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Full Length Research Article

NOVEL LOW-ERROR INTERPOLATION METHOD FOR A FALL PREVENTION PROGRAM USING THE SINGLE- SUBJECT DESIGN STATISTICAL MODEL SPRE

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ABSTRACT

Over 30% of adults, aged 65 and older, fall each year (Centers for Disease Control, 2015) and with an aging population, falls, fall related injuries, and costs have become a public health concern (Centers for Disease Control, 2015; Costello and E. Edelstein, 2008). A fall prevention program, Stepping On®, is a multifaceted, multifactorial community-based program (Clemson, *et al*., 2004) that has been shown statistically by a new single-subject design model, SPRE (Weissman-Miller, 2013), to improve fall self-efficacy and reduce falls in elders over 13-14 sessions. The purpose of this research paper is to provide a low-error interpolation method so that SPRE can be used to predict the effectiveness of the Stepping On® program for older adults in seven weekly sessions. Stepping On® was delivered to a small group of community-dwelling older adults for seven weeks. The pilot study data collection included a falls tracking form and Modified Falls Efficacy Scale completed at each session. SPRE was utilized with the low-error interpolation method to provide 13 data points and data analyzed to allow researchers to identify each individual's change point. The low-error interpolation method is derived from numerical analysis and applied to the transformed original data to derive six computed interval data points for each participant, where the error function is very small. Analysis with SPRE was completed for each of five participants. Ten months later, three of these participants' results were reviewed. The data suggests the Stepping On® program results in decreased fear of falling and increased falls self-efficacy. The low-error interpolated data provided statistically accurate results when used with the Stepping On® fall prevention program analyzed with SPRE in Health and Medical Sciences.

Key words: Falls in Elders; Linear Interpolation; SPRE; Stepping On®

INTRODUCTION

Falls are the leading cause of fatal and nonfatal injuries among older adults (Centers for Disease Control (CDC), 2015; Mahoney, 2007), and with a rapidly aging population, falls and fall related injuries have become an increasing health concern and economic burden for persons 65 years and older. In 2013, the direct cost of medical care resulting from falls in older adults was over 34 billion dollars (CDC, 2015). Of those who fall, 20 to 30 percent will suffer moderate to severe injuries including hip fractures, contusions, lacerations, injuries to the lower extremities, and brain injuries (CDC, 2015). Moreover, falls may result in emotional and psychological consequences such as a fear of falling. Fear of falling, which is defined as a lasting concern about falling (Painter, *et al*., 2012), can increase fall risk and has been associated with a lack of activity engagement, lower quality of life and decreased self-efficacy (Bertera and Bertera, 2008; Bilotta, Bowling and Vergani, 2011; Painter, *et al*., 2012; Lee, Mackenzie and James, 2008; Murphy and Tickel-Degen, 2001). Falls are the result of multiple risk factors which include intrinsic factors related to the individual such as physical changes due to aging or illness, poor vision, or declines in cognitive function (Greany and Di Fabio, 2010).

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Other risk factors are extrinsic and external to the person such as medication use, home and outdoor environments, lighting, and the use of mobility and safety equipment (Greany and Di Fabio, 2010). Interventions to prevent falls may address a single or multiple risk factors. A single factor intervention may include exercise or home modifications (Stevens and Burns, 2015). Multifactorial interventions are individualized to address specific intrinsic and extrinsic factors contributing to falls and fall risks (Diener, D., Mitchell, 2005, Stevens and Burns, 2015). A systematic review of fall prevention research suggests multifactorial fall prevention programs are the most effective at preventing falls (Chase, Mann, Wasek, and Arbesman, 2012).

The Stepping On ® program (Clemson, *et al*., 2004) is one of 12 multifactorial fall prevention programs endorsed by the CDC as having evidence to prevent falls among community-dwelling older adults (Stevens and Burns, 2015). The Stepping On® program is a seven-week course in which participants meet for two hours of instruction and group discussion once a week in small groups to promote falls self-efficacy and behavior changes in order to reduce falls (Clemson, *et al*., 2004). Sessions are facilitated by a trained health professional (occupational therapist, physical therapist, or nurse). Other content experts are required to deliver the program information.

