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Modeling Longitudinal Relationships Between Habit and Physical Activity: Two Cross-Lagged Panel Design Studies in Older Adults

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These longitudinal studies in older adults targeted mediated relationships between habit and physical activity (PA). In The Netherlands two independent studies were conducted among 1976 (Study 1: *M*age = 63.63, *SD* = 8.66, 30% functional limitations) and 2140 (Study 2: *M*age = 62.75, *SD* = 8.57, 45% functional limitations) adults aged 50 years or older. Cross-lagged panel designs were applied to examine whether habit mediates the relationship between prior and later PA and whether PA simultaneously mediates the relationship between prior and later habit. Data on habit and PA were collected by means of questionnaires at baseline (t0) and at 6 (t1) and 12 (t2) months after baseline measurement. Results of structural equation modeling analyses were not unambiguous. Indications for the existence of both hypothesized mediation effects were found, but no clear, unequivocal pattern appeared. Somewhat more support was found for the PA-habit-PA path than for the habit-PA-habit path. More research is needed to draw more definitive conclusions.

Keywords: habit, SRBAI, physical activity, mediation analysis, cross-lagged panel design, older adults

Regular physical activity (PA) is associated with many physical and mental health benefits (e.g., Hamer, Lavoie, & Bacon, 2014; Lee et al., 2012; Reiner, Niermann, Jekauc, & Wolf, 2013). Worldwide, a large proportion of older adults are currently insufficiently active to obtain these health benefits (Hallal et al., 2012; Sun, Norman, & While, 2013). In The Netherlands, where the current studies were conducted, 40% of the adults aged 45 to 65 and 31% of the adults aged 65 and older are insufficiently physically active (Centraal Bureau voor de Statistiek, 2016). They do not meet the international PA recommendation to be moderately or vigorously physically active for at least 30 min per day on at least 5 days per week (Haskell et al., 2007; Nelson et al., 2007). Consequently, stimulating PA in this age group by developing effective PA interventions is of major relevance. Development of such effective interventions relies on insight into the determinants of PA and their working mechanisms. In order to contribute to this insight the current studies examine whether habit mediates the relationship between prior and later PA and whether PA simultaneously mediates the relationship between prior and later habit (see Figure 1 for conceptual model).

Many health behaviors are typically executed repeatedly (Ajzen, 2002; Verplanken, 2010). Repetition may result in habit formation. That is, habits form through satisfactorily repeating behavior in a specific context (Lally, Van Jaarsveld, Potts, & Wardle, 2010), whereby control over the behavior is gradually transferred from deliberative thoughts to contextual stimuli (Lally, Wardle, & Gardner, 2011). As a result these contextual stimuli acquire the potential to activate behavior, so that upon encountering these stimuli, automatic, habitual responses are activated (Bargh, 1994; Orbell & Verplanken, 2010). These responses are performed in the absence of conscious control or mental effort (Verplanken, 2006; Wood, Quinn, & Kashy, 2002). Automatic, habitual behavior does not depend on supporting intentions and should thus persist even when motivation or self-control resources are lowered (Gardner, 2015; Neal, Wood, & Drolet, 2013). Drawing on this feature, calls have been made to encourage habit formation in interventions in order to promote long-term maintenance of health behavior (Rothman, Sheeran, & Wood, 2009).

Like many health behaviors, such as alcohol consumption (Norman, 2011), fruit consumption (De Bruijn, 2010; De Bruijn, Keer, Conner, & Rhodes, 2012; Guillaumie, Godin, & Vézina-Im, 2010), and adherence to asthma medication (Bolman, Arwert, & Völlink, 2011), PA has a habitual component, which has been found to be noticeable in at least four different ways. First, PA correlates moderately to strongly with habit (Gardner, De Bruijn, & Lally, 2011). Second, habit typically explains additional variance in PA over and above intentions (e.g., Rhodes & De Bruijn, 2010). Third, habit moderates the influence of intention on light or moderate PA; intention becomes less predictive of PA as habit strength increases (e.g., Gardner et al., 2011; van Bree et al., 2013). Fourth, within the framework of the theory of planned behavior (Ajzen, 1991), habit mediates the relationship between prior and later PA, as was shown in a recent study (van Bree et al., 2015). Habit thus provides a psychological mechanism that partly explains why prior PA is such a good predictor of later PA. However, the longitudinal relationship between habit and behavior still leaves questions open and needs to be unravelled in more depth. Habit theory states that performing behavior as a partly or completely automatically activated, habitual response to contextual stimuli strengthens existing habits until habit strength asymptotically reaches a plateau (Lally et al., 2010). This process of habit formation applies to both experimental and nonexperimental (i.e., natural) settings. Thus, whereas the study by van Bree et al. (2015) found that prior PA affects habit, which in turn affects later PA, it could also be hypothesized that later PA, which is affected by habit at an earlier time point, in turn affects habit at an

