Is there something beyond stages of changes in the transtheoretical model? A state of art for physical activity

Ahmed-Jérôme Romain*[a], Johan Caudroit[d], Marie Hokayem[e], Paquito Bernard[b,c]

[a] Centre de Recherche du CHU de Montréal (CRCHUM), Montréal, Canada

[b] University Institute of Mental Health at Montreal, Montréal, Quebec, Canada

[c] Université du Québec à Montréal, Montréal, Quebec , Canada

[d] Laboratoire sur la Vulnérabilité et L'innovation dans le Sport, University of Lyon 1, Lyon, France

[e]Lebanese University

*Corresponding author: Ahmed Jérôme Romain

Centre de Recherche du CHU de Montréal (CRCHUM), Montréal, Canada

e-mail: aj.romain@gmail.com

Is there something beyond stages of change in the transtheoretical model? The state of art for physical activity

Abstract

Over the past 30 years there has been a growing interest in the application of the transtheoretical model (TTM) in the domain of physical activity (PA). Even though this model has been widely used to implement PA interventions, most of these interventions did not use all the TTM's theoretical constructs. Indeed, several studies focused exclusively on the stages of change while this construct is only descriptive. So, in the present review, we wanted to encourage researchers to go beyond stages of change when they use the TTM. To do so, we aimed to provide an overview of the TTM and its constructs while also presenting on one hand longitudinal studies examining the association between PA and TTM constructs and on the other hand summarising the efficacy of TTM-based interventions as to present future TTM challenges.

Keywords: physical activity; transtheoretical model; stages of change; processes of change; mediators of change

1. Theoretical models, such as the Transtheoretical model, can be used to drive physical activity interventions if accurately implemented

2. The Transtheoretical model has key regulatory components that are the processes of change, self-efficacy, decisional balance and temptation

3. The key regulatory components of the Transtheoretical model can be used to individualize counselling to physical activity

4. Stages of change are a construct, not a theory, and therefore should not be used to tailor physical activity interventions

Is there something beyond stages of changes in the transtheoretical model? The state of art for physical activity

Introduction

As recently evidenced, the world actually faces an increasing prevalence of physical inactivity (Andersen, Mota, & Di Pietro, 2016) which partly explains the ever rising worldwide prevalence of major non-communicable diseases (Sallis et al., 2016). This physical inactivity epidemic constitutes an economic burden to the international healthcare systems of up to 53.8 billion dollars US in 2013 (Ding et al., 2016). So, there is a pressing urgency to promote physical activity (PA) by implementing interventions that take into account the reasons favoring its adoption.

In this context, theory-based interventions constitute an interesting option, not only because they are assumed to be better than non-theoretical interventions, but due to the fact they provide a framework that makes interventions easier to replicate and disseminate in real-life settings. A recent meta-analysis of randomized controlled trials (RCT) concluded that theory-based interventions in PA promotion effectively increase PA and that none of the psychological theories included were found to be superior in PA promotion (Gourlan et al., 2016). This meta-analysis of 31 interventions (over the 82 included) using the transtheoretical model (TTM) also highlighted that this model is among the most used theories to promote PA (Prochaska & DiClemente, 1983). The TTM conceptualizes the process of intentional behavior change by assuming that: a) a single theory cannot account for the complexity of human behavior change; b) behavior change is a process that unfolds over time through several stages; c) these stages are stable and open to change; d) specific processes should be used at specific stages to facilitate the efficacy of behavior change (Prochaska, Redding, & Evers, 2008). It is interesting to note that the TTM speculates a nonlinear transition between the stages of change (SOC) with patterns of discontinuity (Lippke & Plotnikoff, 2006).

Even though the TTM is widely used, it remains poorly implemented in interventions seeking to improve PA behavior (Romain, Bortolon, et al., 2016) and this can be explained by the fact that many researchers are probably unaware of all the TTM's constructs. In view of these observations, it was therefore necessary to explain how to use the TTM and its underlying mediators in research and intervention contexts. The objectives of the present narrative review were to: a) briefly provide an overview of the TTM and the mediators of change on which it is based; b) discuss studies

examining longitudinal associations between PA change and TTM mediators; c) outline TTM-validated questionnaires; d) examine the efficacy of TTM-based interventions for PA promotion; e) debate future TTM challenges.

The transtheoretical model and its mediators

TTM identifies change as a progressive process through a series of five different SOC over time (Prochaska & DiClemente, 1983). Although the SOC are the most popular part of the TTM, notably due to their ease of use and scoring, they also constitute its most descriptive construct. The five SOC are: precontemplation [not ready] (not intending to change in the next 6 months), contemplation [getting ready] (intention to change within the next 6 months), preparation [ready] (intention to change within 30 days), action (new behavior is initiated within the last 6 months), and maintenance (behavior is sustained for more than 6 months). Thus while going through the SOC an individual starts by intending to adopt the behavior criteria in the early pre-action SOC (precontemplation, contemplation, and preparation) to later adopt and maintain this newly acquired behavior throughout the action and maintenance stages (Prochaska & Velicer, 1997). If SOC represent the most descriptive part of the TTM, it is mainly because they explain "where" people are in terms of motivation but not "how" to motivate them or "why" they move across stages. Indeed, according to the TTM, the transition between the different SOC is influenced by its mediators of change (its theoretical constructs) that include decisional balance, temptation, self-efficacy, and processes of change (POC) (Prochaska, DiClemente, & Norcross, 1992).

Decisional balance is defined as the perception of advantages (Pros) and/or disadvantages (Cons) related to the decision of undertaking or not a behavior (Prochaska et al., 1994). Temptation is the urge to engage in a specific behavior in the midst of difficult barriers (Hausenblas et al., 2001). Self-efficacy, a component of the social cognitive theory (Bandura, 1977), is defined as a person's judgment of his/her capabilities to organize and execute courses of action required to attain designated types of performance (Bandura, 1997). Finally, there are the POC that help clarify how behavior changes take place; while SOC help pinpoint when those modifications occur. POC are comprised of a total of five experiential processes and five behavioral processes that need to be executed to ensure a certain progress through the SOC and achieve the desired behavior change. Experiential processes are defined as processes in which individuals obtain information based on their own experiences while behavioral processes regroup strategies used to

modify the environment to help change the behavior (Burkholder & Nigg, 2001; Romain, Chevance, Caudroit, & Bernard, 2016) (see Table 1 for a definition of POC). In the TTM, the relationship between its mediators and the SOC has been tested extensively (Burkholder & Nigg, 2001; Marshall & Biddle, 2001) and was found to be consistent throughout different types of behavior (e.g., smoking, diet). However, contrary to the initiation assumption formulated in tobacco cessation, the POC by SOC sequence was found to be different. Indeed, in smoking cessation, experiential and behavioral POC act sequentially with experiential POC used in the early stages and behavioral POC in the later stages (action and maintenance). Inversely, in PA, this sequential order was not found with experiential and behavioral POC acting in tandem, with the use of both increasing across stages (Marshall & Biddle, 2001; Rosen, 2000) (see figure 1 for an illustration). This crucial point will be further discussed subsequently.

In the TTM, mediators explain "why" people modify their behavior. In order to better understand how changes occur, it is essential to focus on longitudinal, interventional or observational studies (Rhodes & Quinlan, 2015), rather than cross-sectional research designs.

What do longitudinal observational studies using TTM mediators tell us about the transition between SOC of physical activity?

Observational studies provide a primary insight to understand the complex associations between SOC and the mediators of the TTM. For this purpose, in this section, only observational studies having investigated the role of these mediators in the transition between SOC were included.

Plotnikoff, Hotz, Birkett, and Courneya (2001) assessed whether self-efficacy, decisional balance and POC predict the transition between exercise SOC within a 12-month period among 1602 adults. Results showed that self-efficacy, decisional balance and, both experiential and behavioral POC, were predictors of the transition between SOC. To be more precise, the transition out of precontemplation and contemplation stages was predicted by higher levels of self-efficacy, perception of advantages (Pros), and behavioral POC. Also, the transition out of the preparation stage was predicted by higher levels of self-efficacy and Pros. Moreover, retention in post-action stages was predicted by higher levels of Pros versus lower Cons, and by the activation of both, experiential and behavioral POC. So, Plotnikoff et al.'s (2001) study partially supports the validation of TTM in exercise.

A similar study testing the TTM's capacity for predicting PA transitions was performed among 1674 adults with type 1 or type 2 diabetes over 6 months (Plotnikoff, Lippke, Johnson, & Courneya, 2010). Findings provided moderate support for the TTM constructs in predicting PA stage transitions, with very few differences between type 1 and 2 diabetic groups. Indeed, the transition from precontemplation to contemplation was predicted by the Pros and the experiential POC. The transition out of preparation was only predicted by higher self-efficacy. Transition out of the action stage was predicted by the Pros and the behavioral POC while remaining in the maintenance stage was predicted by higher levels of self-efficacy, Pros, experiential and behavioral POC. Analogous results were found in a prospective investigation where TTM showed significant potential for motivating women with multiple sclerosis to increase their PA over a period of 12 months (Levy, Li, Cardinal, & Maddalozzo, 2009).

