTM-based interventions could be to target POC with the lowest scores before the intervention (Romain et al., 2018b). This strategy is supported by a large body of knowledge on the centrality of POC in TTM interventions (Romain et al. 2018b; Nigg et al., 2019) and the fact that experiential and behavioral POC increased PA (Romain et al., 2014; Romain et al., 2018; Lipschitz et al., 2015). In this regard, N-of-1 designs facilitate the development of personalized interventions (Chevance et al., 2020; Kwasnicka & Naughton, 2020).

Aims

The primary aim of the present study was to test whether a POC-personalized TTM-based intervention could increase PA among inactive adults. The secondary aim was to examine whether the intervention increased the level of (non)targeted POCs, self-efficacy, and decisional balance. A third aim was to explore the effects of our intervention on physical fitness and measured weight.

Our hypotheses were : a) PA levels (device-measured and self-reported) will be significantly higher during and after the intervention in comparison to baseline measures; b) the score of targeted POCs

will increase during the intervention; c) the score of non-targeted POCs will remain stable during the intervention; d) self-efficacy and decisional balance levels will increase during the intervention.

Methods

Participants

Participants from Montreal, Brossard and Longueuil (QC, Canada) were recruited during July 2021 using a Facebook ad. Our inclusion criteria were: 1) physically inactive (Godin's questionnaire score < 23 (Amireault & Godin, 2015); 2) 18 to 65 years old; 3) comfortable reading and understanding French; 4) being able to do PA; 5) willingness to follow an PA intervention. Exclusion criteria were: 1) a self-reported diagnosis of severe mental illness or a disorder of substance use; 2) a sensory disorder; 3) pregnant women; 4) a physical disability; 5) a positive answer to the PA Readiness Questionnaire provided by the Canadian Society for Exercise Physiology.

Potential participants were invited to an initial in person meeting to sign the informed consent letter and receive an accelerometer. Afterwards, they were invited to complete 2 questionnaires (see Table S1.1) online using the Zoom communication platform. Each participant was rewarded 30 CAD dollars when they gave back the accelerometer at the end, or 50 CAD dollars upon completion of all questionnaires. This study was approved by the Ethics Committee of [masked for review] (certificate number: 4148).

Study design and procedures

This N-of-1 study followed a multiple baseline ABA design for PA measures and an AB protocol design for TTM measures. All phases were designed as follows:

In phase A, the randomized baseline period (1- to 2-week), all questionnaires were completed once on the first day. In phase B, the 10-week intervention, participants met their PA-counselor for weekly sessions, and TTM questionnaires were sent every week. Phase A2 was a 2-week observation period. PA was assessed with self-report and device measures during all ABA phases. A randomization sequence was created using R with a 1:1 allocation using random block sizes of 2.

The Single-Case Reporting Guideline In Behavioral Interventions statement was followed to guide the reporting of our study (Tate et al., 2017; see details in Table S1.2). Initial assessments were completed with a research assistant during a video-conference. Then, a research assistant and the main researcher visited the participants to perform a fitness test and provide them with an accelerometer. TTM questionnaires were filed once on initial evaluation and weekly during phase B (Figure S1.1).

Measures

Initial evaluation

The following information was collected using questionnaires prior to the intervention: sex, age, socio-demographic, environmental perception related to PA, social status perception, PA's stages of change (more details are provided in Table S1.1 and section 1 of supplementary file).

Physical activity

Device measured physical activity. Participants wore a waterproof wrist-worn accelerometer (GENEActiv), and were instructed to wear it 24/7. The accelerometer used herein is valid and reliable for low, moderate and high intensity PAs (Esliger et al., 2011). Participants could not see the accelerometer data. Each participant's device was interchanged for a new one mid-intervention due to battery life. The primary outcome for our analyses was the total PA per day.

Self-reported physical activity. An online agenda was provided to participants (Dowd et al., 2018). Every day, participants reported their PA type (e.g., walk, swim, dance, broom sweeping, etc.), duration, and rate of perceived exertion (Figure S1.2). This agenda was also a self-monitoring tool for our participants (Gleeson-Kreig, 2006). The combination of device- and self-reported PA measures has been recommended particularly to identify PA volume, types and domains (e.g., active transport) (Prince et al., 2019).

