# Novel Scale Development for Fear of Falling and Falls: Analysed using a Semiparametric Ratio Estimator (SPRE)

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**Abstract**
Fear of falling (fof) and falls in older adults are an increasingly severe worldwide public health problem impacting quality of life and functional status. The Falls Weight Function (FWF) uses a new scale developed to enable researchers to incorporate fear of falling (fof) into analyses with participants who have already experienced a fall. FWF is a weight function used in initial data transforms for ordinary least squares regression analysis using the semiparametric ratio estimator (SPRE) to predict a change point and subsequent point estimations. FWF data is defined as belonging to a discrete set of numbers that is finite or countable. In a pilot study using Stepping On® fall prevention treatment for elders, initial data is taken from a screening tool where fof responses are counted and summed as increments of 10 values. These values, which range from .1 to 1.0, are multiplied by 1fall. The un-weighted value of 1 fall is multiplied by the weight function for fof. Then the scale of falls and fof is the same, and represented on a continuum from fear of falling to having a fall, so that all participants can be treated together and analysed in the same set of linear regressions.

Keywords: Fear of Falling, (fof), weight function, FWF, semiparametric ratio estimator, SPRE

## 1. Introduction

It is particularly important to treat older adults who have a fear of falling (fof) together with those who have had a fall in any fall prevention program to address the causes and reduce the incidence of falls. Aging adults represent a hetereogeneous population, which can create difficulties in traditional statistical analysis ( Tinetti et al., 1994) as everyone ages differently. The new Falls weight Function (FWF) uses a new scale developed to enable researchers to incorporate fear of falling (fof) into analyses with participants who have already experienced a fall. The FWF is applied during data structuring in Excel so that it will be applied throughout the regression analyses of the semiparametric ratio estimator (SPRE) for single-subjects and small *n* designs.

Why are we interested in predicting health outcomes for fear of falling and falls in older adults? The motivation for this paper comes from occupational and physical therapy where falls and fear of falling (fof) in older adults have been treated and analysed separately, which has excluded those with fof from standard fall remediation programs. Falls, fear of falling and fall related self-efficacy are related yet separate behavioral constructs which can negatively impact older adults and that are measured typically using different scales. A new measurement strategy which allow analysis for both fof and falls is used in this study to best identify effective intervention strategies. The outcome of falling does not directly equate with fof although fof does equate to low fall-related self efficacy and activity restriction (Jørstad et al., 2005;Tinetti et al.,1994;Tinetti et al., 1990). High fear, high number of falls and low self efficacy can cause restrictions in activity and quality of life (Jørstad et al., 2005; Mary E Tinetti et al., 1994). As a result, despite the different constructs involved, many fall prevention programs address fallers, those at risk for falls and those with a fear of falling using the same content. Research on the effectiveness of program content in fall prevention should effectively address the older adult population across all of these constructs. The difficulty lies in methods to analyze this diverse population in statistically sound methodology.

## 1.1 Background

America is growing older. The percentage of 65 and older adults in the US is projected to increase from 13% of the population in 2012 to 21% of the population in 2040. while those 85 and over will triple in number by the year 2040 (*Profile of Older Americans: 2013*, 2013). Increasing age has been associated with increasing fall risk and risk of injury due to falls (Centers for Disease Control and Prevention [CDC], 2010; Lawlor, Patel, & Ebrahim, 2003). The numbers are startling; in a three month survey, 15% of older adult respondents reported falling at least once with injuries reported by 31% of those who had fallen (Stevens, Corso, Finkelstein, & Miller, 2006). One in three older adults fall each year, and falls are the leading cause of both injury and death in the older adult population CDC, 2010. Fear of falling can lead to avoiding activities, decreased quality of life, and increased depression (Arfken, Lach, Birge, & Miller, 1994; Schepens, Sen, Painter, & Murphy, 2012; Tinetti, De Leon, Doucette, & Baker, 1994). Fear of falling increases with age, gender (women), and frailty in the older adult population (Arfken et al., 1994).