In addition, Dishman, Vandenberg, Motl, and Nigg (2010) assessed TTM constructs relating to the 2010 guidelines for regular moderate or vigorous PA, at 6-month intervals three or more times over 24-months among a cohort of 497 multi-ethnic participants. The results provided great support to core TTM constructs by showing that people meeting, or partially meeting, PA guidelines had a decrease in temptation, an increase in self-efficacy with also a higher use of both, experiential and behavioral POC. Only decisional balance was not associated with PA guidelines. Nevertheless, the absence of results regarding decisional balance is not supported by one of the first longitudinal papers on TTM showing that Pros, Cons, self-efficacy but not POC were associated with leisure exercise three years after initial assessment in adolescents (Nigg, 2001).

The aforementioned studies provide important information to consider such as the fact that all TTM constructs were predictors of the transition between the different SOC but to different extents.

So, regarding PA, to progress through SOC, people need to find more reasons to exercise (the Pros) than not to (the Cons), feel more confident (self-efficacy) by increasing the use of both experiential and behavioral strategies (POC). These arguments are corroborated by findings from a previous meta-analysis of cross-sectional studies on TTM applications to PA (Marshall & Biddle, 2001).

The pre-cited research supports the use of TTM interventions in the context of PA by demonstrating that all TTM constructs are necessary to adopt or sustain a physically active lifestyle. However, it should be noted that these

observations were drawn from observational studies so to confirm them it is necessary to analyze results from interventional studies.

Do intervention studies tell the same story as observational research?

One of the interesting aspects of the TTM is that it enables researchers to create interventions that target specific constructs while ensuring a higher internal validity in the analysis of change over time (Rhodes & Quinlan, 2015). In other words, TTM findings inform the design of individualized stage matched expert system interventions that target variables most predictive of progress at each SOC (Marcus, Nigg, Riebe, & Forsyth, 2000; Redding et al., 1999). Such tailored interventions can reach subjects at all stages of readiness, providing positive feedback on constructs showing sufficient effort and corrective feedback as well as those reflecting that more effort is needed and displaying significant changes over time.

Intervention studies and progression through stages of change in the context of physical activity

Several interventional studies support TTM constructs. For example, Lowther, Mutrie, and Scott, (2007) performed a 12-month study among 312 healthy subjects separated into two PA groups (exercise consultation or fitness assessment) and found that behavioral POC were important to progress from contemplation to preparation, as well as to predict the regression from the maintenance stage of PA. Moreover, and similarly to observational studies, both experiential and behavioral POC predicted the transition from pre-action to post-action stages. Nevertheless, it should be noted that the other TTM constructs were not included.

Among 62 adults with obesity, Romain et al. (2014) performed a one-week multidisciplinary intervention where participants were contacted after one year. Their results showed that both experiential and behavioral POC were associated with the transition between SOC. Individuals becoming active increased their use of POC. Nevertheless, findings were limited by the fact that only POC were considered.

Interventional studies and physical activity level

In one of the first TTM-based studies, Marcus et al. (1998) realized a 3-month motivationally tailored intervention. Their results underlined that individuals having progressed through SOC after the intervention increased their PA from 39 to 115 minutes per week. However, their conclusion was limited by the absence of data on the other TTM

constructs. So, it is necessary to consider studies including these constructs in order to better understand how they regulate the efficacy of the intervention. Gallagher, Jakicic, Napolitano, and Marcus (2006) performed a 6-month behavioral weight loss intervention based on social cognitive theory among 165 overweight women. Except for the temptation construct, all other TTM components were included and the intervention significantly modified self-efficacy, experiential and behavioral POC. However, when the amount of PA performed/executed was examined (150-199 min/week; 200-299 min/week; > 300 min/week), results showed that the more women engaged in PA, the more they had advanced levels of self-efficacy and higher use of behavioral POC.

Regarding PA participation expressed in terms of PA guidelines (self-reported), a similar study was carried out over a 24-month period, with assessment each 6-months, among 144 overweight adults (Riebe et al., 2005). The results indicated that people maintaining PA recommendations had higher self-efficacy, lower cons and also higher use of experiential and behavioral POC compared to the group that never met the PA recommendations.

In a well-designed TTM-based intervention in the form of consultation sessions among 70 inactive overweight adults with type 2 diabetes, Kirk et al. (Kirk, Mutrie, MacIntyre, & Fisher, 2004; Kirk, Mutrie, MacIntyre, & Fisher, 2003) obtained a 28% increase in the self-reported PA among the intervention group compared to a 12% decrease of PA in the control group. Moreover, this PA increase was associated with a higher use of both experiential and behavioral POC in the intervention group (Kirk et al., 2004).

So, intervention studies significantly support the use of the TTM in the domain of PA while also validating observational studies' findings. Indeed, as opposed to TTM assumption applied to smoking cessation, it seems that people need to use all constructs to become active. This is particularly true when analyzing the role of POC seeing that participants used both experiential and behavioral POC to adopt or maintain PA, even over long periods of time (Riebe et al., 2005).

Can TTM mediators really mediate physical activity behavior?

To better understand the efficacy and mechanisms of PA interventions, the analysis of TTM mediators is key (Rhodes & Pfaeffli, 2010) though few studies have addressed this issue. Consequently, there are still elements of the TTM that

are poorly understood particularly regarding PA. Nevertheless, some studies provide some insight on this missing piece of information.

Lewis et al. (2006) examined whether all TTM variables (except temptations) could be mediators of PA behavior after a stage-matched intervention. They underlined that only self-efficacy and behavioral POC partially satisfied criteria of mediation. The failure to satisfy a complete mediation could be explained by the fact that their study was underpowered (N = 110). However, Lewis et al.'s study (2006) provided interesting preliminary support on mediating variables of PA.

So far, Napolitano et al. (2008) performed a similar 6-month intervention study on 239 inactive adults, revealing that only experiential and behavioral POC were mediators of the relationship between the intervention and the PA level. Nevertheless, in this context, although experiential POCs were considered as mediators, they were significantly associated with lower PA levels. Also, and from a public health perspective, after controlling for several variables, it was reported that per one standard unit increase in behavioral POC, PA duration was enhanced by 84 minutes compared to the control group. When mediation was examined at 12 months (Papandonatos et al., 2012), all TTM variables were shown to be significant mediators of the relationship between the TTM intervention and PA level, even though, when a measure of exercise-induced feelings was introduced among mediators, only behavioral POC remained significant.

Moreover, in a physician-based intervention using the TTM framework, Pinto, Lynn, Marcus, DePue, and Goldstein (2001) found that the decisional balance index (e.g., Cons minus Pros score), and behavioral POC significantly mediate the relationship between the intervention effect and the self-reported PA level after 6 weeks in older adults. Experiential POC tended to have a statistically significant impact though self-efficacy was not significant. However, at 8-month, none of the TTM variables were found to be significant mediators of PA behavior (Hutchison, Breckon, & Johnston, 2009). Then, Baruth et al. (2010) showed after 24 months that behavioral POC were the only mediators of the relationship between the TTM intervention and PA/cardiorespiratory fitness relationship in sedentary adults. So, these two studies support the use of TTM, and more particularly behavioral POC in PA behavior modulation.

Consequently, while the TTM provides information about its mediators, few studies have really addressed this relevant issue (Rhodes & Pfaeffli, 2010). While some research failed to show any mediation effects, most studies showed that

TTM mediators significantly modify PA level even though the sample size was too small to provide any robust conclusion, but (Fahrenwald, Atwood, Walker, Johnson, & Berg, 2004; Rabin, Pinto, & Frierson, 2006).

Among the most prominent TTM mediators, self-efficacy and behavioral POC were found to be of great importance in PA interventions even though further explanations are necessary to understand the extent of their impact. The consistent association between these variables/mediators may be explained by the fact that they are often well correlated. Nevertheless, other assumption can be drawn from their significant relation. Loprinzi and Cardinal (2011) performed a study on the supposition that behavioral POC and self-efficacy are important in PA behavior change and that the literature does not really provide any clear explanation. So, among breast cancer patients, they examined the mediation link between PA, behavioral POC and self-efficacy and highlighted that behavioral POC were related to PA and that this relationship was mediated by self-efficacy. This result was also confirmed by the *Training Interventions and Genetics of Exercise Response* study, in which, self-efficacy, experiential and behavioral POC were correlated to PA at the baseline period of their trial, with only behavioral POC mediating the relationship between self-efficacy and adherence to exercise (defined as the number of exercise sessions attended compared to the possible number of exercise sessions offered) (Dishman, Jackson, & Bray, 2014).

Consequently, even though these findings solidify further our understanding of the TTM when relating to PA change, they do not negate the role of experiential POC that can trigger the intention to exercise in different populations (Nigg, 2005).

Initial TTM instruments development for physical activity behaviour change

In the TTM, one of the undeniable limitations is that most assessment tools are presented in English which restricts their use to English-speaking countries also not all studies used validated questionnaires in their surveys. So, to overcome this issue, we present in the following paragraph a systematic overview of the different worldwide validations that exist.

TTM research in the context of PA has been initiated by Marcus and colleagues (1992), who have published three validation studies for assessing the four key TTM constructs with cross-sectional designs across work-site

samples in Rhode Island. Except for the temptation scale, these questionnaires have been extensively used, examined and adapted.