Transtheoretical constructs measures

Decisional balance scale. The validated 16-item French version of decisional balance scale for PA (Eeckhout et al., 2013) was used to measure advantages (pros) and disadvantages (cons) of PA. Participants had to report the degree of approval using a 5-point Likert scale from 1 "completely wrong" to 5 "absolutely true". Both dimensions of the questionnaire have shown good psychometric properties (Eeckhout et al., 2013). Cronbach's alpha were 0.85 and 0.73 , respectively (Eeckhout et al., 2013).

Physical activity self-efficacy scale. The French version of a 14-item self-efficacy questionnaire (Bandura, 1997) was used to evaluate levels of self-efficacy towards PA. Using a scale going from 0% (not all confident) to 100% (absolutely confident), participants were asked whether they felt confident to undertake PA 3 times/week when facing with 14 different barriers (e.g., fatigue, anxiety) (Romain & Abdel-Baki, 2017). Cronbach alpha was 0.88 in a previous study (Romain & Abdel-Baki, 2017).

Processes of change scale. All 10 POCs were assessed using a validated 28-item POC questionnaire (Bernard et al., 2014). Participants were asked how often they would experience 28 items related to PA base on a Likert scale from 1 "never" to 5 "repeatedly". Each POC was measured by 2 or 3-items. A mean score was used to determine the POC's level. Cronbach's alpha were ranged from 0.72 to 0.86 in the validation study (Bernard et al., 2014).

Fitness and body composition

The Rockport walking test was carried out to estimate the VO2max of participants. This sub-maximal validated test has good fidelity to examine the intervention effects (Kline et al., 1987). A body composition measure was performed with an Inbody 270 (Czartoryski et al., 2020). More details are available in a supplementary file.

Intervention

Intervention development. The following strategies were carried out to develop our intervention: (a) identification of the mechanisms of action associated with each TTM constructs, then the selection of related behavior change techniques (Carey et al., 2019; Johnston et al., 2021); (b) identification of post-publication coded behavior change techniques in TTM-based interventions using the online behavioral change techniques database (http://www.bct-taxonomy.com/interventions, three studies were found) (Carmack et al., 2006; Dinger et al., 2005; Leonhardt et al., 2008); and (c) identification of the most effective behavior change techniques associated with self-efficacy's sources in Warner & French (2018) meta-analysis. More details about these three strategies are available in Table S1.3.

Intervention manual. An intervention manual was developed and included each behavior change technique previously identified. Each session was planned, and specific behavior change techniques were delivered to each participant. Two research assistants with extensive background in kinesiology received three workshops about the implementation of behavior change techniques. Each supervised session combined counseling (ranged from 5 to 38 min) and supervised PA (52 min). Sessions were conducted online via a university Zoom platform.

Counseling sessions. Participants were randomly assigned to a research assistant. After the first POC assessment, the 5 POCs with the lowest scores were identified for each participant, and their related behavior change techniques were targeted (see Table S1.4). Otherwise, behavior change techniques related to self-efficacy sources and decisional balance were identical for all participants. The study design is represented with Figure S1.3. Detailed counseling session schedules are available in Table S1.4 and more detailed information on behavior change techniques in Table S1.5.

Supervised physical activity. PA sessions were conducted after counseling sessions and are detailed in Table S1.6. Participants had two supervised PA sessions from week 1 to 3; one supervised PA session from week 4 to 6; and zero supervised PA sessions from week 7 to 10. Participants were encouraged to perform short bouts of daily PA at a self-paced intensity. The increasing amount of unsupervised PA during the intervention was to develop participants' feeling of autonomy.

Internal validity

N-of-1 are vulnerable to plausible rival hypotheses that may explain the behavioral change such as, maturation, question-behavioral effect, and external factors (Kwasnicka & Naughton, 2020).

Internal validity refers to whether the behavioral change measured during the study is due to the intervention and not to other factors. It was assessed by a short interview with participants at weeks 5 and 10.

Analyses

Statistical analyses. A set of piecewise linear models (with Gaussian or Poisson distribution) were performed to compare PA measures between the phases B, A2 with phase A. This statistical approach has been recommended to analyze N-of-1 with time-series data segmented into phases (Huitema & Mckean, 2000). This model allows to generate the three followings parameters: performance at the beginning (intercept), developmental effect (trend effect, e.g., a continuous increase through all collected data), and intervention effect (level effect) (Wilbert & Lueke, 2021). We also ran a sensitivity analysis that consider the auto-correlation between PA outcomes. These sensitivity analyses were carried out only for models where PA followed a Gaussian distribution because it was implemented only for the latter in the "scan" package (Wilbert & Lueke, 2021).