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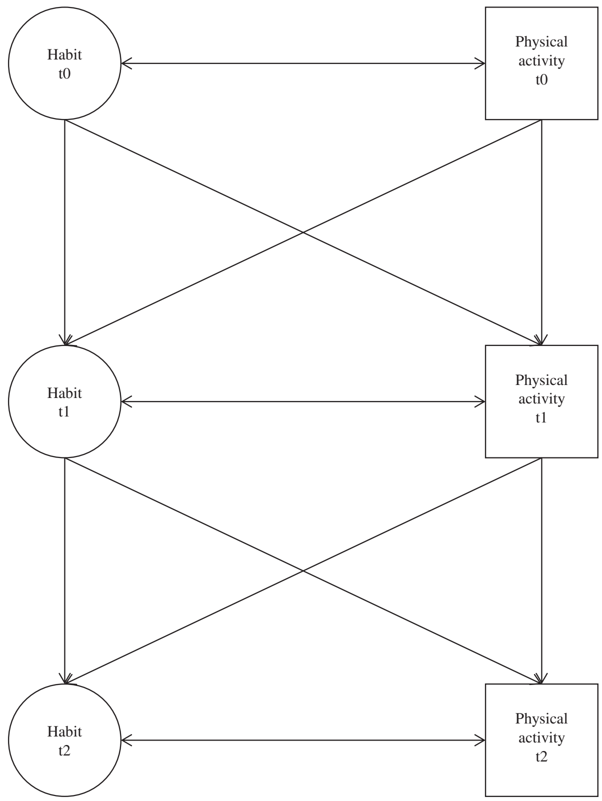

Figure 1 — Conceptual model for the relationships between physical activity and habit. *Note:* Age and the presence of a functional limitation were used as covariates. For reasons of clarity, dummy variables and covariates are not shown. Latent variables are represented in circles, observed variables in rectangles. t0 = baseline measurement; t1 = 6-month measurement; t2 = 12-month measurement.

even later time point. This would imply that PA mediates the relationship between prior and later habit. We are not aware of any study testing this hypothesis. Both mediation hypotheses (i.e., PA-habit-PA and habit-PA-habit) can be tested simultaneously using a cross-lagged panel design (see Figure 1). The time frames in such a design are the same for both mediation effects. Although the hypotheses have a strong common sense character, systematically testing them to sort out whether they can be confirmed or not contributes valuably to a solid theoretical foundation of the interplay between habit and PA. Moreover, insight into these mediation effects in experimental and nonexperimental settings is important for intervention development as well. Meta-analyses found that long-term gains of PA interventions are often limited (Antikainen & Ellis, 2011; Feldsjoe, Neuhaus, Winkler, & Eakin, 2011). Habit formation is a desired outcome for many PA interventions (Lally & Gardner, 2013) as it contributes to maintenance (Rothman et al., 2009). However, although their implicit goal often is that a newly acquired behavioral pattern becomes habitual, the majority of intervention studies are not grounded in habit formation theory (Lally, Chipperfield, & Wardle, 2008). Understanding the relationships between PA and habit may be helpful when designing PA interventions focused on habit formation. A significant PA-habit-PA path would support the implicit assumption that PA sustains over time through habit. A strong habit-PA-habit path would indicate that PA interventions could benefit from incorporating explicit habit formation strategies.

The current studies target adults aged 50 years or older, which is a growing population in the Western world (Christensen, Doblhammer, Rau, & Vaupel, 2009). The purpose of the current studies is to perform structural equation modeling (SEM) analyses to examine, in a cross-lagged panel design, whether habit mediates the relationship between prior and later PA and whether PA mediates the relationship between prior and later habit. It is hypothesized that both mediation effects occur simultaneously.

Methods

Data of two independent studies were used. The Medical Ethics Committee of Maastricht University and the University Hospital Maastricht approved the study protocol of Study 1. That study was registered at the Dutch Trial Register (NTR920). Study 2 was approved by the Medical Ethics Committee of Atrium-Orbis-Zuyd and registered at the Dutch Trial Register (NTR2297). For both studies, informed consent was obtained from all participants.

Participants and Procedures

Study 1. This study was a secondary analysis of data from a clustered randomized controlled trial (RCT) testing the efficacy of two tailored interventions aimed at promoting PA and long-term maintenance of PA in adults, aged 50 years or older (see van Stralen, de Vries, Mudde, Bolman, & Lechner, 2009, 2011). A wait list control condition was part of the RCT. At the end of the study participants from the control condition were given access to the intervention content. Data from both the control group and the two intervention conditions were used in the current study. The procedure of the RCT, including the selection, enrollment, and dropout of participants, the distribution and content of the questionnaires, and the interventions, are described in detail elsewhere (see van Stralen et al., 2008, 2011).

Via six randomly selected Municipal Health Councils, 8,500 Dutch adults, aged 50 years or older, were invited by a written letter to participate in the study. A total of 1,976 adults (23%) agreed to participate and completed the baseline questionnaire. Of these participants, 30% were assigned to the control condition and 70% to the two intervention conditions. Retention rates at 3, 6, and 12 months were 74%, 71%, and 68% respectively, in contrast to the number of baseline participants.

Study 2. This study was a secondary analysis of data from a RCT which aimed to compare the effectiveness and cost-effectiveness of four tailored PA interventions for adults aged 50 years or older (for long-term effectiveness studies, see Peels et al. [2013]; for long-term cost-effectiveness studies, see Peels et al., [2014]). At the end of the study, control group participants were given access to the intervention content. In the current study data from both the control group and the four intervention conditions were used. The procedure of the RCT, including the selection, the participation, and dropout rates, the delivery mode and content of the questionnaires, and the interventions, are described in detail elsewhere (see Peels et al., 2013).

In six Municipal Health Council regions, 13,666 Dutch adults, aged 50 years or older, were invited by a written letter to participate in the study. A total of 2,140 adults (16%) agreed to participate and completed the baseline questionnaire. Of these participants, 19% were assigned to the control condition and 81% to the four different intervention conditions. In contrast to the number of baseline participants, retention rates at 3, 6, and 12 months were 58%, 55%, and 59% respectively.