As recommended by Reed, Velicer, Prochaska, Rossi, and Marcus (1997), the SOC measure was developed as an algorithm to categorize individuals in 1 of 5 SOC. This scale consists of one item with five statements representing each a stage going from the "Precontemplation" to the "Maintenance" stage. So, a reliable SOC algorithm has to include a clear definition of PA, its frequency and duration. PA defined as 30 minutes session, at least 4 times per week is generally recommended (Nigg et al., 2005; Romain et al., 2012) and the validity of this SOC algorithm has been shown with self-reported PA and anthropometrical measures in adults (Hellsten et al., 2008; Nigg et al., 2005).

Regarding POC, Marcus et al. (1992) have adapted the initial scale, developed for smoking cessation by Prochaska, Velicer, DiClemente, and Fava (1988), for the context of PA. The scale contained 39 items measuring both experiential and behavioral POC (α = .62 to .88). Later, Nigg, Norman, Rossi, and Benisovich (1999) created a new and shorter measure of POC, which contains 30 items measuring the ten POC for PA (α = .62 to .85).

Regarding self-efficacy, Marcus, Rossi, et al. (1992) have validated a 5-items measure scale assessing self-efficacy for PA (α = .82). In addition, Benisovich, Rossi, Norman, and Nigg (1998) developed the multidimensional self-efficacy questionnaire, which comprises of 18 items measuring the individual's confidence in his ability to overcome PA related barriers (e.g., excuse making, bad weather) (α = .77 to .85).

Finally, Marcus, Rakowski, and Rossi (1992) have validated a 16-item decisional balance scale for PA with 10 items for the perceived benefits of PA (Pros; α = .95) and 6 items for the perceived costs (Cons; α = .79). Plotnikoff, Blanchard, Hotz, and Rhodes (2001) updated this scale by using 10 items (5 Pros; α = .79; 5 Cons ; α =.71) for PA.

The temptation measure was validated by Hausenblas et al. (2001). In their initial development and validation, two factors were reported: affect (5 items; α = .81) and competing demands (5 items; α = .86). Another 7-item version showed a similar structure (Geller, Nigg, Motl, Horwath, & Dishman, 2012).

Regarding the validation of TTM scales in PA, several studies have investigated the validity, adaptation, translation and application of TTM constructs in different populations and languages (see Table 2 for summary and supplementary file 1 for the complete Table)

TTM questionnaires available in eleven different languages

Among studies presented in the Table 2, several researchers have used the original TTM questionnaires validated in English (Blaney et al., 2012; Carnegie et al., 2002; Dishman, Jackson, & Bray, 2010; Geller et al., 2012; Kearney, De Graaf, Damkjaer, & Engstrom, 1999; Maddison & Prapavessis, 2006; Norman, Velicer, Fava, & Prochaska, 1998; Pickering & Plotnikoff, 2009; Rhodes, Berry, Naylor, & Wharf Higgins, 2004; Sallis et al., 1988;

Skaal, 2013; Skaal & Pengpid, 2012; Vita & Owen, 1995). TTM scales were then translated into eleven different languages (see Table 2). Psychometric studies have validated TTM constructs from English to French (Bernard et al., 2014; Eeckhout, Francaux, Heeren, & Philippot, 2013; Eeckhout, Francaux, & Philippot, 2012; Eeckhout, Francaux, & Philippot, 2012; Romain, Bernard, Hokayem, Gernigon, & Avignon, 2016), Finnish (Cardinal, Tuominen, & Rintala, 2003, p. 200), Dutch (Ronda, Van Assema, & Brug, 2001), German (Bucksch, Finne, & Kolip, 2008; Fuchs & Schwarzer, 1994; Kanning, 2010; Tergerson & King, 2002), Greek (Korologou, Barkoukis, Lazuras, & Tsorbatzoudis, 2015) (Bebetos et al., 2012), Persian (Farmanbar, Niknami, Lubans, & Hidarnia, 2012; Sanaeinasab, Saffari, Nazeri, Karimi Zarchi, & Cardinal, 2013), Korean (Y. Kim, Cardinal, & Lee, 2006; Y.-H. Kim, 2007), Chinese (Tung, Gillett, & Pattillo, 2005; Yang & Chen, 2005) (Si et al., 2011;), Malaysian (Phing, 2014), Japanese (Horiuchi, Tsuda, Kobayashi, Fallon, & Sakano, 2016, Oka, 2000, 2003), Taiwanese (Sechrist, Walker, & Pender, 1987) and Spanish (Gonzalez et al., 2000). No psychometric investigation has, to our knowledge, interpreted/adapted the temptation scale in other languages.

Investigating invariance of TTM questionnaires

The different types of invariance (configural, metric, and scalar) of TTM questionnaires (Table 2) have been investigated across various time sets and subgroup characteristics with results showing that TTM constructs were invariant according to sex, student status, ethnicity, age, body mass index, employment, PA level, protocol adherence, level of education and diabetes type (Bernard et al., 2014; Dishman, Jackson, et al., 2010; Geller et al., 2012; Paxton et al., 2008; Pickering & Plotnikoff, 2009). These analyses were performed with English and French versions of TTM questionnaires (Bernard et al., 2014; Geller et al., 2012).

Moreover, the longitudinal invariance of TTM constructs has also been provided across 3- and 6-month periods with studies showing that any temporal differences or modifications identified can be interpreted as changes due to time or intervention mistakes but not measurement errors (Dishman, Jackson, et al., 2010; Geller et al., 2012).

Are TTM-based interventions effective in promoting PA?

Over the last decade, interventional researchers in health psychology and behavioral medicine have gradually integrated the specific methodological requirements of evidence-based medicine (Keefe & Blumenthal, 2004). In this methodological paradigm, the RCT design is recognised as the highest level of investigative methodology to establish the efficacy or effectiveness of health behavior change interventions (Davidson et al., 2003). In this context, several critics, have questioned the worth of TTM interventions in promoting PA arguing that SOC may not be applied to PA

change due to the complexity of this behavior, the lack of validated staging algorithms and the possibility that the most reliable determinants of PA change are not included in the TTM (Adams & White, 2005; Armitage, 2009; Brug, 2004). However, two systematic reviews only including RCTs, examined the efficacy of TTM interventions on PA promotion with findings indicating that TTM-based interventions induce a small-to-medium effect size for PA behavior change. The most recent review (Romain et al., 2016) included 33 RCTs, with 4950 and 5400 participants in the interventional and control groups, respectively. Fourteen studies included exclusively adults with chronic illness (e.g., multiple sclerosis). The length of intervention ranged from 2 to 100 weeks and PA level was an inclusion criterion, but not stage progression. Also, all constructs related to PA were self-reported. This review obtained an overall effect size of $d = 0.33$ (95% confidence interval (CI) [0.22, 0.43]) for PA behavior change which was consistent with Gourlan et al. (2016) [($d = 0.31$ (95% CI [0.20, 0.42])]. These effect sizes need to be interpreted in the context of public health (Prentice & Miller, 1992) seeing that even a slight PA increase may lead to a major health impact (Khan et al., 2012).

Evidence-based rather than evidence-inspired TTM-interventions to change physical activity behavior

In line with previous recommendations (Michie & Johnston, 2012), a thorough analysis of theoretical moderators of TTM-based interventions has been performed in the present narrative review. Romain et al. (2016) observed that TTM-based interventions implementing at least three constructs (e.g., self-efficacy, decisional balance, POC) obtained a three times larger effect size ($d = 0.49$ (95% CI [0.29, 0.69]) versus applying 2 constructs or less ($d = 0.16$ (95% CI [0.06, 0.25]) regarding PA promotion. Moreover, bivariate meta-regressions showed that self-efficacy and POC were the most active and effective components to modulate PA levels while SOC were not. Hence, TTM-based interventions significantly improved PA whether they were stage-matched or non–stage matched (22/33 RCTs), and whether participants were selected by stage or not selected by stage (13/33 RCTs) during the inclusion phase. This empirical finding was in line with experimental weaknesses mentioned in previous TTM published critics (Adams, 2003; Armitage, 2009; Rhodes & Nigg, 2011). For instance, Adams and White (2005) argued that although stage-matched intervention may induce stage progression, it is not always followed by actual behavior change.

Nonetheless, although well designed TTM studies had larger effect sizes, it is also known that other moderators can affect the efficacy of theory-based interventions. Therefore, the efficacy of TTM-based interventions could be

overestimated due to methodological weaknesses. Indeed, factors such as the number of experimental patients, methodological quality score, and intervention duration (> 14 weeks) were found to decrease the overall effect size of theory based-interventions on PA behavior (Bernard et al., 2016). Even though this investigation did not focus exclusively on TTM-based interventions, these results could be also applied to TTM-based interventions.

Evidence based conclusions

Two meta-analyses including more than 30 RCTs conclude that TTM-based interventions are effective in promoting PA change in adults. Also, interventions tailored with all TTM constructs and lasting less than 14-weeks are more effective in altering PA behavior. So, although the TTM has some weaknesses that should be acknowledged (e.g., classification of individuals into 5 distinct stages, lack of temporal sequence examination, social context not considered) (Armitage, 2009), TTM-based interventions increase PA levels in inactive adults with or without chronic disease when implemented beyond stages (Armitage & Arden, 2010; Romain, Bortolon, et al., 2016) and when interventions are TTM-driven rather than TTM-inspired (Romain, Bortolon, et al., 2016).