## 1.2 Pilot Studies

Several pilot studies have been completed using SPRE analysis methods in conjunction with Stepping On®, a 7 week standardized fall prevention program. The Stepping On Program® is guided by cognitively based theories and adult learning models (Clemson, 2009). Participants with either concern or fear of falling, history of falls or both were included in both the original RCT study as well as the recent pilots using SPRE. However, in the original program, participants with fof were not analysed with those who had had a fall. Participants who were community dwelling older adults showed up to a 30% reduction in fall rate following the program(Clemson et al., 2004; Stevens, 2010) The program is designed to improve self-efficacy or confidence to prevent falls, reduce incidence of falls, and facilitate ability to identify fall risk behaviors and how to mitigate this risk by behavioral choices and skills (Clemson et al., 2004).. An analysis of data from a pilot study by Ahmad, Lesko, Marslander and Randall (2014) provides well-documented trials to determine the efficiency and accuracy of Stepping On® response results. It uses the new SPRE model for the small group assuming that response data is given for each individual and the mean response of 3 participants at any point in time. The collected data was for an initial 22 participants treated by occupational therapists, where data from the Activities-specific Balance Confidence (ABC) Scale developed by Powell et al., (1995) was noted once per week from the start of the trial to the conclusion at 7 weeks. Since the SPRE model requires 13-14 data points per participant, 6 data points were interpolated as given by Byrd, A.C., Goodbar, H.A., Lesley, W.N., Martin, C.C. (2013). The Ahmad et al. analysis computes and compares 3 individual point estimates, where the p-values were statistically significant with $p \leq 0.05$, to the mean data starting from a change-point derived from initial data in the first 7.0 weeks. This analysis is chosen to illustrate the statistical use of the FWF in SPRE for fall prevention in older adults because little statistical analytical work has been published which looks at prevalence and incidence of adults with fof together with those who have fallen.

## 2. Method

In many cases, statistical estimations can be made from initial data from a least squares regression, or by predicting a trend line, or in time series forecasting when the use of a model to forecast future events is based on known past events. However, health outcomes are often in the form of an exponential cumulative distribution of a survival function, when residuals are not distributed normally (Cleves, Gould, & Gutierrez, 2004) and for time-to-event-data (Hosmer, Lemeshow, & May, 2008) or a parametric Weibull cumulative distribution where past performance may be unavailable or not relevant to the disease outcomes being measured. Therefore, the SPRE model has been developed to derive a 'change point' where the participant adapts to the therapy, and to predict long-term outcomes in the form of a Weibull distribution using initial data from the patient(s) in a clinical trial or in therapy.

### 2.1 Assumptions for data using the Falls Weight Function (FWF)

The first assumption is that fof data is taken from a 10-16 point survey of falls concern for a participant during different activities. The second assumption is that in a discrete setting, a weight function is a positive function defined on a discrete set A, which is finite or countable. A third assumption is that in fear of falling (fof), the weight function is defined as positive and countable.

### 2.2 Assumptions for the data using the FWF in the SPRE model

The first assumption is that approximately 13-14 data points in the primary trial follows an initial quasi-linear form that can be analyzed by ordinary least squares to develop a change point. This is true for a single subject or a small group where the mean indicates the response to treatment. The second assumption is that the outcome values are ordered data. If the data are not approximately linear, then transforms are used to linearize the data; if both axes are transformed, then values on the time axis are ordered together with the ordered outcome data. A third assumption is that a change point can be determined from initial data before an arbitrary cutoff in time or treatment numbers. A fourth assumption is that long-term data outcomes can be predicted from the change-point using the ratio of the point estimation function (Weissman-Miller, 2012) times the prior outcome prediction as given by Weissman-Miller (2013).

### 2.3 Derive the Falls Weight Function

For a real value function, the un-weighted sum of 'f' on A is:

$$\sum_{a \in A} f(a) \qquad (1)$$

A weighted function w where $\mathbb{R}^+$ equals a set of positive real numbers is:

$$A \to \mathbb{R}^+ \qquad (2)$$

The weighted sum is then:

$$\sum_{a \in A} f(a) \cdot w(a) \qquad (3)$$

In this summation, $f(a) = 1$ (fall) for this function where 1.0 is the image of 'a' under 'f'. Then $f(a) = 1$ is a partial function with respect to the weighted elements. When the weighted sum is in the numerator of the ratio transform data used in occupational therapy to transform the raw data so that it can be analysed using the ordinary least squares model (OLS) in SPRE (Weissman-Miller, Shotwell & Miller, 2012), then the transform for the fof data is given as:

$$\sqrt{\frac{\sum_{a \in A} f(a)w(a)}{Measure}} \qquad (4)$$

In this pilot study the measure used was the ABC scale, where the data to be analysed was given by a ratio as given in equation (4) of the square root of the ratio of the FWF divided by the ABC scale, or by the number of falls divided by the same scale.