The purpose of this study is to determine the effectiveness of the low-error interpolation method to provide a full dataset for statistical analysis with the Stepping On® program in decreasing the fear of falling and the incidence of falls in community-dwelling older adults for small datasets. This study used the new methodology Semiparametric Ratio Estimator (SPRE) to analyze data (Weissman-Miller, Shotwell, and Miller, 2012; Weissman-Miller, 2013). The SPRE methodology requires 13-14 data points per participant; however, the Stepping On licensure protocol dictates only seven sessions, resulting in seven data points. To meet the 13-14 data point criteria required of the SPRE, six data points were interpolated using the Linear Interpolation (LERP) (Linear Interpolation Value Calculator, 2013). In the original pilot study, Byrd *et al* (Byrd, Goodbar, Lesley and Martin, 2013) used the Modified Falls Efficacy Scale (MFES) (Hill, *et al*., 1996) and the Falls Reporting Form (FRF) (Clemson, Cummings and Heard, 2003) to track the participants' falls efficacy and incidence of falls throughout the study, prior to the final statistical analysis.

MATERIALS AND METHODS

The design of this study was a quasi-experimental, single-subject pilot study. Participants were recruited from a convenience sample of community-dwelling older adults over the age of 65 from a local church community. Participants in the study were categorized into two different groups: those who had experienced a fall within the past six months, and those who had not experienced a fall within the past six months but identified a fear of falling as stated on the study intake forms. Inclusion criteria and exclusion criteria were given in the Stepping On® Program. Permission to conduct the study was obtained from the Institutional Review Board of the University.

The *Modified Falls Efficacy Scale (MFES)* (Hill, *et al*., 1996) and the *Falls Reporting Form (FRF)* (Clemson, Cummings and Heard, 2003) were used to track the participants' falls efficacy and incidence of falls throughout the study. The *MFES* is based on the original *Falls Efficacy Scale* (FES) (Tinetti, Richman, Powell, 1990). The individual rates his or her confidence that an activity can be performed without falling and is scored on a scale of 0-10 with 0 representing no confidence at all and 10 representing complete confidence. Studies conclude that the MFES is a valid and reliable measure of self-efficacy pertaining to falls (Edwards and Lockett, 2008; Hill, *et al*., 1996) concluded that the MFES demonstrated strong test retest reliability and provides a reliable, detailed measure of balance performance, activity level, and fear of falling. The Modified Falls Efficacy Scale (MFES) was given at the beginning of all seven sessions of the Stepping On® program.

The *Falls Behavioral Scale (FaB)* (Clemson, Cummings and Heard, 2003) is an ordinal scale that measures how often participants engage in everyday activities. Participants respond with "never, sometimes, often, and always" for 30 statements. The data were used to determine how often the participants engage in both indoor and outdoor activities. The FaB assessment tool was designed to identify the older person's awareness of behaviors that could reduce fall risk. This instrument has shown internal consistency of 0.84 using Cronbach's alpha. The Content Validity Index for the FaB was estimated at 0.93. The "Doing Activities" section of the FaB was used for computation of the Falls Weight Function.

Falls Weight Function is measured by the last column labeled "Very Concerned" on the "Doing Activities" portion of the FaB and is used in calculations. The Falls Weight Function allowed for the person with a fear of falling but no falls to be grouped into the same analysis category as the people who had experienced a fall. The Falls Weight Function (FWF) is a new mathematical measure to enable researchers to incorporate fear of falling into analyses with participants who have already experienced at least one fall (Weissman-Miller and Graham, 2014; Weissman-Miller and Graham, 2015). The FWF is a weight function used in the initial data analysis phase as belonging to a discrete set of numbers that is finite and countable. In this study, the checked marks in the 'Very Concerned' screening tool were counted and summed as increments of the total 10 values.

These values, which could range in this case from 0.1 to 1.0, were then multiplied by 1.0 fall, which scaled the fear of falling consistent with having had a fall. In this trial, most of the participants entered with 1.0 fall. Then, the un-weighted value of falls, 1.0 fall, is multiplied by a fraction of 1.0, which is the weight for the fear of falling by the sum of the check marks on each participant's "Very Concerned" column about falling in any of the 10 specific activities. Treating fear of falling in this manner ensured that the scale of falls and fear of falling was the same so that both groups of participants could be treated together and analyzed in the same set of linear regressions in SPRE. While it is true that fear of falling and having had a fall are different constructs, considering both as events having the same scale in values allowed the researchers to analyze them together in the same analysis.