Visual analysis. A formal visual inspection of the data was carried out by two researchers (JL, PB) to examine TTM constructs' patterns, fitness, and weight changes. Each TTM construct's longitudinal pattern was classified as follows: = large increase, = increase, → = no variation, = decrease, = large decrease, ~ = non-linear variation. Disagreements were resolved through discussion, and a consensus reached. Missing data are reported for each variable but were not replaced, as this may have distorted the visual analysis.

Transparency and openness. Actigraphic data were prepared with the *ggir* R package (Migueles et al., 2019). Analyses and graphics have been performed with R 4.1 and *tidyverse*, *scan* and *ggplot2* packages (Wilbert & Lueke, 2021). Data, open materials and R scripts are available in supplementary files (https://osf.io/zbxdm/). The present study design and its analysis were not pre-registered.

Results

Participant characteristics

Nine females and three males were recruited (Table 1). Five participants were randomized in a 2-week phase A. Accelerometer data were available only for five participants.

Adherence to intervention

Four participants, B, D, F, H dropped out the intervention and one participant (E) was excluded due to poor adherence to measures (See Table S2.1).

Device measured and self-reported physical activity

Overall, the device measured PA of five participants (with available data) was not significantly higher during B and A2 phases. Two participants (I and L) showed a significant positive trend during their inclusion. Figure 1 depicts participants daily PA and findings from regression analyses are presented in Table 2. Detailed outputs of regression models are available in Supplementary files.

Regarding self-reported PA, six out of the seven participants significantly increased their PA levels in comparison to phase A. Furthermore, a significant positive trend during their inclusion was found for four out of seven. The most frequent self-reported PAs were in ascending order: walking, PA, mind-body related activities (Figure S2.1).

Sensitivity analyses suggested that the inclusion of autocorrelation in the Gaussian models did not modify the findings.

Effects of the intervention on the Transtheoretical constructs

The targeted POCs appeared visually to be substantially higher from baseline after the intervention was delivered for all participants with available data (visual analyses in Table 2).

Regarding the non-targeted POCs, various patterns emerged from visual analyses of individual trajectories. Self-efficacy levels had visually nonlinear patterns among three participants.

Results for fitness test and body composition

An increase >5% in comparison to baseline was found in three participants. Four participants increased their muscle mass from 1.8% to 4% at the end of the intervention. Individual findings are presented in Figure S2.2.

Discussion

The purpose of the present study was to test the effect of an individualized TTM-based intervention on PA outcomes. Our study was the first study to develop a POC-personalized strategy in a TTM-based PA intervention by using a set of behavior change techniques. Our first hypothesis was partially validated. Indeed, device-measured PA levels did not significantly increase during B and A2 phases even though two participants had a significant positive trend during the three phases. Otherwise, for self-reported PA, six participants increased their PA throughout the intervention and five participants showed a significant positive trend. Nonetheless, our TTM-based intervention was effective to increase self-reported PA levels in the same way previous studies suggested it (Gourlan et al., 2016; Romain et al., 2018a). In contrast, previous N-of-1 studies reported daily step increase interventions (Valbuena et al., 2015; Zarate et al., 2019) as compared to baseline.

The significant positive trends observed in our participants, in device-measured or self-reported PA outcomes, also suggested that PA change can be more progressive than expected. In other words, a longer intervention time could be associated with higher PA level during Phases B and A2.

Finally, the gap between device- and self-reported PA findings may be explained by the high level of daily variability in accelerometer data (Valbuena et al., 2017). Indeed, current recommended N-of-1 analyses appear not adapted to model highly variable data (Valbuena et al., 2017). Thus, perhaps, more complex statistical approaches should be developed to take account this variability and auto-correlation in subsequent studies (Chevance et al., 2020).