The $A \to \mathbb{R}^+$ is given in this pilot study by the fear of falling fof 'Very Concerned' column of the intake survey. In this study, the un-weighted function of 'f' on 'a' is given in equation (1). The weighted function in equation (3) is the Falls Weight Function (FWF) where the $f(a)$ equals 1 fall and $w(a)$ is the weighted sum of each survey box checked from 0.10 to 1.00 for each of the 10 items on the survey, which then equal 1 fall. The total of these countable responses is a fraction of all possible responses from 1/10 to 1.00. The ABC ratio given in equation (4) as the measure is applied to each random variable X, Y of the OLS regression because it is a function of the linear transform of the raw data. Now, fear of falling (fof) is directly compared to 1 fall through the OLS, where both $R^2$ and p-values, of the highest or lowest F distribution in the SPRE model, form the change point for each participant. The scale of falls and fof is the same, and represented on a continuum of fear of falling to having a fall, so that all participants can be treated together and analysed in the same set of linear regressions. The fof-falls scale is now continuous from 0.1 to any number of falls on the real number line and given as: **0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1,2,3,4,5,…,n.**

While this new scale does not mean that the constructs of fof or having a fall are causal, it does mean that they are now shown to be related so that all older adults can now benefit and they may all be treated with the same falls prevention programs – without the exclusion of participants who have not fallen but who have fof.

### 2.4 The change point in the initial patient least squares data for FWF in SPRE

Generally speaking, change-point regression is a regression problem in which the expected value of the dependent variable or response is assumed to have a different functional form in several neighborhoods of the explanatory variable space according to Khodadadi and Asgharian (2008). In the SPRE model, the determination of the change point is a structural change that for weight loss shows the dynamic nature of the changes. Details of the methodology are given in Weissman-Miller (2013). The time at the change point is the location of the ratio predictions for long-term estimates, which produces a gradually changing predictive model. This is true for data measured for FWF and falls. These results were computed by the R Development Core Team (2010), R Commander by Fox (2005) and using a program called SPRE written in R by D. Weissman-Miller (2014) and running in RStudio (2014). It should be noted that in using FWF in this SPRE model, the F statistic is still determined comparatively from the regression analyses, where the P value is used to determine statistical significance of the regression analysis to that point. The resulting change point, of the highest or lowest F statistic computed, is then denoted by the value of time, or treatment session number, together with the measured outcome in the dataset.

## 3. Results

A comparison of falls data with fof data is shown in Figure (1). It can be seen that the data are similar in slope although not identical. Furthermore, the graph shows that the participant who had a fall started with a lower balance confidence than the participant with fof. This makes sense when comparing the data side by side. Furthermore, the participant who had sustained a fall increased confidence more than the participant with fof.

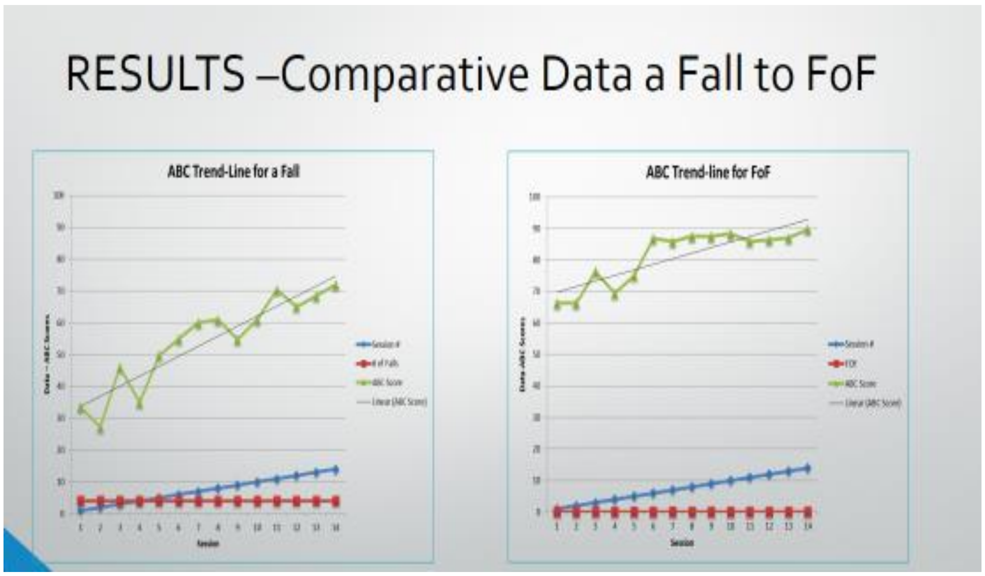


**Figure (1) Comparison data for participants with a fall and fof**
Used with permission from Byrd, A.C., Goodbar, H.A., Lesley, W.N., Martin, C.C. (2013).

