Applying Mixed-Effects Location Scale Modeling to Examine Within-Person Variability in Physical Activity Self-Efficacy

Genevieve Fridlund Dunton[1,*], Audie A. Atienza[2], Jimi Huh[1], Cynthia Castro[3], Donald Hedeker[4] and Abby C. King[5]

[1]*Department of Preventive Medicine, University of Southern California, 2001 N. Soto Street, Los Angeles, CA 90033, USA*

[2]*Science of Research and Technology Branch, Behavioral Research Program, National Cancer Institute, 6130 Executive Blvd, Rockville, MD 20852, USA*

[3]*Stanford Prevention Research Center, Stanford University School of Medicine, 1265 Welch Road, Mail Code 5411, Stanford, CA 94305-5411, USA*

[4]*Division of Epidemiology & Biostatistics, School of Public Health, University of Illinois, Chicago, 1603 W. Taylor, Chicago, IL 60612, USA*

[5]*Division of Epidemiology, Department of Health Research & Policy, and Stanford Prevention Research Center, Department of Medicine, Stanford University School of Medicine, 259 Campus Drive, HRP Redwood Building, T221, Stanford, CA 94305-5405, USA*

Abstract: *Background*: Physical activity self-efficacy is conceptualized as a construct that is changeable and responsive to contextual factors. The current study applied mixed-effects location scale modeling to examine within-person variability in physical activity self-efficacy among middle-aged and older adults (N = 14 adults, mean age = 59.4 years) who were attempting behavior change.

Methods: An electronic diary was used to record self-reported self-efficacy and physical activity *via* Ecological Momentary Assessment (EMA) twice a day (2:00 pm and 9:00 pm). Data from weeks 1-6 were analyzed using a Mixed-Effects Location Scale Model in SAS PROC NLMIXED.

Results: Participants differed from each other in the degree to which physical activity self-efficacy varied from day to day (p = .03). Within-person variation in self-efficacy was negatively related to levels of brisk walking each week (p = .002), and decreased over time (p = .03).

Conclusions: Preliminary results suggest that fluctuations in self-efficacy may be as important for predicting short-term behavior as the overall or mean level of self-efficacy.

Keywords: Within-person variability, Multilevel modeling, Walking, Mood, Adults.

INTRODUCTION

Participation in regular physical activity declines as adults enter the sixth decade of life [1]. To identify modifiable factors that could serve as potential intervention targets to promote physical activity, research has sought to understand the psychosocial mechanisms and processes underlying physical activity behavior change. Self-efficacy (i.e., confidence in one's ability to perform a specific behavior) plays an important role in physical activity among mid-life and older adults [2, 3]. Social-Cognitive Theory posits that self-efficacy processes are malleable and responsive to psychological and situational cues—characteristics that make it a potential candidate for therapeutic change [4]. However, the predominant approach to understanding self-efficacy among researchers has been to treat it as a person-level construct (i.e., making between-person comparisons), thus ignoring possible day-to-day variability in response to contextual factors. To better understand the dynamic interaction between self-efficacy and physical activity behavior it may be necessary to take a within-person (i.e., intra-individual) perspective [5].

The current pilot study applied a novel statistical strategy, mixed-effects location scale modeling [6,7], to examine factors that predict within-person day-to-day variability in physical activity self-efficacy among adults ages 50 years and older who participated in an 8-week hand-held computer-based intervention to increase physical activity. This research aimed to determine whether within-person day-to-day variability in physical activity self-efficacy changed across the course of the intervention (Aim 1). We hypothesized that day-to-day variability in self-efficacy scores would decrease with

*Address correspondence to this author at the Department of Preventive Medicine, University of Southern California, 2001 N. Soto Street, 3rd floor, Rm 302E, MC 9239, Los Angeles, CA 90033-9045, USA; Tel: 323-442-8224; Fax: 323-442-8201; E-mail: dunton@usc.edu

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time during the intervention. We also sought to determine whether day-to-day variability in physical activity self-efficacy was related to level of brisk walking on any given week (Aim 2). We hypothesized that an individual's self-efficacy scores would be less variable during weeks when he/she performed more brisk walking. We also sought to determine whether day-to-day variability in self-efficacy was associated with gender, age, body mass index, mood, and day of the week (Aim 3).