Procedural Outline

To reduce the incidence of falls in elders, the Stepping On program has a protocol of seven weekly sessions with varying content. The procedure outlined below minimizes the potential for error in the interpolated data while remaining true to the Stepping On® protocol. An outline of the procedure using SPRE is given in Table 1. Interpolate the data, given in Step 3, is a compilation of collecting all the data, entering two adjacent data points into the calculator at any one time, and finally producing the specific values of each of the interpolated data points.

Considerations for Linear Interpolation

The analytical method SPRE requires 13-14 sessions to determine a change point (defined as compliance to treatment) with quasi-normal residuals from which point estimations/predictions can be made for future outcomes. Therefore, interpolations of six sessions had to be performed. Interpolation is "a method for constructing a function, $f(x)$ that fits a known set of data points". There are several considerations in interpolating six alternate session results within the seven mandated sessions for this program.

Table 1. Procedural Outline for Semiparametric Ratio Estimator (SPRE) Method using the SPRE program in R

Step #	Purpose	Procedure	Outcome
Step 1	Data Collection	MFES scale – raw data Falls Reporting Form – raw data	Data Observed
Step 2	Getting Data into R	Create active data set from the Falls/MFES score in excel as csv	Data package
Step 3	Interpolate data	Enter data collected into Interpolation calculator Statistically order the data and format into	Get total of 13 data points Bring outcome data points closer together in a
Step 4	Linearize the data	Session and FData columns for analysis	visible linear pattern
Step 5	Calculate highest or lowest F statistic to predict 'change point'	The SPRE program uses backward stepwise regression… To formulate highest F statistic for R2 for each dataset	Identify the highest F statistic in order to predict the 'change point' where subject adapts to treatment for interpolated data.
Step 6	SPRE to predict future outcomes	Analysis of Weibull distribution as a ratio by SPRE program	Calculation from SPRE ratio for 40 sessions from the 'change point'.
Step 7	Results of the prediction	SPRE program creates 2 graphs 1st for the error functions and 2nd for the predictions	1st–random scatter of the error functions indicates normal distribution: 2nd–the curve flattens when the client becomes stable at a particular session number.

Minimize the Magnitude of the Data

The first consideration is to minimize the order of magnitude of the experimental data as much as possible before using LERP (linear interpolation) to fill in the necessary data. Therefore, the interpolation should be made almost at the last step of data preparation, where the order of magnitude of the square root of the data ratio is small. This will minimize the error associated with the interpolation.

Fitting the Data

To construct the error function needed to interpolate the six data points between seven sessions of the Stepping On Falls Program analyzed by SPRE, the third order polynomial should be fit, in the case of Stepping On as measured by MFES, as after the inverse data is performed but before the data is ordered, the data is transformed as:

$$\sqrt{\#Falls(or)FWF \big/ 10 * MFES} \quad (1)$$

This will then match the order of magnitude of measuring falls or FWF with the ABC measure, so that direct future comparisons may be made across the results of several analyses. When the ABC measure is used for analysis, then the data is transformed as:

$$\sqrt{\#Falls(or)FWF \big/ ABC} \quad (2)$$

Fit the Data Using the Wolfram Alpha Program

The dataset for SPRE should be fit with a curve that will fairly closely run through the seven original data points. In this case we will use a cubic polynomial and then differentiate twice using Wolfram Alpha (2013), available online for computers or the iPad, where the seven data points are fit to the polynomial. The difference between the cubic spline interpolation and the cubic polynomial interpolation is negligible, again because of the small order of magnitude of the dataset. In general, those measures that are designed to be administered once per week may be considered for interpolation by SPRE.

Then the data between known data points is interpreted using LERP, a known Linear Interpolator Value Calculator (2013).

The Error Function

The most important part of this analysis is given by the error function. The error function for these data points is derived from Parnell (2013) and computed from the 2^{nd} derivative of the cubic polynomial function as:

$$C(x_b - x_a)^2 \text{ where } C = \frac{1}{8}\max_{y\epsilon(x_a,x_b)} |g''(y)| \quad (3)$$

This means that the largest difference between two original data points is squared and divided by eight and then multiplied by the maximum value of the second derivative of the cubic polynomial function. This function was selected not only to model the actual test data, but also because it is stable. The max/min of the function is derived from the 2^{nd} and 1^{st} derivatives of the polynomial function where the solutions to the second derivative are inserted into the equation for the first derivative to find the maximum and minimum of the function. These calculations were analyzed in Wolfram Alpha, Statistics and Mathematics modules by inputting the original seven data points and automatically calculating the result. In this code, the 3^{rd} order polynomial has been derived using a least squares fit for the least error. The error will be in the neighborhood of E-4, which is a very small number. For example, using similar data selected at random from the falls program conducted in 2013, the error on interpolation is approximately between = 0.5958 E- 6% and 0.1391 E-5% at this order of magnitude, which are very small errors.