Future research initiatives for TTM research in the context of physical activity

A refined physical-activity-specific Transtheoretical Model

From the first psychometric studies to the more recent prospective cohort studies (Plotnikoff, Hotz, et al., 2001; Plotnikoff et al., 2010) and meta-analyses (Gourlan et al., 2016; Marshall & Biddle, 2001; Romain, Bortolon, et al., 2016), a massive dataset exists concerning TTM interventions in PA. Interestingly, researchers observed that several TTM assumptions specific to smoking cessation were inapplicable to PA research (Romain, Horwath, & Bernard, 2016), and that consequently there is a need to refine TTM application to the context of PA (Rhodes & Nigg, 2011). Indeed, as proposed by Noar and Head (2014), both general and behavioral-specific versions of a theory's application could co-exist. Recent work suggests that a PA-specific TTM should be proposed with new assumptions. Therefore, two seminal assumptions of the TTM should be modified when applied to PA behavior: a) the relative importance of SOC should be revised in favor of POC and self-efficacy; these two constructs should be prioritized as targets to explain or modify PA behavior. b) The predominant role of experiential POC during pre-contemplation,

contemplation and preparation SOC should be replaced by a tandem use of both, experiential and behavioral POC which has been supported by cross-sectional (Bernard et al., 2014; Hwang & Kim, 2011; Marcus, Rossi, et al., 1992; Nigg & Courneya, 1998) and longitudinal (Dishman, Vandenberg, Motl, & Nigg, 2010b; Kirk et al., 2004; Lipschitz et al., 2015; Plotnikoff, Hotz, et al., 2001) studies. These studies consistently found that in the later SOC (action and maintenance), experiential and behavioral processes were more triggered, while the contrary was also found in the earlier precontemplation stage (people tended to use less both types of POC). To illustrate this argument, Plotnikoff et al. (2001) showed that the transition out of the precontemplation stage (a pre-action stage) was predicted by behavioral processes and not by experiential processes (contrary to the original TTM assumption). The same pattern was found for the transition out of the contemplation stage (another pre-action stage). These findings are key because they highlight how TTM assumptions should be modified according to a PA context.

Future research questions on TTM use for physical activity behavior change

a) Is there an interaction hypothesis?

Among the emerging hypotheses in PA research, there is the interaction hypothesis based on the fact that during interventions, experiential and behavioral POC are used in tandem rather than sequentially (Marshall & Biddle, 2001; Rosen, 2000) and that this conjoint use could be explained by an interaction between them. This interaction hypothesis was tested in only one study demonstrating that the interaction between experiential and behavioral POC predicted moderate PA among adults (Romain, Horwath, et al., 2016). Although of interest, with only one study examining this hypothesis, it is difficult to draw any final conclusion. A prospective investigation of POC and PA with monthly repeated measures analyzed with latent-growth modeling with parallel change processes would be an interesting future study to test the interaction hypothesis.

b) Should research target the quality/type or the quantity/number of POCs?

The present review suggests that by using both experiential and behavioral POC, individuals can initiate or sustain their PA behavior change. Considering the latter, we wonder if interventions should promote a specific type of POC (e.g., an online intervention targeting only POC with lower scores), or aim at activating a higher number of POC (e.g., intervention targeting all 10 POC). For example, Romain, Bernard, Galvez, and Caudroit (2015) showed that,

after a 3-month intervention, people with type 2 diabetes that decreased their self-reported PA level were those that used fewer POCs but also reduced their use of behavioral POC. So, this study suggests that the number and the type of POC are involved in modifying PA behavior. Nevertheless, more investigations are needed to provide a sound answer to this question

c) Can some POCs have a suppressor effect on PA?

Two longitudinal studies found a negative association between specific POC and PA level demonstrating the suppressor effect of certain POC. Indeed, Napolitano et al. (2008) found that experiential POC suppressed PA, while in the Pinto and Dunsiger's (2014) study, an increase in social support was found to decrease PA. Even though this suppressor effect could be explained by some methodological considerations, all inhibitory impacts should be examined to avoid the POCs that may negate PA progress. As an example of a possible negative effect, it has been shown that improvement in weight was negatively associated with experiential POC (Napolitano & Hayes, 2011). Further research is needed to determine an optimal implementation strategy for POCs using an idiographic approach. For instance, N-of 1 RCT studies focusing on POC implementation could provide clear evidence based results for questions “b” and “c” (Craig et al., 2008).

d) Can POCs modify environmental perception?

Health behavior change experts underlined that environmental characteristics (e.g., social, physical, organizational) are either barriers or facilitators of PA/ an active lifestyle (Glanz & Bishop, 2010). Contrarily to other theoretical models that only conceptualize the environment as a determinant of PA, the TTM framework helps individuals modify their own environment to initiate or maintain PA. In fact, targeting three specific POC (stimulus control, helping relationships and environmental reevaluation) could facilitate a favorable environment for PA (Romain et al., 2014).

e) Can the construct of temptation account for PA change?

Temptation is the least examined TTM construct, while this construct was found to have interest in other behaviors such as fat reduction, or smoking cessation (Plummer et al., 2001; Yusufov et al., 2016), there is no clear evidence of its role in TTM-based PA interventions. Future ecological momentary assessment studies could be useful in

exploring modifications of environmental perceptions in participants soliciting these POC (Dunton, 2016). This method may also help to determine whether a consistent association exists between temptation and PA behavioral changes.

TTM participating in the cumulative science of behavior change

Concerning PA behavior change, continued efforts are needed to systematically develop "all constructs" of TTM-based interventions in order to ensure a greater level of accuracy and efficacy in predicting PA transitions

Providing details on behavior change techniques ("active ingredients") related to TTM-based interventions focusing on PA could improve their understanding, replication and implementation. Thus scientist/interventionists should cite with precision all behavior change techniques used in their interventions to facilitate research protocols and ensure comparability. Interestingly, a behavior change technique taxonomy has been created to facilitate the reporting of behavior change interventions (Michie et al., 2013). For instance, no information about behavior change techniques were available in the most recent TTM-based interventions included in Romain et al.'s (in press) review.

Efforts are needed to identify techniques better suited in adapting TTM key determinants including POC and self-efficacy regarding PA behavior change. As such, experimental studies should be designed to determine optimal intervention technique(s)/timing while also testing theoretical mechanisms inducing beneficial change in PA behavior (Peters, de Bruin, & Crutzen, 2015). Innovative study designs have been proposed for this purpose with N-of-1 RCT methodology offering a very good research basis for this purpose.

Conclusion

To date, even though there is no such thing as an ideal theory based on an exemplary framework capable of modifying PA behavior, the TTM has revealed itself to be one of the most effective theoretical models in that context (Gourlan et al., 2016). Also, while the TTM is progressively entering the cumulative science of behavioral change, it is important to point out that the major weaknesses of its implementation are insufficient intervention content reporting and SOC overuse in interventions. As adequately written by Bridle et al. (2005), "the stage of change construct is a variable, not a theory, and it is unclear why some researchers would assume that a variable could facilitate consistent intervention effect" (p. 297).

So, other than to test new hypotheses or applications, cross-sectional investigations on PA behavior should be ceased while multi-site longitudinal investigations with repeated measures analyzing the dynamic of behavior change, and identifying associations between PA and TTM constructs must be continued. In 2011, Rhodes and Nigg wrote: "Despite more than 100 studies using the TTM to understand PA, few advances that are PA specific have been documented since the original adaptation of the model from smoking behavior" (p. 116). We are now in 2017, and even though there have been some changes regarding TTM's use in the field of PA, few advances have been truly made

Concerning SOC we should reiterate that a) SOC are not the TTM, b) SOC are organizational but not explanatory constructs, c) SOC are neither a model nor a theory as they are often referred to as.

So, as an answer to our title, we can say that yes, there are key PA regulatory elements beyond TTM stages which are decisional balance, self-efficacy, POC and maybe temptation.

References

Adams, J. (2003). Are activity promotion interventions based on the transtheoretical model effective? A critical review. *British Journal of Sports Medicine*, *37*(2), 106–114. https://doi.org/10.1136/bjsm.37.2.106

Adams, J., & White, M. (2005). Why don't stage-based activity promotion interventions work? *Health Education Research*, *20*(2), 237–243. https://doi.org/10.1093/her/cyg105

Andersen, L. B., Mota, J., & Di Pietro, L. (2016). Update on the global pandemic of physical inactivity. *Lancet (London, England)*, *388*(10051), 1255–1256. https://doi.org/10.1016/S0140-6736(16)30960-6

Armitage, C. J. (2009). Is there utility in the transtheoretical model? *British Journal of Health Psychology*, *14*(Pt 2), 195–210. https://doi.org/10.1348/135910708X368991

Armitage, C. J., & Arden, M. A. (2010). A volitional help sheet to increase physical activity in people with low socioeconomic status: A randomised exploratory trial. *Psychology & Health*, *25*(10), 1129–1145. https://doi.org/10.1080/08870440903121638

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191–215.