METHODS

Overview and Participants

This study conducted secondary analysis of data from the pilot test of an 8-week randomized, controlled intervention study to promote physical activity using hand-held computers. The sample consisted of middle-aged and older adults. Study methods have been described previously [8], and are summarized here. Inclusion criteria consisted of the following: (a) 50 years or older, (b) participating in 60 minutes or less of moderate-to-vigorous-intensity physical activity per week, (c) free of medical conditions limiting physical activity, (d) English language proficiency to allow informed consent and participation in study procedures, (e) willing and able to be instructed in using an electronic diary on a regular basis, and (f) willing to be randomized. Participants were either randomized into a hand-held computer-based intervention arm (where they received a PDA that was programmed to deliver electronic interactive Ecological Momentary Assessment [EMA] surveys with tailored feedback to promote physical activity) or a standard information-only control arm (where they received health educational paper materials pertaining to physical activity). Data for the current analyses were derived from the computer-based electronic EMA surveys, which were only administered in the intervention group. Thus, only intervention group participants were included in our statistical modeling. The major study results are reported elsewhere and show that the intervention was generally effective in increasing physical activity levels and dietary intake relative to control [8]. This research was reviewed and approved by the Institutional Review Board at Stanford University.

Procedure

Participants received a handheld PDA electronic diary (Dell Axim X5, 2003; Dell Inc., Round Rock, TX). These devices are small (83.6[W] x 131.2 [L] x 20.0 [H] mm), portable, lightweight, and battery operated. The device was programmed to ask a series of questions measuring contextual, psychosocial, motivational, and behavioral factors *via* EMA. The electronic PDA prompted participants twice a day (2:00 pm and 9:00 pm) throughout the 8-week study. An auditory signal prompted participants to complete the diary at the designated times. If they did not respond to the first prompt, a second signal was emitted 30 minutes later (and again at 60 and 90 minutes if there was no response). After this time, the diary survey was not available until the next scheduled assessment time.

Measures

Psychosocial factors and physical activity were measured through questions appearing in the electronic EMA sequence. Questions were adapted from past research using momentary assessments *via* pocket computers [9].

Predictor Variables

Brisk walking was assessed with a single item, "How many TOTAL minutes of brisk walking have you engaged in since *[your last log]*? (Add up minutes from all times you walked briskly)." Mood was assessed by asking participants the extent to which they experienced 8 different types of emotions at the moment of the diary prompt. A 10-point response scale ranging from "none" to "extreme" was used for each item. Positive Affect (PA) was assessed using a single item: "How satisfied or content do you feel now?" Negative Affect (NA) was assessed by averaging the responses to items worded similarly to the positive affect item but focused instead on being stressed, lonely/alone, annoyed/angry, fatigued/tired, tense/anxious, and sad/depressed. Perceptions of feeling "stressed," "in control," and under "demand" at the moment of the diary assessment were also measured (1 item each) using the 10-point response scale ranging from "none" to "extreme."

Dependent Variable

Self-efficacy for physical activity was assessed through the diary item: "How confident are you that you can engage in physical activity that increases your heart rate for at least 10 minutes between now and [*the next log*]." A 10-point response scale was used ranging from "not at all confident" to "completely confident."

Data Analysis

Prior to analyses, ratings for all predictor variables (e.g., self-efficacy, mood, stress control, demand) were aggregated by day within individuals to control for diurnal variations. This step was taken because the goal of the study was to examine day-to-day variability in self-efficacy (instead of within-day variations that may be due to time of day). Thus, each aggregated score represented average daily self-efficacy, and within-person variability estimates indicated day-to-day fluctuations. Mixed-Effects Location Scale Models [6,7] tested with SAS PROC NLMIXED were used to estimate within-person variability in self-efficacy. This statistical strategy allows for joint modeling of the mean and variance structures of repeated measures data. Within-person variability can be thought of as variability (i.e., standard deviation) around an individual's mean response across a specified period of time (e.g., one week or across several weeks). With a mixed-effects location scale model (see Eq. 1), a random effect to the within-subject (WS) variance can be included (6). This allows us to determine whether BS variance (σ^2) varies across covariates (see Eq. 2), to determine whether WS variance varies across individuals and to examine the effects of covariates on the WS variance (see Eq. 3).