Measures

Study 1. Data were collected by means of extensive questionnaires at baseline and at 3, 6, and 12 months after baseline measurement (see van Stralen et al., 2008, 2011 for details). For the current study, data on PA and habit from the baseline (t0), 6-month (t1), and 12-month (t2) measurements were used. Baseline measurement lasted from March to June.

At baseline, *age*, *sex*, *body mass index (BMI)*, *educational level* (low, medium, or high), *marital status* (having a partner or not having a partner), and the presence of a *functional limitation* were assessed.

Items referred to sufficient PA, which, in accordance with the PA recommendation for people aged 50 years or older (Haskell et al., 2007; Nelson et al., 2007), was explicitly defined as being at least moderately or vigorously physically active for at least 30 min per day on at least 5 days per week. This definition was repeated several times as a reminder. These reminders were spread proportionally over the questionnaire. Whereas participants were instructed to report their PA of an average, normal week in the last month, the items measuring habit did not refer to a specific time frame.

The primary outcome measure was *total weekly days of PA*, assessed with the self-administered Dutch short questionnaire to assess health-enhancing PA (SQUASH). The overall reliability (r spearman = .57) and relative validity of the SQUASH in relation to Actigraph^{TM} activity monitors (r spearman = .67) were reasonable in older subjects (Wagenmakers et al., 2008). A single-item question of the SQUASH was used: 'On how many days per week are you, in total, moderately or vigorously physically active for at least 30 min by undertaking, for example, heavy walking, cycling, chores, gardening, sports or other moderate or vigorous physical activities?' Although single-item self-reports may be less accurate, studies provided support for the validity and reliability of single-item self-reports of PA (Iwai et al., 2001; Jackson, Morrow, Bowles, FitzGerald, & Blair, 2007; Li, Carlson, & Holm, 2000; Milton, Bull, & Bauman, 2011; Milton, Clemes, & Bull, 2013; Wanner et al., 2014; Weiss et al., 1990). The percentage of occasional missing values (i.e., not due to dropout) for PA was 0.4% (t0), 0.1% (t1), and 0.1% (t2).

Habit was measured using the Self-Report Behavioral Automaticity Index (SRBAI) (Gardner, Abraham, Lally, & De Bruijn, 2012). The SRBAI consists of four items: 'Being sufficiently physically active is something ...I do automatically, ...I do without having to consciously remember, ...I do without thinking, ...I start doing before I realize I'm doing it'. Answering options ranged from 'totally disagree' (–2) to 'totally agree' (2). Cronbach's alpha was .88 (t0), .86 (t1), and .86 (t2). The average percentage of occasional missing values for habit items was 6.5% (t0), 5.3% (t1), and 2.7% (t2).

Study 2. Similar to the approach in Study 1, data were collected by means of questionnaires at baseline and at 3, 6, and 12 months after baseline measurement (see Peels et al., 2012 for details). Data on demographic (t0) and health-related characteristics (t0) and on PA and habit from the baseline (t0), 6-month (t1), and 12-month (t2) measurements were used in this study. Baseline measurement lasted from November to March.

The definition of sufficient PA and the operationalization of *total weekly days of PA* are the same as in Study 1. The percentage of occasional missing values for PA was 2.2% (t0), 3.6% (t1), and 2.2% (t2). *Habit* was measured in a slightly different way compared to Study 1. In Study 2 four automaticity items were taken from the Self-Report Habit Index (SRHI; Verplanken & Orbell, 2003). Two of these items are also part of the SRBAI (see Study 1), the other two are not. Participants had to rate four statements: 'Being sufficiently physically active is something ...I do automatically, ...I start doing before I realize I'm doing it ...I would find hard not to do, ...I have no need to think about doing'. Answering options ranged from 'totally disagree' (–2) to 'totally agree' (2). Cronbach's alpha was .90 (t0), .87 (t1), and .86 (t2). The average percentage of occasional missing values for habit items was 2.7% (t0), 5.7% (t1), and 4.7% (t2).

Analyses

Means and standard deviations were calculated using SPSS 23 (IBM Corp., Armonk, NY). The research questions were examined in a SEM framework. The analyses were conducted with Mplus 5.21 (Muthén & Muthén, 1998–2007), using maximum likelihood estimation to cope with missing values.

Participants of both the control group and the intervention conditions were included in the current studies. To control for influence of interventions, the analyses were adjusted for treatment condition by the use of dummy variables. However, in order to eliminate any concern about possible residual intervention effects not controlled for by dummy variables, the analyses were also conducted in the control group alone.

As recommended by Byrne (2012), the measurement model and structural model were constructed separately. Habit was a latent construct, measured by separate indicators, as defined in the description of the questionnaire. Confirmatory factor analysis was used to test the measurement model. A minimum factor loading of .40 was applied (Stevens, 2002). The adequately defined measurement model was used for the path analysis with latent variables in the structural model.

In the structural model t0 variables were modeled as predictors of t1 variables, which, in turn, were modeled as predictors of t2 variables. Age and the presence of a functional limitation were included as covariates for t1 and t2 variables. In addition to the structural paths, covariances between predictor variables at each time point were included (see Figure 1). Furthermore, since panel data were used, identical indicators across time points were expected to correlate (Bollen, 1989; Landis, Edwards, & Cortina, 2009). Therefore, residual covariances among all identical indicators were defined a priori.