Transtheoretical model's construct patterns

A minimum of targeted 3/5 POCs increased among all participants during our intervention. This finding may confirm our second hypothesis indicating that the level of targeted POC will be higher during the intervention. Therefore, the behavior change techniques used during our intervention modified the targeted POCs and is in line with mechanisms hypothesized by Romain et al. (2018c). Future investigations should explore the mediator effects of targeted POC on intervention effect (Sheeran et al., 2017).

Regarding non-targeted POC, collectively, their patterns were not consistent and no common tendency was observed; therefore, we may reject the hypothesis that non-targeted POCs will remain stable during the intervention. It is possible that delivered behavior change techniques used to target POCs or other TTM constructs also influenced non-targeted POCs. The activation of targeted POCs could be associated with a 'natural' activation of other POCs in a second time period (Romain et al., 2015). For instance, (non)targeted behavioral POCs plasticity may be higher than experiential POCs, which is likely given the interaction between experiential and behavioral POCs has been previously described (Romain et al., 2018c).

Herein, two participants visually increased their self-efficacy (J and L), one increased its positive decisional balance (C), and negative decisional balance remained stable for most participants. These results may partially confirm our fourth hypothesis that both self-efficacy and decisional balance levels would be superior during the intervention. These mixed results may be explained by the number of POCs used as this construct is known to firstly influence self-efficacy and decisional balance (Nigg et al., 2019). Besides, it is possible that the change in POC use was not important enough to increase self-efficacy and decisional balance for some participants.

General discussion

Health psychology intervention are slowly moving towards personalization to optimize its effect. TTM-based interventions have been extensively studied (Romain et al., 2018b), and yet, a structure to

ensure future intervention efficacy emerges (Kwasnicka & Naughton, 2020; Michie et al., 2011; Sheeran et al., 2017). Our study partially answered to three previous pitfalls in behavioral experimental medicine: *a*) the need to identify mechanism of action, manipulation and precise conditions (Sheeran et al., 2017), *b*) the need to personalize PA behavior change interventions, *c*) the need to understand how the intervention affect targeted-constructs. More broadly, our POC-personalized intervention could be tested in more various contexts such as gyms or rehabilitation centers or in different populations.

Limits and Strengths

The present study has some limitations to acknowledge. First, to control the maturation effect, the duration of phase A was randomly set to one or two weeks. However, a measurement reactivity effect (i.e., changes in people's behavior due to being measured as part of a research project, König et al. 2022) associated with self-reported and device PA assessment may have been occurred for some participants. For instance, one participant (C) performed a long hike during the observation phase. Second, the procedural fidelity was not measured though a document including an intervention plan with a detailed step-by-step procedure was put together for counselor to follow. Future research should record data to assess how accurately the plan was applied during research as described with the 17th item of the SCRIBE list (Tate et al., 2017). Third, the weekly assessments of the theoretical constructs did not allow us to perform quantitative analyses (e.g., cross-correlation or randomization test) at an idiographic level (Lanovaz & Turgeon 2020). Fourthly, weekly patterns of POC scores need to be interpreted with caution because they may represent marginal differences. Future studies on the minimal important difference identification to infer change in POC are recommended.

The main strength of this study is its evidence-based intervention development and its replicability. First, we used behavior change techniques associated with the TTM constructs to facilitate the replicability of future TTM-based interventions. Additionally, this study features the importance to take an idiosyncratic approach when addressing PA change, as this approach is considered as the next step to investigate long-term change in PA behavior (Chevance et al., 2020). Finally, the study includes a separate analysis on levels of decisional balance, self-efficacy and POC to understand their influence during the intervention. In other words, identifying the most effective strategies in promoting PA change, whom it works on, and the specific circumstances in which it happened (Sheeran et al., 2017).

Conclusion

This study provides the first evidence of a POC-personalized TTM-based intervention in inactive adults. In other words, this study provides an effective method, unique to each inactive

individual's struggle, to increase PA levels independently with a set of 'easy to apply' advice based on previous literature. This intervention increased PA levels for most participants at a slow but sustainable rate. Similar methodology can be applied to future interventions and PA programs deliver by health professionals.