Bandura, A. (1997). *self-efficacy: the exercise of control*. New-york, Freeman.

Baruth, M., Wilcox, S., Dunn, A. L., King, A. C., Marcus, B. H., Rejeski, W. J., … Blair, S. N. (2010). Psychosocial mediators of physical activity and fitness changes in the activity counseling trial. *Annals of Behavioral Medicine*, *39*(3), 274–289. https://doi.org/10.1007/s12160-010-9178-4

Benisovich, S. V., Rossi, J., Norman, G., & Nigg, C. (1998). Development of a multidimensional measure of exercise self-efficacy. *Annals of Behavioral Medicine*, *20 (suppl)*.

Bernard, P., Carayol, M., Gourlan, M., Boiché, J., Romain, A. J., Bortolon, C., … Ninot, G. (2016). Moderators of Theory-Based Interventions to Promote Physical Activity in 77 Randomized Controlled Trials. *Health Education & Behavior* https://doi.org/10.1177/1090198116648667

Bernard, P., Romain, A.-J., Trouillet, R., Gernigon, C., Nigg, C., & Ninot, G. (2014). Validation of the TTM processes of change measure for physical activity in an adult French sample. *International Journal of Behavioral Medicine*, *21*(2), 402–410. https://doi.org/10.1007/s12529-013-9292-3

Blaney, C. L., Robbins, M. L., Paiva, A. L., Redding, C. A., Rossi, J. S., Blissmer, B., … Oatley, K. (2012). Validation of the measures of the transtheoretical model for exercise in an adult African-American sample. *American Journal of Health Promotion*, *26*(5), 317–326. https://doi.org/10.4278/ajhp.091214-QUAN-393

Bridle, C., Riemsma, R. P., Pattenden, J., Sowden, A. J., Mather, L., Watt, I. S., & Walker, A. (2005). Systematic review of the effectiveness of health behavior interventions based on the transtheoretical model. *Psychology & Health*, *20*(3), 283–301. https://doi.org/10.1080/08870440512331333997

Brug, J. (2004). The Transtheoretical Model and stages of change: a critique: Observations by five Commentators on the paper by Adams, J. and White, M. (2004) Why don't stage-based activity promotion interventions work? *Health Education Research*, *20*(2), 244–258. https://doi.org/10.1093/her/cyh005

Bucksch, J., Finne, E., & Kolip, P. (2008). The transtheoretical model in the context of physical activity in a school-based sample of German adolescents. *European Journal of Sport Science*, *8*(6), 403–412. https://doi.org/10.1080/17461390802438748

Burkholder, G. J., & Nigg, C. R. (2001). overview of the transtheoretical model. In P. M. Burbank & D. Riebe (Eds.), *Promoting Exercise and Behavior Change in Older Adults: Interventions with the Transtheoretical Model*. Springer Publishing Company.

Cardinal, B. J., Tuominen, K. J., & Rintala, P. (2003). Psychometric assessment of Finnish versions of exercise-related measures of Transtheoretical Model constructs. *International Journal of Behavioral Medicine*, *10*(1), 31–43.

Carnegie, M. A., Bauman, A., Marshall, A. L., Mohsin, M., Westley-Wise, V., & Booth, M. L. (2002). Perceptions of the Physical Environment, Stage of Change for Physical Activity, and Walking among Australian Adults. *Research Quarterly for Exercise and Sport*, *73*(2), 146–155. https://doi.org/10.1080/02701367.2002.10609003

Craig, P., Dieppe, P., Macintyre, S., Michie, S., Nazareth, I., Petticrew, M., & Medical Research Council Guidance. (2008). Developing and evaluating complex interventions: the new Medical Research Council guidance. *BMJ (Clinical Research Ed.)*, *337*, a1655.

Ding, D., Lawson, K. D., Kolbe-Alexander, T. L., Finkelstein, E. A., Katzmarzyk, P. T., van Mechelen, W., … Lancet Physical Activity Series 2 Executive Committee. (2016). The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *Lancet (London, England)*, *388*(10051), 1311–1324. https://doi.org/10.1016/S0140-6736(16)30383-X

Dishman, R. K., Jackson, A. S., & Bray, M. S. (2010). Validity of Processes of Change in Physical Activity Among College Students in the TIGER Study. *Annals of Behavioral Medicine*, *40*(2), 164–175. https://doi.org/10.1007/s12160-010-9208-2

Dishman, R. K., Jackson, A. S., & Bray, M. S. (2014). Self-regulation of Exercise Behavior in the TIGER Study. *Annals of Behavioral Medicine*, *48*(1), 80–91. https://doi.org/10.1007/s12160-013-9573-8

Dishman, R. K., Vandenberg, R. J., Motl, R. W., & Nigg, C. R. (2010a). Using Constructs of the Transtheoretical Model to Predict Classes of Change in Regular Physical Activity: A Multi-Ethnic Longitudinal Cohort Study. *Annals of Behavioral Medicine*, *40*(2), 150–163. https://doi.org/10.1007/s12160-010-9196-2

Dunton, G. F. (2016). Ecological Momentary Assessment in Physical Activity Research. *Exercise and Sport Sciences Reviews*. https://doi.org/10.1249/JES.0000000000000092

Eeckhout, C., Francaux, M., Heeren, A., & Philippot, P. (2013). Mesure de la balance décisionnelle en vue de pratiquer une activité physique régulière (BDAP): adaptation et validation francophone de l'échelle Decisional Balance for Exercise. *Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology*, *63*(3), 185–191. https://doi.org/10.1016/j.erap.2013.01.001

Eeckhout, C., Francaux, M., & Philippot, P. (2012). Mesure des processus de changement vis-à-vis de la pratique d'une activité physique régulière (QPC) : adaptation et validation francophone du questionnaire Exercise processes of change. *Science & Sports*, *27*(6), 333–344. https://doi.org/10.1016/j.scispo.2011.10.013

Eeckhout, C., Francaux, M., & Philippot, P. (2012). Auto-efficacité perçue pour la pratique d'une activité physique: Adaptation et validation francophone du Exercise Confidence Survey. *Canadian Journal of Behavioural Science/Revue*

Canadienne Des Sciences Du Comportement, *44*(1), 77–82. https://doi.org/10.1037/a0025317

Fahrenwald, N. L., Atwood, J. R., Walker, S. N., Johnson, D. R., & Berg, K. (2004). A randomized pilot test of "Moms on the Move": a physical activity intervention for WIC mothers. *Annals of Behavioral Medicine*, *27*(2), 82–90. https://doi.org/10.1207/s15324796abm2702_2

Farmanbar, R., Niknami, S., Lubans, D. R., & Hidarnia, A. (2012). Predicting exercise behaviour in Iranian college students: Utility of an integrated model of health behaviour based on the transtheoretical model and self-determination theory. *Health Education Journal*, *72*(1), 56–69. https://doi.org/10.1177/0017896911430549

Fuchs, R., & Schwarzer, R. (1994). [self-efficacy towards physical exercise: reliability and validity of a new instrument]. Zeitschrift Für Differentielle Und Diagnostische Psychologie, 15, 141–154.

Gallagher, K. I., Jakicic, J. M., Napolitano, M. A., & Marcus, B. H. (2006). Psychosocial Factors Related to Physical Activity and Weight Loss in Overweight Women. *Medicine & Science in Sports & Exercise*, *38*(5), 971–980. https://doi.org/10.1249/01.mss.0000218137.25970.c6

Geller, K. S., Nigg, C. R., Motl, R. W., Horwath, C. C., & Dishman, R. K. (2012). Transtheoretical model constructs for physical activity behavior are invariant across time among ethnically diverse adults in Hawaii. *Psychology of Sport and Exercise*, *13*(5), 606–613. https://doi.org/10.1016/j.psychsport.2012.02.006

Glanz, K., & Bishop, D. B. (2010). The role of behavioral science theory in development and implementation of public health interventions. *Annual Review of Public Health*, *31*, 399–418. https://doi.org/10.1146/annurev.publhealth.012809.103604

Gourlan, M., Bernard, P., Bortholon, C., Romain, A., Lareyre, O., Carayol, M., … Boiché, J. (2016). Efficacy of theory-based interventions to promote physical activity. A meta-analysis of randomised controlled trials. *Health Psychology Review*, *10*(1), 50–66. https://doi.org/10.1080/17437199.2014.981777

Hausenblas, H. A., Nigg, C. R., Dannecker, E. A., Downs, D. S., Gardner, R. E., Fallon, E. A., … Loving, M. G. (2001). A missing piece of the transtheoretical model applied to exercise: Development and validation of the temptation to not exercise scale. *Psychology & Health*, *16*(4), 381–390. https://doi.org/10.1080/08870440108405514

Hellsten, L., Nigg, C., Norman, G., Burbank, P., Braun, L., Breger, R., … Wang, T. (2008). Accumulation of behavioral validation evidence for physical activity stage of change. *Health Psychology, 27*(1S), S43-53. https://doi.org/10.1037/0278-6133.27.1(Suppl.).S43

Horiuchi, S., Tsuda, A., Kobayashi, H., Fallon, E. A., & Sakano, Y. (2016). Self-efficacy, pros, and cons as variables associated with adjacent stages of change for regular exercise in Japanese college students. *Journal of Health Psychology*. https://doi.org/10.1177/1359105315621779

Hutchison, A. J., Breckon, J. D., & Johnston, L. H. (2009). Physical Activity Behavior Change Interventions Based on the Transtheoretical Model: A Systematic Review. *Health Education & Behavior*, *36*(5), 829–845. https://doi.org/10.1177/1090198108318491

Hwang, J., & Kim, Y. H. (2011). Adolescents' physical activity and its related cognitive and behavioural processes. *Biology of Sport*, *28*(1), 19.