Overall model fit was assessed using a combination of fit indices. Chi-square tests were conducted to test for differences between theoretical and observed models. A good model fit is indicated by $p > .05$ (Tabachnick & Fidell, 2007). This p-value, however, is sensitive to large sample sizes and easily produces a statistically significant result therein (Kline, 2011). In addition, Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Tucker-Lewis index (TLI) were calculated to evaluate model fit. An adequate model fit is indicated by RMSEA < .08, CFI > .90, and TLI > .90 (Schumacker & Lomax, 2010; van de Schoot, Lugtig, & Hox, 2012), whereas a good model fit is obtained when RMSEA < .06, CFI > .95, and TLI > .95 (Hu & Bentler, 1999).

Mediation effects were estimated using the product of coefficients test (e.g., MacKinnon, 2008). This test determines how much of the effect of an independent variable on a dependent variable is exerted through one or more mediator variables. It assumes the mediation effects to be normally distributed, which is usually only the case in large samples (Jose, 2013), a prerequisite that is met in this study. In addition, 95% confidence intervals (CI) based on the distribution of the product were calculated, using RMediation (Tofighi & MacKinnon, 2011). CIs based on the distribution of the product take nonnormality of the mediation effects into account (Tofighi & MacKinnon, 2011). The percentage mediated effect (PME) was used as an effect size to evaluate the magnitude of the mediation effects (see MacKinnon, 2008). PME requires a sample size of at least 500 (MacKinnon, Warsi, & Dwyer, 1995), a criterion that is met in this study. The completely standardized indirect effect ($\hat{a}\hat{b}_{cs}$) (Preacher & Kelley, 2011) was also used as an effect size. This effect size was evaluated according to Cohen's r^2 criteria (.01 = small; .09 = medium; .25 = large) (Cohen, 1988). The total amount of variance explained in PA(t1), PA(t2), habit (t1), and habit(t2) was calculated and evaluated using Cohen's f^2 effect size (.02 = small; .15 = medium; .35 = large) (Cohen, 1988).

Results

Descriptives

Study 1. With participants' ages varying from 50 to 98 years, the mean age in the total sample was 63.63 years (*SD* = 8.66). Males were slightly underrepresented (43%). About half of the participants (51%) met the PA recommendation at baseline. Functional limitations were reported by 30% of participants. The average BMI was 25.48 (*SD* = 3.76). Level of education was low for 48%, medium for 19%, and high for 33% of participants. Of all participants, 81% had a partner. Means and standard deviations of PA and habit and maximum likelihood bivariate correlations are shown in Table 1.

Study 2. Participants' ages varied from 49 to 94 years (*M* = 62.75, *SD* = 8.57). Sex was nearly equally distributed (51% women, 49% men). Less than half of the participants (44%) met the PA recommendation at baseline. Functional limitations were reported by 45% of participants. The average BMI was 25.86 (*SD* = 3.99). Of all participants, level of education was low for 47%, medium for 27%, and high for 26%, while 83% reported having a partner. Descriptive statistics of PA and habit are provided in Table 1.

Measurement Models

Study 1. The measurement model showed a good model fit, χ^2 (39) = 195.78, $p < .001$, CFI = .98, TLI = .97, RMSEA = .05. With factor loadings ranging from .70 to .85, all factor loadings exceeded the minimum level of .40.

Study 2. The measurement model yielded a good model fit, χ^2 (39) = 252.28, $p < .001$, CFI = .98, TLI = .97, RMSEA = .05, with factor loadings ranging from .74 to .89.

Structural Models

Study 1. The structural regression model yielded an acceptable model fit, χ^2 (106) = 652.03, $p < .001$, CFI = .95, TLI = .93, RMSEA = .05. A significant mediation effect was found for the habit(t0)-PA(t1)-habit(t2) path (product of coefficients' $z = 2.73$, $p = .006$, CI = [.004; .019], $\hat{a}\hat{b}_{cs} = .011$, PME = 2.7%). The PA(t0)-habit(t1)-PA(t2) path reached marginal significance ($z = 1.84$ $p = .067$, CI = [.000; .011], $\hat{a}\hat{b}_{cs} = .005$, PME = 2.4%) (see Figure 2). The $\hat{a}\hat{b}_{cs}$'s of the significant mediation effects indicate small effect sizes. Age(t0) was not a significant predictor of PA and habit on both t1 and t2 ($p > .10$). Less functional limitations on baseline predicted more PA (path estimate = .072, $p = .004$) and habit (path estimate = .093, $p < .001$) on t2, but not on t1 ($p > .10$).

The structural model explained 25.2% of variance in PA(t1), 33.5% of variance in PA(t2), 44.7% of variance in habit(t1), and 49.1% of variance in habit(t2), indicating large effect sizes: $f^2_{PA(t1)} = .34$, $f^2_{PA(t2)} = .50$, $f^2_{Habit(t1)} = .81$, and $f^2_{Habit(t2)} = .96$.