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Figure 1 Findings for participants with available device measured PA (blue) and self-reported PA data (green)

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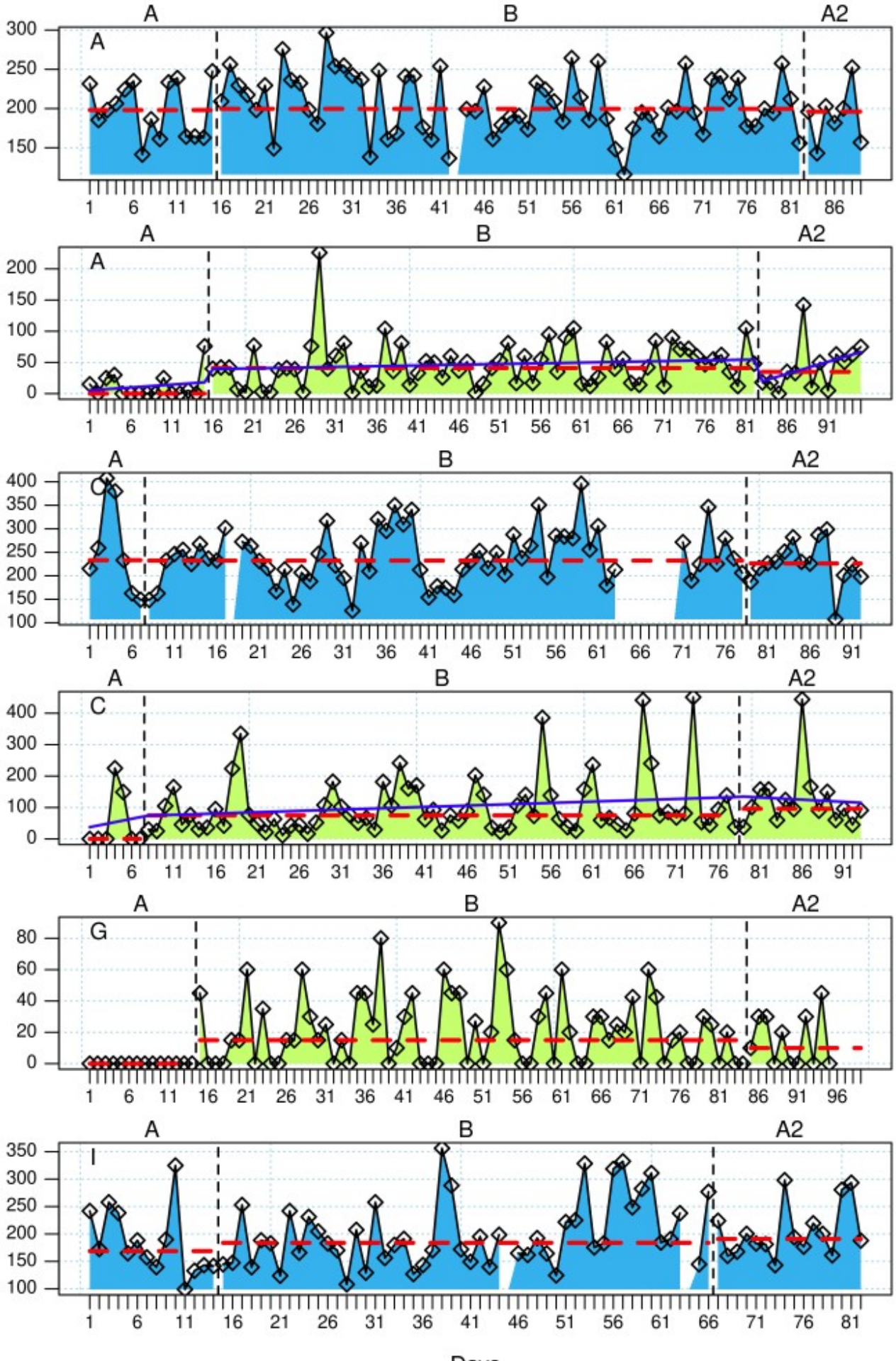