Kanning, M. (2010). Physically active patients with coronary artery disease: A longitudinal investigation of the

processes of exercise behaviour change. *British Journal of Health Psychology*, *15*(3), 583–597. https://doi.org/10.1348/135910709X477476

Kearney, J. M., De Graaf, C., Damkjaer, S., & Engstrom, L. M. (1999). Stages of change towards physical activity in a nationally representative sample in the European Union. Public Health Nutrition, 2(1A), 115–124.

Keefe, F. J., & Blumenthal, J. A. (2004). Health psychology: what will the future bring? *Health Psychology*, *23*(2), 156–157. https://doi.org/10.1037/0278-6133.23.2.156

Khan, K. M., Thompson, A. M., Blair, S. N., Sallis, J. F., Powell, K. E., Bull, F. C., & Bauman, A. E. (2012). Sport and exercise as contributors to the health of nations. *Lancet (London, England)*, *380*(9836), 59–64. https://doi.org/10.1016/S0140-6736(12)60865-4

Kim, Y., Cardinal, B. J., & Lee, J. Y. (2006). Understanding exercise behavior among Korean adults: A test of the transtheoretical model. *International Journal of Behavioral Medicine*, *13*(4), 295–303.

Kim, Y.-H. (2007). Application of the transtheoretical model to identify psychological constructs influencing exercise behavior: A questionnaire survey. *International Journal of Nursing Studies*, *44*(6), 936–944. https://doi.org/10.1016/j.ijnurstu.2006.03.008

Kirk, A. F., Mutrie, N., MacIntyre, P. D., & Fisher, M. B. (2004). Promoting and maintaining physical activity in people with type 2 diabetes. *American Journal of Preventive Medicine*, *27*(4), 289–296. https://doi.org/10.1016/j.amepre.2004.07.009

Kirk, A., Mutrie, N., MacIntyre, P., & Fisher, M. (2003). Increasing physical activity in people with type 2 diabetes. *Diabetes Care*, *26*(4), 1186–1192. https://doi.org/10.2337/diacare.26.4.1186

Korologou, S., Barkoukis, V., Lazuras, L., & Tsorbatzoudis, H. (2015). Application of the Transtheoretical Model to Physical Activity in Deaf Individuals. *Adapted Physical Activity Quarterly*, *32*(3), 223–240. https://doi.org/10.1123/APAQ.2013-0073

Levy, S. S., Li, K.-K., Cardinal, B. J., & Maddalozzo, G. F. (2009). Transitional shifts in exercise behavior among women with multiple sclerosis. *Disability and Health Journal*, *2*(4), 216–223. https://doi.org/10.1016/j.dhjo.2009.04.001

Lewis, B. A., Forsyth, L. H., Pinto, B., Bock, B. C., Roberts, M., & Marcus, B. H. (2006). Psychosocial Mediators of Physical Activity in a Randomized Controlled Intervention Trial. *Journal of Sport and Exercise Psychology*, *28*(2), 193–204.

Lippke, S., & Plotnikoff, R. C. (2006). Stages of change in physical exercise: a test of stage discrimination and nonlinearity. *American Journal of Health Behavior*, *30*(3), 290–301. https://doi.org/10.5555/ajhb.2006.30.3.290

Lipschitz, J. M., Yusufov, M., Paiva, A., Redding, C. A., Rossi, J. S., Johnson, S., … Prochaska, J. O. (2015). Transtheoretical Principles and Processes for Adopting Physical Activity: A Longitudinal 24-Month Comparison of Maintainers, Relapsers, and Nonchangers. *Journal of Sport and Exercise Psychology*, *37*(6), 592–606. https://doi.org/10.1123/jsep.2014-0329

Loprinzi, P. D., & Cardinal, B. J. (2011). Self-efficacy mediates the relationship between behavioral processes of change and physical activity in older breast cancer survivors. *Breast Cancer*, *20*(1), 47–52.

https://doi.org/10.1007/s12282-011-0298-x

Lowther, M., Mutrie, N., & Scott, E. M. (2007). Identifying Key Processes of Exercise Behaviour Change Associated with Movement through the Stages of Exercise Behaviour Change. *Journal of Health Psychology*, *12*(2), 261–272. https://doi.org/10.1177/1359105307074253

Maddison, R., & Prapavessis, H. (2006). Exercise Behavior Among New Zealand adolescents: A Test of the Transtheoretical Model. *Pediatric Exercise Science*, (18), 351–363.

Marcus, B. H., Emmons, K. M., Simkin-Silverman, L. R., Linnan, L. A., Taylor, E. R., Bock, B. C., … Abrams, D. B. (1998). Evaluation of motivationally tailored vs. standard self-help physical activity interventions at the workplace. *American Journal of Health Promotion*, *12*(4), 246–253.

Marcus, B. H., Nigg, C. R., Riebe, D., & Forsyth, L. H. (2000). Interactive communication strategies: implications for population-based physical-activity promotion. *American Journal of Preventive Medicine*, *19*(2), 121–126.

Marcus, B. H., Rakowski, W., & Rossi, J. S. (1992). Assessing motivational readiness and decision making for exercise. *Health Psychology*, *11*(4), 257–261.

Marcus, B. H., Rossi, J. S., Selby, V. C., Niaura, R. S., & Abrams, D. B. (1992). The stages and processes of exercise adoption and maintenance in a worksite sample. *Health Psychology*, *11*(6), 386–395.

Marshall, S. J., & Biddle, S. J. (2001). The transtheoretical model of behavior change: a meta-analysis of applications to physical activity and exercise. *Annals of Behavioral Medicine*, *23*(4), 229–246.

Michie, S., & Johnston, M. (2012). Theories and techniques of behaviour change: Developing a cumulative science of behaviour change. *Health Psychology Review*, *6*(1), 1–6. https://doi.org/10.1080/17437199.2012.654964

Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., … Wood, C. E. (2013). The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine*, *46*(1), 81–95. https://doi.org/10.1007/s12160-013-9486-6

Napolitano, M. A., & Hayes, S. (2011). Behavioral and psychological factors associated with 12-month weight change in a physical activity trial. *Journal of Obesity*, *2011*, 515803. https://doi.org/10.1155/2011/515803

Napolitano, M. A., Papandonatos, G. D., Lewis, B. A., Whiteley, J. A., Williams, D. M., King, A. C., … Marcus, B. H. (2008). Mediators of physical activity behavior change: A multivariate approach. *Health Psychology*, *27*(4), 409–418. https://doi.org/10.1037/0278-6133.27.4.409

Nigg, C., Hellsten, L., Norman, G., Braun, L., Breger, R., Burbank, P., … Greaney, M. (2005). Physical activity staging distribution: Establishing a heuristic using multiple studies. *Annals of Behavioral Medicine*, *29*(2), 35–45.

Nigg, C. R. (2001). Explaining adolescent exercise behavior change: a longitudinal application of the transtheoretical model. *Annals of Behavioral Medicine*, *23*(1), 11–20. https://doi.org/10.1207/S15324796ABM2301_3

Nigg, C. R, Norman, G., Rossi, J. S., & Benisovich, S. V. (1999). Processes of exercise behavior change: redeveloping the scale. *Annals of Behavioral Medicine*, *21*, 79.

Nigg, C. R. (2005). There is more to stages of exercise than just exercise. *Exercise and Sport Sciences Reviews*, *33*(1),

32–35.

Nigg, C. R., & Courneya, K. S. (1998). Transtheoretical model: Examining adolescent exercise behavior. *Journal of Adolescent Health*, *22*(3), 214–224.

Noar, S. M., & Head, K. J. (2014). Mind the gap: bringing our theories in line with the empirical data - a response to commentaries. *Health Psychology Review*, *8*(1), 65–69. https://doi.org/10.1080/17437199.2013.855593

Norman, G. J., Velicer, W. F., Fava, J. L., & Prochaska, J. O. (1998). Dynamic typology clustering within the stages of change for smoking cessation. *Addictive Behaviors*, *23*(2), 139–153

Oka, K. (2000). Recent trends of research on exercise adherence utilizing the transtheoretical model of behavior change [in Japanese]. Research of Physical Education, 45(4), 543–561.

Oka, K. (2003). [Stages of change for exercise behavior and self-efficacy for exercise among middle-aged adults]. [Nihon Koshu Eisei Zasshi] Japanese Journal of Public Health, 50(3), 208–215.