As shown in Table (1), there is only one highest F statistic in this dataset at Session 3. In any therapy, the treatment should be carried out past a first mode to be sure that all relevant modes, such as a second mode of response, have been recorded.

It can be seen from the analyses in Table (1) that the highest F statistic is at time = 3 sessions from the backward stepwise elimination method, including the variables x (time) and y (outcome). Each dataset, starting at an assumed full model at 13 sessions from 7 weeks, is analyzed to determine $R^2$ and the F statistic. Then the next dataset is analyzed from 13 sessions down to 2 sessions.

In this paper, a change point is defined as the outcome and the session number for the highest F statistic for analysis of the mean, where the participant outcomes with respect to time are no longer linear (Miller, Weissman-Berman, & Martin, 2008; Weissman-Miller & Miller, 2011), or the data point at which the character of the regression changes, in general, from linear to the shape of an exponential or the Weibull cumulative distribution (Weissman-Miller, 2010; Weissman-Miller, 2013).

Using the SPRE program in this analysis, the residuals at the change points were quasi-random and normal predictions for each of the participants, and where the data were statistically significant at the change point a means analysis was conducted and predictions computed together with the mean of 3 participants as shown in Table (1). The results for all are graphed in Figure (2).

| Change Point Calculations: # Falls or FoF / ABC | | | | | Predictions | |
|---|---|---|---|---|---|---|
| Session | $R^2$ | F-statistic | p-value | OrdsqrtABC[1] | Session | Prediction No. |
| 5 | | | | .0502 | 1 | .05101022 |
| 4 | 1.0 | | | .0506 | 2 | .05101040 |
| **3 *** | **.9999** | **19680.0** | **.004538** | .05101 | 3 | .05101056 |
| 6 | .01244 | .0252 | .8885 | .05103 | 4 | .05101067 |
| 13 | .25 | .9998 | .391 | .05121 | 5 | .05101075 |
| 9 | .3108 | 1.804 | .2504 | .05164 | 6 | .05101082 |
| 12 | .4506 | 4.101 | .09873 | .05165 | 7 | .05101088 |
| 8 | .3873 | 3.792 | .09942 | .05175 | 8 | .05101092 |
| 7 | .2931 | 2.903 | .1322 | .05186 | 9 | .05101096 |
| 10 | .3331 | 3.996 | .08064 | .05186 | 10 | .05101099 |
| 11 | .3906 | 5.769 | .03978 | .05208 | 11 | .0510102 |
| 2 | .04236 | 1.018 | .3369 | .05223 | 12 | .05101105 |
| 1 | .01506 | .1682 | .6896 | .02345 | 13 | .05101107 |
| | | | | | 14 | .05101109 |
| | | | | | 15 | .05101110 |
| | | | | | 16 | .05101112 |
| | | | | | 17 | .05101113 |
| | | | | | 18 | .05101114 |
| | | | | | 19 | .05101115 |
| | | | | | 20 | .05101117 |

**Table (1) Participant F's Change Point Calculations, Predicted Values (*=Change point.** Used with permission from Ahmad, S., Lesko, B., Marslender, A., Randall, S. (2014).

In the means analysis, the SPRE model predicts skill improvement via the Stepping On® falls prevention treatment. Participant d had a fall prior to the program, while participants f and p had fear of falling (fof) which were analysed using the FWF. The relative error of point estimates to the primary data is excellent for treatment where there was an early individual change point and subsequent data from the pilot study. The predictions track through the test data. The SPRE ratio predictions from each change point show that there is significant improvement from the start of the trial to the change point for these 3 participants. The SPRE analysis confirms the same result measured in each participant for which there is an early change point.