The same structural model was analyzed using only control group data. The analysis showed an acceptable model fit. The habit (t0)-PA(t1)-habit(t2) path was significant, whereas the PA(t0)-habit(t1)-PA(t2) path was not.[1]

Study 2. The model fit for the structural regression model was good, χ^2 (124) = 472.86, $p < .001$, CFI = .97, TLI = .96, RMSEA = .04. A significant mediation effect was found for the path PA(t0)-habit(t1)-PA(t2) ($z = 4.07$, $p < .001$, CI = [.016; .044], $\hat{a}\hat{b}_{cs} = .030$, PME = 10.8%). The $\hat{a}\hat{b}_{cs}$ indicates a small effect size. The mediation effect of the habit(t0)-PA(t1)-habit(t2) path was not significant ($z = 1.22$, $p = .221$, CI = [–.004; .017], $\hat{a}\hat{b}_{cs} = .007$, PME = 1.3%) (see Figure 2). Age(t0) did not predict PA on both t1 and t2 ($p > .10$) and had marginally significant relationships with habit on t1 (path estimate = –.040, $p = .092$) and t2 (path estimate = .045, $p = .059$).

Table 1 Means, Standard Deviations, Ranges, and Maximum Likelihood Estimated Bivariate Correlations for Study 1 and Study 2

		Study 1									Study 2								
		M	*SD*	Range	1.	2.	3.	4.	5.	6.	*M*	*SD*	Range	1.	2.	3.	4.	5.	6.
1.	Physical activity t0	4.14	2.22	0–7	–						4.02	2.03	0–7	–					
2.	Physical activity t1	4.61	1.98	0–7	.47	–					4.85	1.84	0–7	.56	–				
3.	Physical activity t2	4.55	2.02	0–7	.44	.56	–				4.49	1.98	0–7	.53	.61	–			
4.	Habit t0	.41	.86	–2 to 2	.34	.27	.27	–			.45	.89	–2 to 2	.50	.44	.38	–		
5.	Habit t1	.38	.82	–2 to 2	.27	.32	.26	.63	–		.45	.83	–2 to 2	.49	.51	.44	.71	–	
6.	Habit t2	.37	.85	–2 to 2	.29	.31	.33	.63	.66	–	.45	.81	–2 to 2	.43	.44	.47	.67	.77	–

Abbreviations: t0 = baseline measurement; t1 = 6-month measurement; t2 = 12-month measurement.

Note. All correlations stem from model estimations in which only the correlations depicted above and residual covariances between identical indicators across time points were defined. For Study 1 (*N* = 1,976), the model yielded a good model fit: χ^2 (66) = 443.29, $p < .001$, CFI = .97, TLI = .95, RMSEA = .05. For Study 2 (*N* = 2140), the model showed a good model fit: χ^2 (66) = 308.92, $p < .001$, CFI = .98, TLI = .97, RMSEA = .04.

All correlations are significant at .001 level (two-tailed).

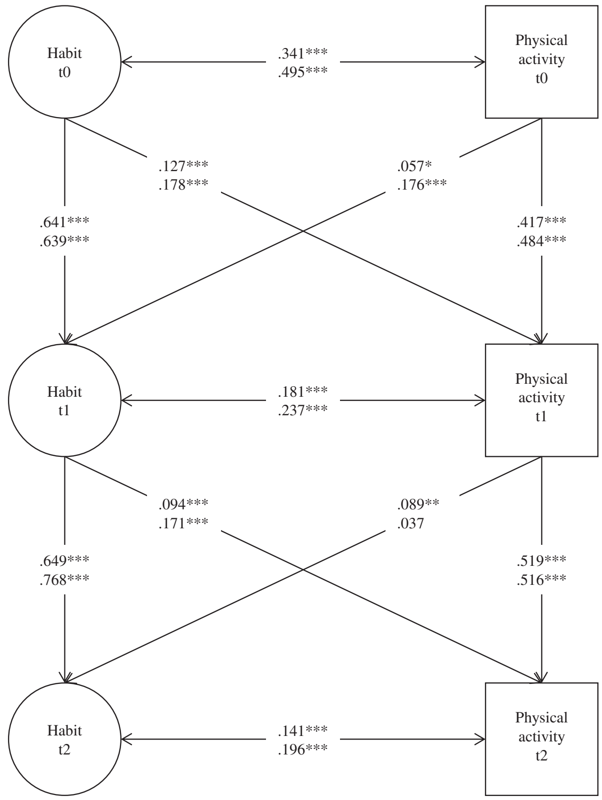

Figure 2 — Cross-lagged panel design with three-wave data. *Note:* Top values indicate standardized maximum likelihood estimates for Study 1; bottom values indicate standardized maximum likelihood estimates for Study 2. Results for analyses using data from both control and intervention conditions are shown. The analyses were adjusted for treatment condition by the use of dummy variables. Age and the presence of a functional limitation were used as covariates. For reasons of clarity, dummy variables and covariates are not shown. Latent variables are represented in circles, observed variables in rectangles. Model fit for Study 1: χ^2 (106) = 652.03, $p < .001$, CFI = .95, TLI = .93, RMSEA = .05. Model fit for Study 2: χ^2 (124) = 472.86, $p < .001$, CFI = .97, TLI = .96, RMSEA = .04. t0 = baseline measurement; t1 = 6-month measurement; t2 = 12-month measurement. $*p < .05$; $**p < .01$; $***p < .001$ (two-tailed).

Less functional limitations on baseline predicted more PA (path estimate = .068, $p = .004$) and habit (path estimate = .055, $p = .022$) on t2, but not on t1 ($p > .10$).