Procedural outline for the Interpolated Results

This research study was a quasi-single subject pilot study to determine the effectiveness of the Stepping On program in reducing fear of falling and incidence of falls in community-dwelling older adults. All information gathered using the MFES and Falls Reporting Form was entered into Excel and analyzed using SPRE methodology to determine if there were any statistically significant changes in fear of falling and incidence of falls for each participant. Ten participants (nine females, one male) started the program, but due to absence and drop out, five participants were excluded from analysis.

Participants who missed a session were unable to be used for the SPRE methodology due to the inability to then interpolate their data. Data were analyzed for the five remaining participants. Two participants (PT002, PT005) had one fall within the past six months, one participant two falls (PT007), one participant three falls (PT004, and the fifth participant (PT010) expressed a fear of falling but had not fallen in the past six months. For each participant, the raw data of the ratio of falls/MFES scores as well as the interpolated data was statistically ordered in ascending sequence with reference to the MFES score for that participant or the therapy outcome using R Excel. F statistics, R2, and P-values were determined using a backward stepwise regression.

Requirements for Linear Interpolation

For occupational therapy clinical data, three requirements have to be met to interpolate the data: 1.The clinical data should be at least an ordinal level of measurement. 2. The Wolfram Alpha program should be used (on computer or iPad) to compute the error function. In this article, the error function is a very small number, and as long as the data is transformed in Excel following equations (1) and (2), the error function will be small (and there is no need to reproduce this analysis). 3. SPRE must be used to predict future outcomes.

Criteria Summary for SPRE

Outcomes are predicted from the change point in the linear data, which then have both internal validity and external validity, where internal validity is given by the least squares method, resulting in an unbiased estimate, and external validity is given when the statistical population parameter μ (mean) at the change point indicates outcome parameters over time for that single participant or a population mean for a small group. For the mean of a small group, if $p \leq 0.05$ for the value of F at the change point, then inferences may be made to similar groups in the population. The predictions have statistical validity for those similar groups (Weissman-Miller, 2013).

RESULTS

A Calculated Error Function

There are five steps in using Wolfram Alpha to calculate the error function. Before any calculation, you input the seven collected and transformed data points into the program. Then, 1. Calculate the equation for the cubic polynomial. That is, the resulting graph will show a curve approximating your data. 2. Then calculate the derivative (d/dx) of this first equation that the program has shown and graphed. 3. The result is an equation and a parabolic graph. The results also show the roots of this analysis. 4. The next step is to calculate the maximum using the roots from step three which is used in the error function. 5. Fill in the values using two adjacent values from your collected data. Then compute equation (3) as interpreted below.

The Interpolation of the data

The five steps are shown below to interpolate the data for a single participant, in this case participant PT002, from which the error function can be calculated.

In each step, the instructions are given above the example of the data or the derivations. It should be noted that these derivations can be accomplished in Wolfram Alpha simply by clicking the appropriate value. This would be the 1st derivation, the 2nd derivation and so on. This mathematical program makes the whole analysis very much easier to do, and provides accurate answers – that is, as accurate as the original observed data. The error is calculated here from Wolfram Alpha in two ways for comparison, using the difference between two adjacent original data points for the local maximum error, or the Global maximum defined in Wolfram Alpha (2013).