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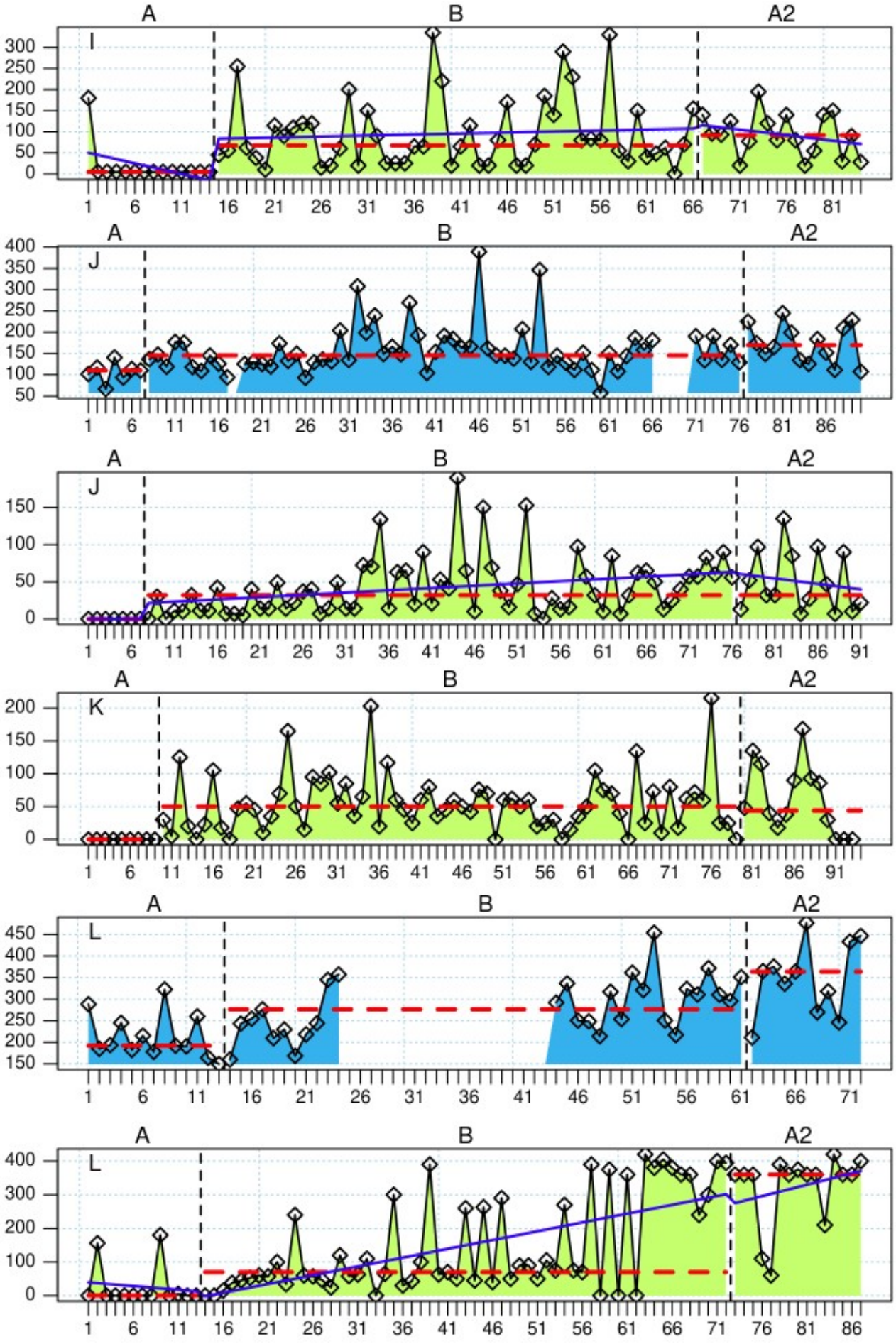
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Note. Vertical axis unit of measurement are daily minutes. Red dash lines represents the median. Blue lines represents the local regression.