Papandonatos, G. D., Williams, D. M., Jennings, E. G., Napolitano, M. A., Bock, B. C., Dunsiger, S., & Marcus, B. H. (2012). Mediators of physical activity behavior change: findings from a 12-month randomized controlled trial. *Health Psychology*, *31*(4), 512–520. https://doi.org/10.1037/a0026667

Paxton, R. J., Nigg, C. R., Motl, R. W., McGee, K., McCurdy, D., Matthai, C. H., & Dishman, R. K. (2008). Are Constructs of the Transtheoretical Model for Physical Activity Measured Equivalently Between Sexes, Age Groups, and Ethnicities? *Annals of Behavioral Medicine*, *35*(3), 308–318. https://doi.org/10.1007/s12160-008-9035-x

Peters, G.-J. Y., de Bruin, M., & Crutzen, R. (2015). Everything should be as simple as possible, but no simpler: towards a protocol for accumulating evidence regarding the active content of health behaviour change interventions. *Health Psychology Review*, *9*(1), 1–14. https://doi.org/10.1080/17437199.2013.848409

Pickering, M. A., & Plotnikoff, R. C. (2009). Factor Structure and Measurement Invariance of a 10-Item Decisional Balance Scale: Longitudinal and Subgroup Examination Within an Adult Diabetic Sample. *Measurement in Physical Education and Exercise Science*, *13*(4), 206–226. https://doi.org/10.1080/10913670903260086

Pinto, B. M., Lynn, H., Marcus, B. H., DePue, J., & Goldstein, M. G. (2001). Physician-based activity counseling: intervention effects on mediators of motivational readiness for physical activity. *Annals of Behavioral Medicine*, *23*(1), 2–10. https://doi.org/10.1207/S15324796ABM2301_2

Pinto, B.M., & Dunsiger, S. I. (2014). Mediators of Exercise Maintenance After Cardiac Rehabilitation. *Journal of Cardiopulmonary Rehabilitation and Prevention*, *35*(1), 13–20. https://doi.org/10.1097/HCR.0000000000000065

Plotnikoff, R. C., Blanchard, C., Hotz, S. B., & Rhodes, R. (2001). Validation of the Decisional Balance Scales in the Exercise Domain From the Transtheoretical Model: A Longitudinal Test. *Measurement in Physical Education and Exercise Science*, *5*(4), 191–206. https://doi.org/10.1207/S15327841MPEE0504_01

Plotnikoff, R. C., Hotz, S. B., Birkett, N. J., & Courneya, K. S. (2001). Exercise and the Transtheoretical Model: A Longitudinal Test of a Population Sample. *Preventive Medicine*, *33*(5), 441–452. https://doi.org/10.1006/pmed.2001.0914

Plotnikoff, R. C., Lippke, S., Johnson, S. T., & Courneya, K. S. (2010). Physical activity and stages of change: a

longitudinal test in types 1 and 2 diabetes samples. *Annals of Behavioral Medicine*, *40*(2), 138–149. https://doi.org/10.1007/s12160-010-9193-5

Plummer, B. A., Velicer, W. F., Redding, C. A., Prochaska, J. O., Rossi, J. S., Pallonen, U. E., & Meier, K. S. (2001). Stage of change, decisional balance, and temptations for smoking: Measurement and validation in a large, school-based population of adolescents. A*ddictive behaviors, 26*(4), 551-571.

Prentice, D. A., & Miller, D. T. (1992). When small effects are impressive. *Psychological Bulletin*, *112*(1), 160–164.

Prochaska, J. O, Velicer, W. F., DiClemente, C. C., & Fava, J. (1988). Measuring processes of change: applications to the cessation of smoking. *Journal of Consulting and Clinical Psychology*, *56*(4), 520–528.

Prochaska, J. O, & DiClemente, C. C. (1983). Stages and processes of self-change of smoking: toward an integrative model of change. *Journal of Consulting and Clinical Psychology*, *51*(3), 390.

Prochaska, J. O, DiClemente, C. C., & Norcross, J. C. (1992). In search of how people change: Applications to addictive behaviors. *American Psychologist*, *47*(9), 1102. https://doi.org/10.1037/0003-066X.47.9.1102

Prochaska, J. O, Redding, C. A., & Evers, K. E. (2008). The transtheoretical model and stages of change. In K. Glanz, B. K. Rimer, & K. Viswanath (Eds.), *Health behavior and health education: Theory, research and practice. 4th edition* (pp. 97–121). Jossey-Bass.

Prochaska, J. O., & Velicer, W. F. (1997). The Transtheoretical Model of Health Behavior Change. *American Journal of Health Promotion*, *12*(1), 38–48. https://doi.org/10.4278/0890-1171-12.1.38

Prochaska, J. O., Velicer, W. F., Rossi, J. S., Goldstein, M. G., Marcus, B. H., Rakowski, W., … Rosenbloom, D. (1994). Stages of change and decisional balance for 12 problem behaviors. *Health Psychology*, *13*(1), 39.

Rabin, C., Pinto, B., & Frierson, G. (2006). Mediators of a randomized controlled physical activity intervention for breast cancer survivors. *Journal of Sport and Exercise Psychology*, *28*(3), 269–284.

Redding, C. A., Prochaska, J. O., Pallonen, U. E., Rossi, J. S., Velicer, W. F., Rossi, S. R., … Maddock, J. E. (1999). Transtheoretical individualized multimedia expert systems targeting adolescents' health behaviors. *Cognitive and Behavioral Practice*, *6*(2), 144–153. https://doi.org/10.1016/S1077-7229(99)80025-X

Reed, G. R., Velicer, W. F., Prochaska, J. O., Rossi, J. S., & Marcus, B. H. (1997). What makes a good staging algorithm: examples from regular exercise. *American Journal of Health Promotion*, *12*(1), 57–66.

Rhodes, R. E., Berry, T., Naylor, P.-J., & Wharf Higgins, S. J. (2004). Three-Step Validation of Exercise Behavior Processes of Change in an Adolescent Sample. *Measurement in Physical Education and Exercise Science*, *8*(1), 1–20. https://doi.org/10.1207/s15327841mpee0801_1

Rhodes, R. E., & Nigg, C. R. (2011). Advancing physical activity theory: A review and future directions. *Exercise and Sport Sciences Reviews*, *39*(3), 113–119.

Rhodes, R. E., & Pfaeffli, L. A. (2010). Mediators of physical activity behaviour change among adult non-clinical populations: a review update. *The International Journal of Behavioral Nutrition and Physical Activity*, *7*, 37. https://doi.org/10.1186/1479-5868-7-37

Rhodes, R. E., & Quinlan, A. (2015). Predictors of physical activity change among adults using observational designs.

Sports Medicine (Auckland, N.Z.), *45*(3), 423–441. https://doi.org/10.1007/s40279-014-0275-6

Riebe, D., Blissmer, B., Greene, G., Caldwell, M., Ruggiero, L., Stillwell, K., & Nigg, C. (2005). Long-term maintenance of exercise and healthy eating behaviors in overweight adults. *Preventive Medicine*, *40*(6), 769–778. https://doi.org/10.1016/j.ypmed.2004.09.023

Romain, A. J., Attalin, V., Sultan, A., Boegner, C., Gernigon, C., & Avignon, A. (2014). Experiential or behavioral processes: Which one is prominent in physical activity? Examining the processes of change 1 year after an intervention of therapeutic education among adults with obesity. *Patient Education and Counseling*, *97*(2), 261–268. https://doi.org/10.1016/j.pec.2014.08.004

Romain, A. J., Bernard, P., Attalin, V., Gernigon, C., Ninot, G., & Avignon, A. (2012). Health-related quality of life and stages of behavioural change for exercise in overweight/obese individuals. *Diabetes & Metabolism*, *38*(4), 352–358. https://doi.org/10.1016/j.diabet.2012.03.003

Romain, A. J., Chevance, G., Caudroit, J., & Bernard, P. (2016). [The transtheoretical model: description, interests and application in the motivation to physical activity among population with overweight and obesity]. *Obésité*, *11*(1), 47–55. https://doi.org/10.1007/s11690-015-0504-7

Romain, A. J., Horwath, C., & Bernard, P. (2016). Prediction of physical activity level using processes of change from the transtheoretical model. Experiential, behavioral, or an interaction effect? *American Journal of Health Promotion*, Epub ahead on print. https://doi.org/10.1177/0890117116686900.

Romain, A. J., Bernard, P., Galvez, M., & Caudroit, J. (2015). Response to an Exercise Intervention for Patients with Type 2 Diabetes: A Preliminary Study of Processes of Change: Physical Activity and Processes of Change. *Journal of Applied Biobehavioral Research*, *20*(3), 130–136. https://doi.org/10.1111/jabr.12034

Romain, A. J., Bernard, P., Hokayem, M., Gernigon, C., & Avignon, A. (2016). Measuring the Processes of Change From the Transtheoretical Model for Physical Activity and Exercise in Overweight and Obese Adults. *American Journal of Health Promotion*, *30*(4), 272–278. https://doi.org/10.1177/0890117116633829

Romain, A. J., Bortolon, C., Gourlan, M., Carayol, M., Lareyre, O., Ninot, G., … Bernard, P. (2016). Matched or nonmatched interventions based on the transtheoretical model to promote physical activity. A meta-analysis of randomized controlled trials. *Journal of Sport and Health Science*. https://doi.org/10.1016/j.jshs.2016.10.007

Ronda, G., Van Assema, P., & Brug, J. (2001). Stages of change, psychological factors and awareness of physical activity levels in The Netherlands. *Health Promotion International*, *16*(4), 305–314.