$$y_{ij} = \mathrm{x}'_{ij}\,\beta + \nu_i + \varepsilon_{ij} \qquad \text{(Eq. 1)}$$

$$\sigma^2{}_{\nu i} = \exp(u_i\ \alpha) \qquad \text{(Eq. 2)}$$

$$\sigma^2_{\varepsilon_{ij}} = \exp(w'_{ij}\tau + \omega_i) \qquad \text{(Eq. 3)}$$

for subject i (i = 1, 2,. . . , N subjects) and prompt j (j = 1, 2, . . . , n_i prompts), where w denotes a vector of covariates and τ stands for a vector of corresponding regression weights and ω represents a random effect.

An unconditional mixed-effects location scale model was first tested without any covariates in order to estimate BS variation in WS variation in day-to-day self-efficacy, and the covariance between mean and WS variability in day-to-day self-efficacy. Next, a series of conditional mixed-effects location scale models tested the extent to which person-level (age, gender, BMI, average mood), week-level (week number, weekly level of walking), and day-level (weekend day versus weekday, average daily mood) factors predicted mean (β) and within-person variability (τ) or self-efficacy. Initially, each of the predictor variables was tested in separate bivariate models. As a final step, predictor variables approaching statistical significance (p < .10) in the individual models were simultaneously entered in a full model to test their independent effects. To examine the effects of missing data, an imputation strategy was conducted, which replaced any given missing data cell with the average weekly value of the variable for that particular subject. Sensitivity analyses then compared the mixed-effects location scale models with versus without imputed data.

RESULTS

Descriptive Statistics

In total, 69 adults were screened for eligibility [8]. Of these individuals, 37 attended a study orientation session and were randomized to the computer-based intervention (n = 19) or the standard information control (n = 18). Successful electronic diary retrieval occurred for 14 of 19 intervention participants, which was the sample size in the current study. Reasons for non-retrieval included not returning the electronic diary (n =2) and corruption of files during the process of retrieving or transferring the data (n = 3). Therefore, the final study sample consisted of 14 adults, ages 51– 77 years (M = 59.4, SD = 6.4 years). Of this sample, 50% were women and 69% were married. Seventy-nine percent were white/non-Hispanic, 64% had a college degree or higher, 50% were employed full-time, and 57% reported excellent or very good health status. The average Body Mass Index (BMI) was 28.1 (SD = 4.1), which falls in the overweight range (BMI values between 25-30) [10]. Daily minutes of brisk walking generally increased over time. From weeks 1 to 6, this positive change across the sample was approaching significance ($\hat{\beta}$ = 0.85, SE = 0.41, p = .06). On a 10-point scale, the average score for self-efficacy was 6.7, SD = 1.9 across the entire study period.

EMA Compliance Rates

The average number of days per week in which EMA data were recorded declined across the 8-week study, with the largest decrease occurring during week 7. Therefore, to examine the most representative pool of data, subsequent analyses targeted weeks 1-6. During this time, participants completed an average of 9.3 (SD = 2.9) diary entries per week (about 66% of the 14 prompted diary assessments), summing to a total of 761 diary entries across all participants for the first 6 weeks. Of these diary entries, 58% were responded to at the first prompt, and the remaining were responded to after one of the subsequent prompts. The number of missed prompts per person was unrelated to age, gender, race/ethnicity, marital status, income, employment status, BMI, mean self-efficacy or mean

Table 1: Mixed-Effects Location-Scale Model for Self-efficacy and Intervention Week— Maximum Likelihood Estimates and Standard Errors (SE)

Parameter	Mean (β)	BS var. (α)	WS var. (τ)
Intercept	6.43 (0.40)***	0.69 (0.39)	0.67 (0.27)*
Intervention week	0.08 (0.03)*		-0.11 (0.05)*
Between person var. in scale			0.66 (0.20)*
Covariance (mean and WS var.)			-0.84 (0.40)

BS var. = between-subjects variation. WS var. = within-subjects variation. ***$p < .001$. * $p < .05$.

physical activity (p values > .05). After aggregating data by day within individuals, there was a total of 470 days represented. Sensitivity analyses found that results did not differ for models *with* versus *without* imputed missing data. Thus, the following results are presented for the mixed-effects location scale models run on the original raw data without imputation of missing values.