Table 1 Characteristics of participants

ID	Sex	Age	Status	Child at home	Level of education	Income ($)	SOC
A	W	52	CLP	0	University	>100k	Prep
B	M	50	Married	3	University	>100k	Prep
C	W	39	Married	2	University	>100k	Prep
D	W	46	Married	0	University	80k and 100k	Prep
E	W	38	CLP	3	University	60k and 80k	Prep
F	W	45	Single	2	High school	40k and 60k	Prep
G	W	27	Single	0	University	<20k	Prep
H	W	25	Single	0	University	<20k	Prep
I	M	47	CLP	3	University	60k and 80k	Prep
J	W	28	Single	0	College	40k and 60k	Prep
K	W	32	Single	0	University	40k and 60k	Prep
L	M	41	Single	0	College	<20k	Prep

Note. GPA = assessing levels of physical activity and fitness environmental questionnaire; SOC = Stage of Change; CLP = Common-Law partner; Prep = Preparation

Table 2 Intervention content based on Transtheoretical constructs and self-efficacy sources

	Name of BCT	TTM's construct	Mode of delivery	Use frequency
1.1	Goal setting (behavior)	POC-B, SeL	Tool + zoom discussion	1/W (1st W + followup)
1.2	Problem solving	SE, Physiological and affective states	Text (participant → counsellor)	1/W (start of W)
1.3	Goal setting (outcome)	POC-B, SeL	Tool + zoom discussion	1/W (start of W)
1.6	Discrepancy between current behavior and goal	POC-B, SeL	Zoom discussion	1/ 2W (mid W)
1.7	Review outcome goal(s)	POC-B, SeL	Zoom discussion	1/ 2W (end of W)
1.8	behavioral contract	POC-B, SeL	Tool + zoom discussion	2/10W
3.1	Social support (unspecified)	POC-B, HR	Homework, discuss next time BCT comes back	1/W (end of W)
3.2	Social support (practical)	POC-B, HR	Homework, discuss next time BCT comes back	1/ 2W (start of W)
4.1	Instruction on how to perform the behavior	POC-E, CR	Tool + zoom discussion	3/ 10W (1/ start of block)
4.2	Information about antecedents	POC-E, CR	Zoom discussion	1/10W
5.1	Informer about health consequences	POC-E, CR	Tool + zoom discussion	3/10W (1/block, 2nd W, mid W)
5.2	Salience of consequences	POC-E, SR	Tool + zoom discussion	1/10 sem (mid intervention)
5.5	Anticipated regret	POC-E, DR	Tool + zoom discussion	1/2W (mid W)
5.6	Information about emotional consequences	POC-E, DR	Zoom delivery + visual message by text	3/10W (start of block, start of W)
6.1	Demonstration of the behavior	POC-E, SL	In person or online or on phone	3/10W (end of block, end of W)
6.2	Social comparison	SE, Vicarious experiences	Zoom discussion	1/10W
6.3	Informagtion about others' approval	POC-E, SL	Homework, discuss next time BCT comes back	2/10 sem (end of 2nd and 3rd block, mid W)
7.1	Prompts/cues	POC-B, SC	Tool + zoom discussion	1/W (mid W)
7.8	Associative learning	POC-B, SC	Tool + zoom discussion	3/ 10W(start of block, end of W)
8.2	Behavior substitution	POC-B, CC	Tool + zoom discussion	3/ 10W (start of block, end of W)
8.3	Habit formation	POC-B, SC	Tool + zoom discussion	1/W (mid W)
8.4	Habit reversal	POC-B, CC	Tool + zoom discussion	1/W (mid W)
8.7	Graded tasks	SE, Mastery experiences	Tool + zoom discussion	1W
9.2	Pros and cons	DB	Tool + zoom discussion	3 / 10W (start of block)
9.3	Comparative imagining of future outcomes	POC-E, SR	Tool + zoom discussion	2/10W (2nd and 3rd block, start of W)
10.3	Non-specific reward	POC-B, RM	Text	1/W (end of W)
10.4	Social reward	POC-B, RM	Text	1/ 2W

10.6	Non-specific incentive	POC-B, RM	Homework, discuss next time BCT comes back	1/W (end of W)
10.8	Incentive (outcome)	POC-B, RM	Homework, discuss next time BCT comes back	1/2weel (start of W)
10.9	Self-reward	POC-B, RM	Zoom discussion	3/10W (start of block, start of W)
10.10	Reward (outcome)	POC-B, RM	Zoom discussion	1/W (end of W)
11.2	Reduce negative emotions	POC-E, DR	Tool + zoom discussion	2/10W (mid 1st and 2nd block, end of W)
12.1	Restructuring the physical environment	POC-E, ER	Homework, discuss next time BCT comes back	5x/10W (1/W 1st block, follow up mid W 2nd and 3rd block)
		POC-B, SC	Homework, discuss next time BCT comes back	5x/10W (1/W 1st block, follow up mid W 2nd and 3rd block)
12.2	Restructuring the social environment	POC-E, ER	Tool + zoom discussion	4x/ 10W (2 2nd and 3rd block)
12.3	Avoidance/reducing exposure to cues for the behavior	POC-B, SC	Tool + zoom discussion	4x/10W (2 block 1 and 2)
12.5	Adding objects to the environment	POC-B, SC	Homework, discuss next time BCT comes back	1/W (start of W)
13.5	Identity associated with changes behavior	POC-B, SeL	Zoom discussion	as soon as practicable
15.1	Verbal persuasion about capability	SE, Verbal persuasion	Text	1/W
15.3	Focus on past success	SE, Mastery experiences	Tool + zoom discussion	1/10W (start of W)