Rosen, C. S. (2000). Is the sequencing of change processes by stage consistent across health problems? A meta-analysis. *Health Psychology*, *19*(6), 593.

Sallis, J. F., Bull, F., Guthold, R., Heath, G. W., Inoue, S., Kelly, P., … Lancet Physical Activity Series 2 Executive Committee. (2016). Progress in physical activity over the Olympic quadrennium. *Lancet (London, England)*, *388*(10051), 1325–1336. https://doi.org/10.1016/S0140-6736(16)30581-5

Sallis, J. F., Pinski, R. B., Grossman, R. M., Patterson, T. L., & Nader, P. R. (1988). The development of self-efficacy scales for healthrelated diet and exercise behaviors. Health Education Research, 3(3), 283–292. https://doi.org/10.1093/her/3.3.283

Sanaeinasab, H., Saffari, M., Nazeri, M., Karimi Zarchi, A., & Cardinal, B. J. (2013). Descriptive analysis of Iranian adolescents' stages of change for physical activity behavior. *Nursing & Health Sciences*, *15*(3), 280–285. https://doi.org/10.1111/nhs.12020

Sechrist, K. R., Walker, S. N., & Pender, N. J. (1987). Development and psychometric evaluation of the exercise benefits/barriers scale. Research in Nursing & Health, 10(6), 357–365.

Skaal, L., & Pengpid, S. (2012). The predictive validity and effects of using the transtheoretical model to increase the physical activity of healthcare workers in a public hospital in South Africa. *Translational Behavioral Medicine*, *2*(4), 384–391. https://doi.org/10.1007/s13142-012-0136-5

Skaal, L. (2013). Processes of change used by healthcare workers to participate in physical activity: What motivates healthcare workers to exercise? African Journal for Physical, Health Education, Recreation and Dance, 19(4.1), 843–853.

Tergerson, J. L., & King, K. A. (2002). Do perceived cues, benefits, and barriers to physical activity differ between male and female adolescents? The Journal of School Health, 72(9), 374–380.

Tung, W.-C., Gillett, P. A., & Pattillo, R. E. (2005). Applying the Transtheoretical Model to physical activity in family caregivers in Taiwan. *Public Health Nursing*, *22*(4), 299–310. https://doi.org/10.1111/j.0737-1209.2005.220405.x

Vita, P., & Owen, N. (1995). A Perspective on the Behavioural Epidemiology, the Determinants, and the Stages of Exercise Involvement. Australian Psychologist, 30(2), 135–140. https://doi.org/10.1080/00050069508258918

Yang, P.-S., & Chen, C.-H. (2005). Exercise stage and processes of change in patients with chronic obstructive pulmonary disease. *The Journal of Nursing Research*, *13*(2), 97–105.

Yusufov, M., Paiva, A. L., Redding, C. A., Lipschitz, J. M., Gokbayrak, N. S., Greene, G., ... & Prochaska, J. O. (2016). Fat reduction efforts: A 24-month longitudinal comparison of a large sample of maintainers, relapsers, and non-changers. *Health promotion practice, 17*(1), 116-126.

Processes of change	Definition
Experiential processes of change	
Consciousness raising	Efforts to better understand the problematic behavior
Dramatic relief	Affective aspects of behavior change
Self reevaluation	Cognitive or emotional appraisal of the impact of the behavior on the individual
Environmental reevaluation	Impact of negative or positive behavior on individual's social and physical environment
Social liberation	Recognition that actual social norms encourage individuals to reach/sustain their healthier lifestyle
Behavioral processes of change	
Self liberation	Commiting to change and believing in this commitment
Helping relationships	Using the support of caring others to modify behaviour
Counterconditioning	Substituting unhealthy for healthy behaviour
Reinforcement management	Use of reinforcement and reward to support/sustain healthy behaviour
Stimulus control	Modifiying the environment to encourage healthy behaviour

Table 1: Processes of change and their definitions

Continent	Country	Authors	Language	Constructs
Europe	Belgium	Eeckhout et al., 2011a,b; Eeckhout et al., 2013	French	POC, SE, DB
	France	Bernard et al., 2013; Romain et al., 2015		POC, SOC
	Finland	Cardinal et al., 2003	Finnish	DB, POC, SE
	German	Bucksch et al., 2008; Kanning, 2010	Dutch	POC,SOC, SE, DB
	Netherland	Ronda et al., 2001	German	SOC
	Greece	Bebetos et al., 2012; Korologou, 2015	Greek	DB, POC, SE, SOC
Asia	Iran	Sanalinassab et al., 2013; Farmanbar et al., 2012	Persian	DB, POC, SE, SOC
	Korea	Kim et al., 2006; Kim, 2007	Korean	DB, POC, SE, SOC
	Taiwan	Tung et al., 2005; Yan et al., 2005	Chinese	DB, POC, SE, SOC
	China	Si et al., 2011		DB, POC, SE, SOC
	Malaysia	Phing, 2014	Malay	SOC
	Japan	Horiuchi et al., 2016	Japanese	SOC, DB, SE
America	USA	Geller et al., 2012; Dishman et al., 2010; Blaney et al., 2012	English	DB, POC, SE, SOC
	Canada	Rhodes et al., 2004; Pickering et al., 2009		POC, DB
	Mexico	Gonzalez et al., 2000	Spanish	SOC
Oceania	New Zealand	Maddison et al., 2006	English	DB, POC, SE, SOC
	Australia	Carnegie et al., 2013		SOC
Africa	South Africa	Skaal et al., 2012, Skaal, 2013		SOC, POC

Table 2: Systematic summary of the different worldwide studies carried out on TTM constructs

Note. Constructs: SOC= Stage of change; POC= Processes of change; SE= Self-efficacy; DB= Decisional balance;

More details about validation processes, psychometric information and study participants are available in the Supplementary file.

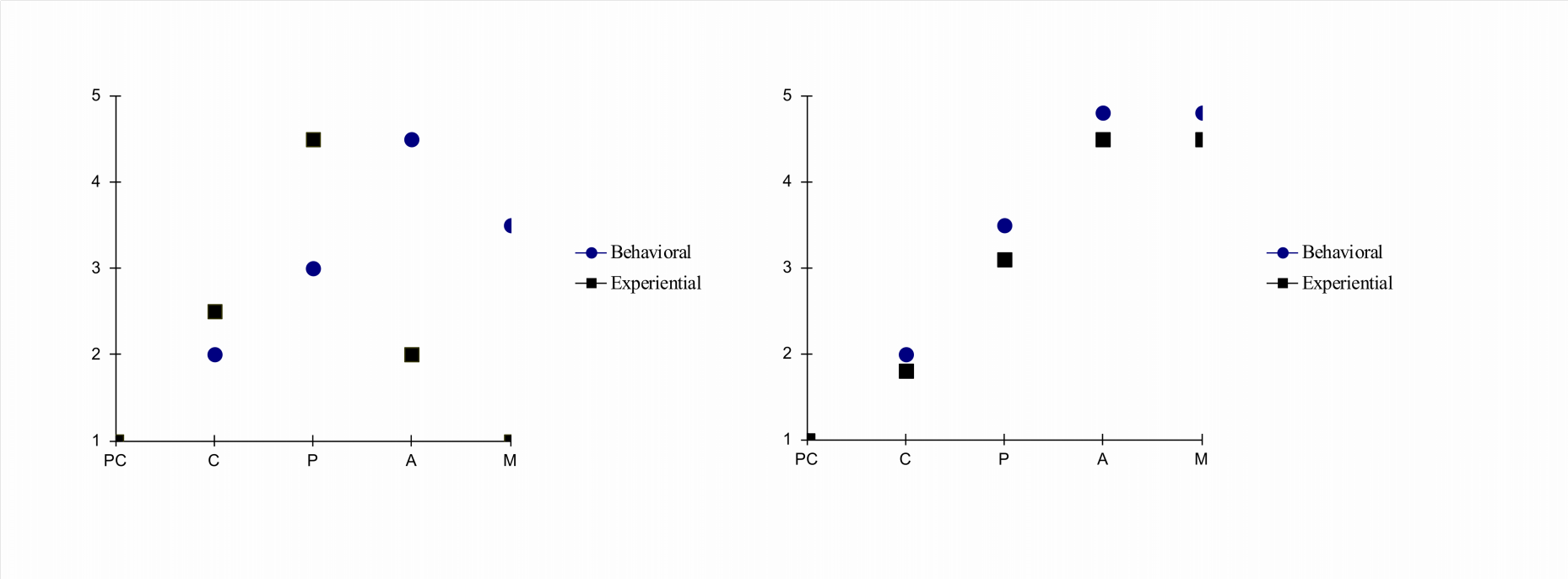

Figure 1: Schematic representation of the relationship between processes and stages of change in tobacco use (left figure; sequential association) and physical activity (right figure; tandem association).

Notes: This figure has been adapted from Romain et al. (2017) with their authorization. , PC: precontemplation, C: contemplation, P: preparation, A: action, M: maintenance.