Day-to-Day Variability in Self-Efficacy

The unconditional mixed-effects location-scale model showed that participants differed significantly from one another in amount of within-person variability in physical activity self-efficacy ($\hat{\tau}$ = 0.71, SE = 0.30, p = .03). The covariance between one's mean level of and within-person variability in self-efficacy was approaching significance ($\hat{\tau}$ = -0.77, SE = 0.40, p =.077), indicating that individuals with higher overall mean self-efficacy levels had less within-person variability in self-efficacy.

Does Day-to-Day Variability in Self-Efficacy Change Over Time? (Aim 1)

The results for the mixed-effects location-scale model with time (week number) as a predictor of mean and day-to-day variability in self-efficacy are shown in Table **1**. The mean ($\hat{\beta}$) coefficient for week number was statistically significant and positive (p = .02), suggesting that self-efficacy increased over time. In contrast, the model showed that within-person day-to-day variability in self-efficacy decreased over the 6 weeks as indicated by the negative within-subjects (WS) var. ($\hat{\tau}$) coefficient for intervention week (p = .03).

Does Physical Activity Level Predict Day-to-Day Variability in Self-Efficacy? (Aim 2)

Table **2** shows the results for the mixed-effects location-scale model testing the associations of physical activity with mean and within-person day-to-day variability in self-efficacy. The mean ($\hat{\beta}$) coefficient for weekly level of walking was significant (p < .001), indicating that each week, mean self-efficacy was positively associated with mean walking level (p < .001). The within-subjects (WS) var. ($\hat{\tau}$) coefficient for weekly physical activity was also significant (p = .002), suggesting that within-person day-to-day variability in self-efficacy was lower during weeks when mean walking levels were higher.

Do Person- and Day-Level Factors Predict Day-To Day Variability in Self-Efficacy? (Aim 3)

Person- and day-level factors were tested as predictors of within-person day-to-day variability in self-efficacy in a series of mixed-effects location-scale models. Person-level factors including gender, BMI, and average mood ratings (i.e., PA, NA, stressed, in control, under demand) were unrelated to within-person

Table 2: Mixed-Effects Location-Scale Model for Self-efficacy and Weekly Walking Level—Maximum Likelihood Estimates and Standard Errors (SE)

Parameter	Mean (β)	BS var. (α)	WS var. (τ)
Intercept	6.29 (0.38)***	0.59 (0.39)	0.79 (0.30)*
Weekly walking level	0.01 (0.002)***		-0.01 (0.002)**
Between person var. in scale			0.90 (0.39)*
Covariance (mean and WS var.)			-0.85 (0.43)

BS var. = between-subjects variation. WS var. = within-subjects variation. ***$p < .001$. **$p < .01$. * $p < .05$.

day-to-day variability in self-efficacy (p's > .05). However, age was approaching significance ($\hat{\tau}$ = 0.07, SE = 0.03, *p* = .067), such that older individuals demonstrated more within-person day-to-day variability. An examination of day-level factors indicated that within-person day-to-day variation in self-efficacy was higher on weekend days as compared to weekdays, which was approaching significance ($\hat{\tau}$ = 0.33, SE = 0.16, *p* = .06). Within-person day-to-day variation in self-efficacy was unrelated to daily mood ratings.

As a final step, variables approaching significance in the individual models reported above (i.e., week number, weekly physical activity level, age, and day of the week) were simultaneously entered into a full mixed-effects location scale model. Results from this analysis indicated that weekly walking level ($\hat{\tau}$ = -0.01, SE = 0.002, *p* = .004) and day of the week ($\hat{\tau}$ = 0.37, SE = 0.16, *p* = .04) remained as statistically significant predictors of day-to-day variability in self-efficacy after adjusting for the other variables in the model.