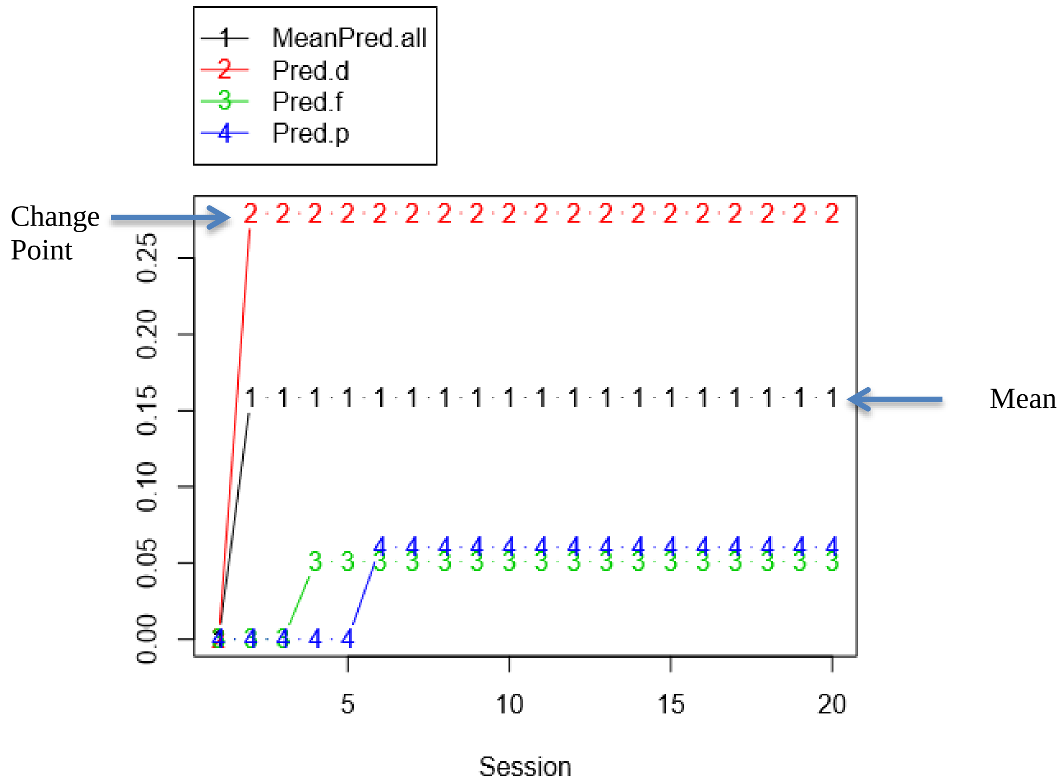


**Figure (2)** Point estimates of 3 participants from the change point with the mean in the Falls Prevention program as measured by ABC. Used with permission from Ahmad, S., Lesko, B., Marslender, A., Randall, S. (2014).

The predictions in this paper are based on the calculation of individual change points for 3 participants where the change point of the means analysis are based on the values of previous events. For this reason, this model is especially useful in predicting the response to treatment for individuals who have had a least 1 fall or who have a fear of falling fof. Furthermore, predicting the numbers of treatments until the participant becomes stable reduces waste and controls costs in health care.

## 4.0 CONCLUSIONS

The point estimates are very similar for the long-term test data for treatment of individuals who have had a fall or who have a fear of falling (fof), as shown in Figure (2). This point estimator from the SPRE ratio using FWF or the number of falls has also been shown to be consistent at the upper and lower bounds of prediction and robust for single subjects or a small group (Weissman-Miller, 2013). Furthermore, the absolute bias ratio of this SPRE ratio will be typically small in practice as given in Meng (1993), whether the model is for a small group or the long-term predicted outcomes for a single subject. If the small group has 3–10 participants, then it is proposed that inferences may be made to a similar, larger population provided that the p value at the change point is $\leq 0.05$. Finally, these two groups can be analysed together using the semiparametric ratio (SPRE) which allows for the heterogeneity in single-subject or small group design.

## REFERENCES

Ahmad, S., Lesko, B., Marslender, A., Randall, S. (2014). The effectiveness of the Stepping On program in reducing the fear of falling and incidence of falls in the independent community-dwelling older adult population. (Unpublished m*aster's thesis). Brenau University, Gainesville, GA*.

Arfken, C. L., Lach, H. W., Birge, S. J., & Miller, J. P. (1994). The prevalence and correlates of fear of falling in elderly persons living in the community. *American Journal of Public Health*, *84*(4), 565-570.

Byrd, A.C., Goodbar, H.A., Lesley, W.N., Martin, C.C. (2013). Effectiveness of the Stepping On Program in reducing the fear of falling and the incidence of falls in community-dwelling adults. (Unpublished m*aster's thesis). Brenau University, Gainesville, GA*.

Centers for Disease Control and Prevention [CDC]. (2010). Web-based Injury Statistics Query and Reporting System (WISQARS) [database online]. Available from URL: www.cdc.gov/ncipc/wisqars

Cleves, M. A., Gould, W. W., Gutierrez, R. G. (2004). *An Introduction to survival analysis using STATA (Revised ed.).* College Station, TX: State Press.