The structural model explained 37.9% of variance in PA(t1), 41.3% of variance in PA(t2), 57.0% of variance in habit(t1), and 64.1% of variance in habit(t2), indicating large effect sizes: $f^2_{PA(t1)} = .61$, $f^2_{PA(t2)} = .70$, $f^2_{Habit(t1)} = 1.33$, and $f^2_{Habit(t2)} = 1.79$.

The analysis was also conducted using only control group data. The model fit was found to be acceptable. The PA(t0)-habit(t1)-PA (t2) path was significant. The habit(t0)-PA(t1)-habit(t2) path was not significant.[2]

Discussion

The two current longitudinal studies in older adults used a cross-lagged panel design to test the hypothesis that habit mediates the relationship between prior and later PA, while PA simultaneously mediates the relationship between prior and later habit. Results were to some degree ambiguous (see Table 2). The hypothesized mediating role of PA in the relationship between prior and later habit was confirmed in Study 1. However, this result was not replicated in Study 2. The PA-habit-PA path was marginally significant in Study 1 and significant in Study 2 when using data for analysis from the combined control and intervention conditions. This path also reached significance when only using control group data in Study 2, but not in Study 1. The effect sizes of all significant mediation effects were small. It is, however, not uncommon for mediation effects to be small in size (MacKinnon, 2008). Altogether, the current studies found indications for the existence of both hypothesized mediation effects. These indications were somewhat stronger for the PA-habit-PA path than for the habit-PA-habit path (see Table 2). Overall, results did not show a clear, unequivocal pattern.

Evidence, albeit not unequivocal, was found for the PA-habit-PA path. This result strengthens an assumption underlying many interventions. PA interventions in older adults often result in small and short-lived behavior changes (van der Bij, Laurant, & Wensing, 2002). Habit formation has been proposed as an effective way to prevent relapses and to ensure long-term maintenance of behavior (Lally et al., 2008; Rothman et al., 2009; Verplanken & Wood, 2006). Based on this proposition habit formation, intervention studies have been conducted in several health domains, such as weight loss (Lally et al., 2008), dental flossing (Judah, Gardner, & Aunger, 2013), balance and strength training (Fleig et al., 2016), and exercise (Fleig, Pomp, Schwarzer, & Lippke, 2013). Quantitative analyses showed that these interventions were effective. Qualitative analyses indicated that participants experienced increases in automaticity (Fleig et al., 2016; Lally et al., 2008, 2011). These findings demonstrate that habit formation via an intervention is possible. However, the majority of intervention studies do not explicitly target habit formation, but assume that behavior will gradually become habitual (Lally et al., 2008). In other words, in the PA domain, many interventions assume a PA-habit-PA path. As can be seen in Table 2, the current studies found significant PA-habit-PA paths in two out of four tests and a marginal significant path in one out of four tests. This result partly confirms the hypothesis of existence of PA-habit-PA paths in nonintervention settings (i.e., the analyses were either controlled for intervention condition or were only conducted in control

Table 2 Significances and Nonsignificances of Mediation Effects for Study 1 and Study 2

		habit(t0)-PA(t1)-habit(t2)	PA(t0)-habit(t1)-PA(t2)
Study 1	Intervention and control group	Significant	Marginally significant
	Control group	Significant	Nonsignificant
Study 2	Intervention and control group	Nonsignificant	Significant
	Control group	Nonsignificant	Significant

groups) and strengthens the abovementioned assumption underlying many interventions. How can the nonsignificant finding in the analysis of the control group of Study 1 be explained? In Study 1, the control group may lack power, which was noticeable in the maximum likelihood path estimate of PA(t0) on habit(t1) of the control group compared to the estimate of the combination of control and intervention conditions. Although the estimates were roughly the same, the estimate was significant (.057, see Figure 2) when analyzing data from the combination of control and intervention conditions, but not significant when using data from only the control group (.063, result not shown). The nonsignificance of the PA-habit-PA path in the control group may as well be ascribed to a lack of power. At the same time, this mediation effect was significant in the control group in Study 2. What could be the reason for this dissimilarity in results between Study 1 and Study 2? In Study 2 the correlation between PA(t0) and habit(t1) was stronger than in Study 1, which may account for a stronger maximum likelihood path estimate of PA(t0) on habit(t1) in Study 2 (.210, significant, result not shown) than in Study 1 (.063, not significant, result not shown). The weaker correlation has contributed as well to the nonsignificance of the mediation effect in Study 1. Different operationalizations of habit may account for the differences in correlations between Study 1 and Study 2. In Study 1 the SRBAI (Gardner et al., 2012) was used. This measurement instrument consists of four automaticity items taken from the SRHI (Verplanken & Orbell, 2003). In their validation study Gardner et al. (2012) found that although seven SRHI-items measured automaticity, four of them most confidently and consistently captured habit's automaticity. The SRBAI is built up of these four items. In Study 2 an alternative habit scale was used, consisting of two SRBAI items and two out of the three automaticity items from the SRHI that were not included in the SRBAI. Of these latter two items, neither judging expert in the study by Gardner et al. (2012) was at least 90% certain that they represented automaticity. The habit scale that was used in Study 2 has thus captured habit's automaticity differently compared to Study 1, and with slightly less confidence. The difference in habit scales may have had an impact on the correlations with PA, resulting in stronger correlations for the alternative habit scale with PA than for the SRBAI. In sum, the current studies found indications that PA sustains over time through habit, although the pattern was not completely unequivocal. In order to gain deeper insight into habit's role as mediator of the relationship between prior and later PA, it is recommended to replicate the current studies, using observational as well as experimental designs.