DISCUSSION

This pilot study tested a novel application of mixed-effects location scale modeling [6, 7] to examine within-person day-to-day variability in physical activity self-efficacy. The preliminary results indicated that while some people experienced consistent levels of self-efficacy (i.e., confidence in their ability to be active) from day to day, others were quite variable.

The negative associations between within-person day-to-day variability in self-efficacy and brisk walking levels during any given week support the notion that within-person variation in social-cognitive processes such as self-efficacy may contribute to behavioral performance [11]. Researchers have proposed that there is heightened within-person variability during the acquisition of a new behavior, as individuals learn how to incorporate new behavior patterns into their daily routines [12]. However, as one reaches and surpasses the target level of performance, continued fluctuations in psychological processes may indicate a lack of robustness and be less adaptive [11]. Decreased day-to-day fluctuations in self-efficacy during weeks with higher physical activity and in the latter weeks of a behavior change attempt, as shown in this study, may signify the successful acquisition of behavioral skills and functioning. However, these findings should be interpreted cautiously given the small sizes of the model coefficients and the lack of information regarding their true clinical significance. Further research is needed to better understand the complex interrelationships between self-efficacy and performance across the behavior acquisition process. Future studies should seek to identify the length of the time periods (e.g., how many weeks or months) during which prolonged variability in self-efficacy can be particularly detrimental to physical activity behavior change.

Patterns of day-to-day variability and consistency in self-efficacy were unrelated to most of the person- and day-level factors tested. Within-person day-to-day variability in self-efficacy did not reliably differ by gender or BMI, although variability increased slightly with age. Day-to-day variability in self-efficacy was also unrelated to daily mood and overall mood levels. However, these results should be interpreted with caution given the small number of subjects in this pilot study. Patterns of within-person day-to-day variability and consistency in self-efficacy could result from unmeasured personality differences or individual differences in daily exposure to varying as compared to stable environments [13]. It is also possible that person-level factors influence within-person variability across different time periods than examined in the current study (e.g., variability across months or years) [14].

There were several limitations to this study. The wait-list control group received standard written materials and did not have electronic data available for analysis for this current paper. Therefore, we were not able to compare the observed patterns of variability in self-efficacy with individuals who were not trying to change their behavior. Also, compliance with the electronic diary protocol declined in the last two weeks of the 8-week study, making it necessary to focus our analyses on the first six weeks of behavior change. Although the use of single-item measures is not preferable, it is often necessary in this type of EMA research in order to limit the length of each electronic survey to less than a few minutes. Furthermore, differences in variability between individuals could reflect individual response sets (i.e., some people may simply choose the same response over time because it was the most expedient way to respond on the surveys). Also, we were unable to test the time delay in electronic diary response as a potential confounder because the analyses were aggregated by day. Due to the small number of participants involved, we had limited power to detect small effects in the between-person analyses examining age, gender and BMI as predictors of within-person variability. These analyses should be replicated in studies with larger samples and different age groups. Lastly, this study did not have the ability to test the direction of causality for the association between walking and within-person day-to-day variability in self-efficacy.

The results preliminarily suggest that, among middle-aged and older adults attempting to increase their regular physical activity levels, the extent to which an individual's self-efficacy beliefs fluctuate on a day-to-day basis may be as important for predicting behavior over the short-term as the overall or mean level of self-efficacy for that individual. Based on these initial findings, interventions seeking to promote increases in regular physical activity for this age group may consider developing strategies to reduce day-to-day variability self-efficacy variability in addition to increasing levels of mean self-efficacy. Furthermore, whether the effects of reducing variability vary at different levels of mean self-efficacy (e.g., moderate versus high levels) is an important direction for future research. The best ways of reducing variability in self-efficacy remain to be investigated, as do the relations between within-person variations in self-efficacy and longer-term physical activity participation. This study represented a first step in examining the factors that may predict day-to-day variability in physical self-efficacy. Future research is needed to replicate and extend these findings in larger samples.

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