Note. PA = Physical activity; BCT = Behavior Change Technique; TTM = Transtheoritical Model; DB = Decisional Balance; SE = Self-Efficacy; POC = Processus of Change; CR = Consciousness Raising; DR = Dramatic Relief; ER = Environmental Reevaluation; SR = Self-Reevaluation: SL = Social Liberation; CC = Counterconditioning; HR = Helping Relashionships; RM = Reinforcement Management; SeL = Self-Liberation; SC = Stimulus Control.

Table 3 Results from piecewise linear models

ID	Device measured PA									Self-reported PA								
	B>A1			A2>A1			Trend			B>A1			A2>A1			Trend		
	B	SE	*p*	*B*	SE	*p*	*B*	SE	*p*	*B*	SE	*p*	*B*	SE	*p*	*B*	SE	*p*
A	24.07	14.25	0.09	3.02,	24.80	0.35	0.04	0.23	0.08	1.15	0.09	0.001	0.85	0.11	0.001	0.01	0.001	0.001
C	-36.25	27.53	0.19	74.14	41.33	0.07	0.52	0.38	0.38	0.34	0.06	0.001	0.19	0.07	0.01	0.01	0.01	0.001
G	-	-	-	-	-	-	-	-	-	23.76	7.79	0.01	19.11	12.83	0.13	-0.05	0.12	0.67
I	-29.10	24.14	0.23	-72.14	40.78	0.08	1.36	0.52	0.04	1.61	0.07	0.001	1.49	0.09	0.001	0.02	0.03	0.001
K	-	-	-	-	-	-	-	-	-	54.55	18.39	0.01	66.04	27.98	0.05	-	-	-
L	7.07,	30.39	0.64	22.39	47.91	0.81*	1.90,	0.58	0.01*	0.24	0.06	0.001	-0.18	0.08	0.02	0.04	0.001	0.001

Note. * = 19 days of accelerometer measures were missing in phase B

Internal validity of findings = A: Serious knee and shoulder pain in the 2nd week of phase B; C: Diagnosed with Lyme disease during the 2nd week; G: She injured her ankle on the 6th week of phase; I: Some worries about her health and future life expectancy during the 6th week of phase B; K: -, L: He started a new job in a school with children the 9th week of phase B.

Table 4 Visual summary of Transtheoretical constructs patterns

ID	Targeted POCs					# targeted POCs	Non-targeted POCs					SE	DB+	DB-
A	CR	CC	HR	RM	SC	4/5	DR	ER	SR	SL	SeL			
○◊		→								→	→	~	→	~
C	CR	CC	HR	RM	SC	3/5	DR	ER	SR	SL	SeL			
○◊	→			→			→		→	→	→	~		→
I	CR	SL	CC	HR	SC	3/5	DR	ER	SR	RM	SeL			
●○◊		→	→					→		~	~	~		~
J	CR	SR	SL	RM	SC	5/5	DR	ER	CC	HR	SeL			
○								→					→	→
L	CR	DR	SL	HR	SC	4/5	ER	SR	CC	RM	SeL			
●○◊			→				→	→	~				~	→

Note. ⇑ = Large increase; ↑ = Increase; → = No variation; ↓ = Decrease; ⇓ = Large decrease; ~ = Non-linear variation; ● = Significant trend increase in device measured PA; ○ = Significant trend increase in self-reported PA; ◊ = Self-reported PA is superior during phase B and A2 in comparison with phase A; CR = Consciousness Raising; DR = Dramatic Relief; ER = Environmental Reevaluation; SR = Relf-Reevaluation; SL = Social Liberation; CC = Counterconditioning; HR = Helping Relationships; RM = Reinforcement Management; SeL = Self-Liberation; SC = Stimulus Control