The habit-PA-habit path reached significance in Study 1 when using data from the combination of control and intervention conditions as well as from the control group alone. These findings were not replicated in Study 2 (see Table 2). What may account for these different findings? The main difference between Study 1 and Study 2 is the path from PA(t1) leading to habit(t2). Despite a stronger correlation between PA(t1) and habit(t2) in Study 2 than in Study 1, the path from PA(t1) on habit(t2) was significant in Study 1, but not in Study 2 (see Figure 2). Both studies share strong autoregression from habit(t1) on habit(t2), albeit that this autoregression seems to be stronger in Study 2. The difference in autoregression may be a consequence of different operationalizations of habit as described above. The stronger autoregression in Study 2 may have left too little variance in habit(t2) to be modeled by PA(t1). In all, the findings of the current studies show an equivocal pattern, that only partly supports that habit sustains over time through PA, thereby contributing to PA behavior. Based on Study 1 it is recommended to incorporate strategies into interventions for older adults that explicitly focus on forming new PA habits, that expand existing habitual PA patterns (e.g., walking 30 min instead of 20 min after every evening meal) and/or that increase the level of PA contained therein (e.g., intensive walking instead of moderate walking after every evening meal). This recommendation, however, has no foundation in Study 2. More research on the habit-PA-habit path is therefore recommended.

Whereas the mean scores on habit in the current studies were quite stable, PA scores seemed to increase from t0 to t2 (see Table 1). This result may indicate that a habit at the same level of strength, but for more PA, was developed. From a health perspective, that would be a clear gain. The stable mean habit scores were far from the maximum level of the scale (see Table 1). Why did habit not increase despite PA enactment? In their experiment Lally et al. (2010) found that the plateau of habit strength that many participants reached for exercise was below the maximum score for habit. Thus, although below the scale maximum, the rather stable mean scores on habit in the current study may indicate that the research sample had already reached its plateau of habit strength at the start of the study. Small decreases in mean habit strength may be an effect of measuring at this plateau. In order to get a more complete understanding of the mutual influence of PA and habit, it is recommended to replicate the current studies using samples that have lower mean scores on habit at baseline. In addition, another mechanism may have caused small decreases in mean habit scores. Filling in PA questionnaires may have increased the level of awareness of PA behavior, which, in turn, may have negatively affected the unaware, habitual response.

The current studies raised ambiguous findings. As stated above, replication studies are warranted, using both observational and experimental designs. In addition, another direction for future research needs to be mentioned. Examining the longitudinal mediated relationships between habit and health-related behaviors other than PA is recommended. Habits are after all not only important for PA, but also for other health-related behaviors. Research on these mediated relationships can contribute to a fuller grasp of habits. Cross-lagged panel designs may be used as well. A major advantage of cross-lagged panel designs for mediation analysis is that several mediation effects can be tested simultaneously using the same time frame. Variations in populations and in the time lags used will contribute to a deeper and more complete understanding of mediated relationships between habit and health-related behaviors.

Age did not exert a clear influence on PA and habit. The presence of a functional limitation did neither affect PA(t1) nor habit(t1). Three out of four tests showed that the absence of a functional limitation at baseline was associated with more PA 1 year later (i.e., at t2). While in two out of four tests a significant association was found with habit(t2), in one out of four tests a marginal significant association was found. In light of prevention, these results are relevant, as the trend in results seems to indicate that once an older adult has a functional limitation, this will affect the level of PA and habit on the long run. This implies that functional limitations should be addressed, considered, and anticipated in interventions for older adults. How can this be done? Older adults often attribute functional limitations unjustly to the aging process rather than to volitionally controllable, unstable, external sources (Levy, Ashman, & Slade, 2009; Sarkisian, Liu, Ensrud, Stone, & Mangione, 2001), which implies that PA interventions should target older adults' views on aging (Wolff, Warner, Ziegelmann, & Wurm, 2014). Furthermore, many injuries and subsequent functional limitations in older adults are caused by falls (Rubenstein, 2006). PA interventions in older adults should thus include falls prevention. PA programs for older adults that include balance and strength training have been proven effective in reducing falls as well as the risk of falling (Karlsson, Vonschewelov, Karlsson, Cöster, & Rosengen, 2013; Sherrington, Tiedeman, Fairhall, Close, & Lord, 2011). Fleig et al. (2016) showed that older adults can form balance and strength exercise habits.

When functional limitations first arise, they may signal a major life change, depending on the seriousness. Other major life changes for older adults are, for instance, entering retirement, becoming grandparents, or moving houses. Major life changes often disrupt the connection between critical cues in an environment and habitual action (Verplanken & Wood, 2006; Wood, Tam, & Witt, 2005). This opens a window in which a new habit can be attached to cues in the environment (Verplanken & Wood, 2006), which may as well be a PA habit for activities that are still possible in presence of a functional limitation. In their review, Lally and Gardner (2013) identify several effective intervention strategies to create new habits, such as the use of reminders, self-monitoring and self-control, awareness of cues, implementation intentions, and mental contrasting.