Clemson L[1], Cumming RG, Kendig H, Swann M, Heard R, Taylor K. (2004). The effectiveness of a community-based program for reducing the incidence of falls in the elderly: A randomized trial. *Journal of the American Geriatric Society. 52* (9), 1487-94.

Clemson, L. (2009). Enabling older people to prevent falls. NSW Falls Network, University of Sydney.

Fox, J. (2005). The R Commander: A Basic-Statistics Graphical User Interface to R. *Journal of Statistical Software*, September 2005, Volume 14, Issue 9. http://www.jstatsoft.org/

Hosmer, D. H., & Lemeshow, S., May, S. (2008). *Applied Survival Analysis: Regression Modeling of Time-to-event Data (2nd ed.).* Hoboken. N.J.: Wiley-Interscience.

Jørstad, E. C., Hauer, K., Becker, C., & Lamb, S. E. (2005). Measuring the psychological outcomes of falling: a systematic review. *J Am Geriatr Soc*, *53*(3), 501-510. doi: 10.1111/j.1532-5415.2005.53172.x

Khodadadi, A. & Asgharian, M. (2008). Change-point Problem and Regression: An Annotated Bibliography. This working paper is hosted by The Berkeley Electronic Press (bepress) and may not be commercially reproduced without the permission of the copyright holder. http://biostats.bepress.com/cobra/ps/art44

Meng, X.-L. (1993). On the absolute bias ratio of ratio estimators. *Statistics & Probability Letters 18*: p. 345-348.

Miller, R., Weissman-Berman, D., and Martin, L., "A Predictive model for evidence-based practice in occupational therapy: From a single subject to the world", Research paper presentation, April, 2008, American Occupational Therapy Association Annual Conference.

Powell, L.E. & Myers, A.M. (1995). The Activities-specific Balance Confidence (ABC) Scale. The Journals of Gerontology: Series A, 50A, M28-M34.

*Profile of Older Americans: 2013*. (2013). Washington, DC: U.S. Department of Health and Human Services.Department of Health and Human Services.

R Development Core Team (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-Project.org.

R Studio v.0.96. (2014). Downloaded from www.**rstudio**.com/ide/docs/release_**notes**_v0.96

Schepens, S., Sen, A., Painter, J. A., & Murphy, S. L. (2012). Relationship between fall-related efficacy and activity engagement in community-dwelling older adults: A meta-analytic review. *The American Journal of Occupational Therapy, 66*(2), 137-148.

Stevens. (2010). *A CDC compendium of effective fall fnterventions: What works for community-dwelling older adults. 2nd ed.* . Atlanta, GA: : Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, Division of Unintentional Injury Prevention Retrieved from http://www.cdc.gov/HomeandRecreationalSafety/Falls/compendium/0.1_acknowledgements.html.

Stevens, J. A., Corso, P. S., Finkelstein, E. A., & Miller, T. R. (2006). The costs of fatal and non-fatal falls among older adults. *Injury Prevention Journal of the International Society for Child and Adolescent Injury Prevention, 12*(5), 290-295. doi:10.1136/ip.2005.011015

Tinetti, M. E., De Leon, C. F. M., Doucette, J. T., & Baker, D. I. (1994). Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. *Journal of gerontology, 49*(3), M140-M147.

Tinetti, M. E., Richman, D., & Powell, L. (1990). Falls Efficacy as a Measure of Fear of Falling. *Journal of gerontology, 45*(6), P239-P243. doi: 10.1093/geronj/45.6.P239

Weissman-Miller, D.(2010). A Novel Semiparametric Ratio Estimator (SPRE): A Key to Predicting Long-Term Weight Loss in Obesity", JSM Proceedings, 2010.

Weissman-Miller, D., & Miller, R.J. "New Single-Subject and Small-Group Design: Example, Estimating Weight Loss in Obesity", research paper presentation, April, 2011, American Occupational Therapy Association Conference.

Weissman-Miller, D., Shotwell, M.P., & Miller, R.J., (2012). New single-subject and small-n design in occupational therapy: Application to weight loss in obesity. *American Journal of Occupational Therapy, 66,* 455-462.

Weissman-Miller, D. (2013). Novel point estimation from a Semiparametric Ratio Estimator (SPRE): Long-term health outcomes from short-term linear data, with application to weight loss in obesity. *International Journal of Biostatistics, 9(*2*):* 175-184.