Some limitations of the present study have to be addressed. First, a self-report single-item measure of PA was used. Although studies provided support for the reliability and validity of single-item self-reports of PA (Iwai et al., 2001; Jackson et al., 2007; Li et al., 2000; Milton et al., 2011, 2013; Wanner et al., 2014; Weiss et al., 1990), self-reports may be both higher and lower than true levels of PA (Prince et al., 2008), as they may suffer from memory biases (Scollon, Kim-Prieto, & Diener, 2003; Smyth & Stone, 2003). The use of accelerometers in future studies is recommended, as they overcome problems with recall and memory bias. However, accelerometers are also not without limitations, since they cannot accurately detect PA in situations where much of the body remains stationary (e.g., cycling or arm movements in resistance training) (Andre & Wolf, 2007; Bassett et al., 2000; Esliger, Copeland, Barnes, & Tremblay, 2005; Hendelman, Miller, Baggett, Debold, & Freedson, 2000). A recent study found that not all accelerometers are valid (Berendsen et al., 2014). Moreover, the utility of accelerometers is affected by the participants' willingness and commitment to wear them (Esliger et al., 2005). Nevertheless, studies using accelerometers will add to the understanding of the relationships between habit and PA. Second, habit was also assessed using self-report measures. Although the SRBAI, used in Study 1, is a reliable and valid instrument (Gardner et al., 2012), its nature remains subjective. Study 2 relied on a habit scale that consisted of four automaticity items taken from the reliable and valid SRHI (Verplanken & Orbell, 2003). Nevertheless, its nature is also subjective. Third, although chances are low, the existence of seasonal effects cannot entirely be ruled out. Both current studies had a broad, but completely different, inclusion period, with baseline measurement from March to June for Study 1 and from November to March for Study 2. Nonetheless, data patterns were highly comparable, which speaks against the presence of seasonal effects. Moreover, participants were instructed to report their PA of an average, normal week in the last month, which makes reports on weeks with a lot of rainfall or other weather extremes unlikely. Fourth, based on temporal precedence, causal associations in the cross-lagged panel model are assumed. However, this assumption is not a test of causal inference. Fifth, the samples of the current studies displayed rather high levels of PA and stable mean scores on habit, which may affect the generalization of the results.

Several strengths of this study also have to be acknowledged. First, our studies were, to our knowledge, the first to model longitudinal mediated relationships between habit and PA in a cross-lagged panel design, spanning a period of 1 year. Second, our research populations consisted of older adults. Demographic development predictions for the near future indicate a rapid growth of the population of older adults in the Western world (Christensen et al., 2009). As a large proportion of older adults are insufficiently physically active (Hallal et al., 2012; Sun et al., 2013), this points out the major relevance of stimulating PA in older adults. Insight into the working mechanisms of habit and PA may help to design stronger effective interventions to increase PA in older adults, which, ultimately, may help them to obtain many health benefits. Third, we performed SEM analyses, instead of regression analyses, which are frequently used in mediation studies. SEM analyses have the advantage of taking measurement errors into account and providing important additional information about model fit (Byrne, 2012; Schumacker & Lomax, 2010), and thus give a more complete statistical underpinning of the results (Peyrot, 1996). Fourth, we used the product of coefficients test, which provides a direct estimate of the mediation effect (Hayes, 2013; MacKinnon, 2008), and confidence intervals based on the distribution of the product, that take nonnormality of the mediation effects into account (Tofighi & MacKinnon, 2011).

In sum, the present study found indications for the existence of both PA-habit-PA paths and habit-PA-habit paths, but did not show a clear, unequivocal pattern. Somewhat more support was found for the PA-habit-PA path than for the habit-PA-habit path. More research is needed to draw more definitive conclusions.

Endnotes

[1]Model fit for control group Study 1: χ^2 (88) = 269.54, $p < .001$, CFI = .95, TLI = .93, RMSEA = .06. Significant habit(t0)-PA(t1)-habit(t2) path: $z = 1.96$, $p = .050$, CI = [.003; .038], $\hat{a}\hat{b}_{cs} = .016$, PME = 3.4%); nonsignificant PA(t0)-habit(t1)-PA(t2) path: $z = 1.22$, $p = .224$, CI = [–.002; .017], $\hat{a}\hat{b}_{cs} = .006$, PME = 2.6%). Age(t0) was not a significant predictor of PA and habit on both t1 and t2 ($p > .10$). Less functional limitations on baseline predicted more PA on t2 (path estimate = .109, $p = .005$), but not on t1 ($p > .10$), and had a marginally significant relationship with habit on t2 (path estimate = .078, $p = .051$), but not on t1 ($p > .10$).

[2]Model fit for control group Study 2: χ^2 (88) = 206.15, $p < .001$, CFI = .96, TLI = .94, RMSEA = .06. Nonsignificant habit(t0)-PA(t1)-habit(t2) path: $z = .91$, $p = .362$, CI = [–.012; .040], $\hat{a}\hat{b}_{cs} = .011$, PME = 2.2%); significant PA(t0)-habit(t1)-PA(t2) path: $z = 1.85$, $p = .064$, CI = [.003; .068], $\hat{a}\hat{b}_{cs} = \triangleright 032$, PME = 10.7%). The results from normal theory approach (i.e., the p-value) and confidence intervals based on distribution of the product are inconsequential for the PA(t0)-habit(t1)-PA(t2) path. From these two approaches the confidence intervals are most trustworthy (Hayes, 2013; Jose 2013). Thus, the result can be interpreted as significant. Age(t0) was a significant predictor of PA on t2 (path estimate = .113, $p = .027$), but not on t1 ($p > .10$). Habit scores on t1 and t2 were not predicted by baseline age ($p > .10$) Functional limitations on baseline were not significantly associated with PA and habit on either t1 or t2 ($p > .10$).

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