From the initial 7 data points, calculate the equation for the cubic polynomial, then the resulting equation is derived.

d/dx (-0.0000638889 x^3+0.00107976 x^2-0.00592063 x+0.118229) (4)

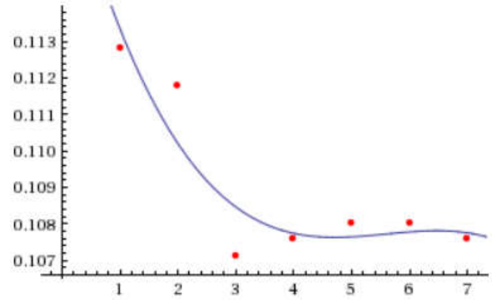

Fig. 1a. The Plot for the Cubic Spline

Then calculate the derivative which is a parabola

d/dx (-0.00592063 + 0.00215952 x - 0.000191667 x^2) (5)

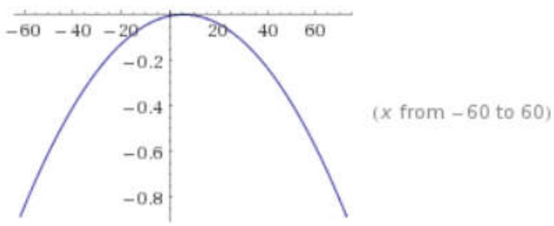

Fig. 1b. The 1stderivative parabola

Interpolate the data, given in Step 3 is a compilation of collecting all the data, entering 2 adjacent data points into the calculator at any one time, and finally producing the specific values of each of the interpolated data points.

d/dx (0.00215952 - 0.000383334 x) (6)

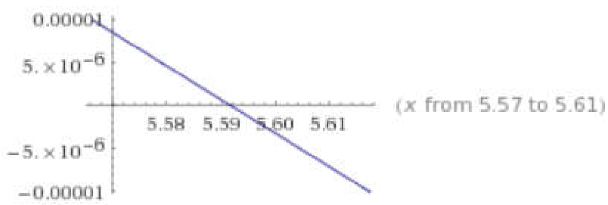

Fig. 1c. The 2nd derivative as a Straight Line

Fill in the values for the equation (3) to obtain the error – where C is the local maximum as in equation

$$(3)\ C(x_b - x_a)^2 \ where\ C = \frac{1}{8}\max_{y\varepsilon(x_a,x_b)}|g^{''}(y)|.$$

Use the 2nd derivative equation to compute difference in two measured linear points from the data:

$$(0.00215952 - 0.000383334 * 0.0047) = \underline{0.002157718} \qquad (7)$$

When 0.0047 = (0.1118-0.1071), original linear point values between sessions 1–3.

The error as shown below = $C \cdot (x_b - x_a)^2 / 8$

Error = ((0.1118-0.1071)^2)/8 * 0.0002157718

In percent, the rounded local error = <u>0. 5957999 E–6.</u> (8)

A possible approximation uses the global maximum from Wolfram Alpha (2013), the error = 0.448E-7%. This error is slightly smaller than the data 1-3 error results. It can be seen that the resulting errors are very, very small numbers, the largest error case = 0. 4318734 E-8.

Comparative Data Error Results

A comparison of local error function results between original data points is given to a potential error result from the maximum root of the parabola, with the maximum determined by the second derivative, and the global maximum calculated from the parabola. This last result is an approximate interpretation of a linear error function for linear interpolation.

It can be seen that as the data points are closer together, the local error function result is reduced. That is one reason the equations (1) and (2) are transformed as the square root of the data.

Results of the Data Analysis

The graph below shows the predictive results of the SPRE analysis on these five participants, PT002, PT004, PT005, PT007, and PT010. Each of these participants had a different 'change point', that is the session at which he/she adapted to the treatment. A slightly increasing line indicates continued improvement and a straight line indicates participant stability. The MFES was used in a ratio with the number of falls, from equation (1) and analyzed by SPRE to confirm that the Stepping On program increases falls confidence or remains stable.

The graph in Fig. 2 shows the results from each participant's 'change point' (when the participant adapts to the program). These results show that each of these participants were nearly clinically stable from the 'change point 'through session 20, including PT004 and PT005 who were stable from their change point at session one. There are very small increases in the resulting predictions, but not enough to show graphically at this scale.

These five participants completed all the required sessions for the program, where the results of the predictions are made from the 'change point' derived from original and interpolated data for each participants who had a fall or fear of falling. It should be noted that the only participant who had a fall during the program was PT007 who fell between session one and two before her 'change point' at session six.

Table 2. Local Error Function Results Compared to an Approximate Global Error Result

Data session numbers	Data - original	Error function	Error function, %
1 - 3	0.1128 – 0.1118	0.2698921 E-9	0. 2698921 E-7
3 - 5	0.1118 – 0.1071	0.5957999 E–8 *	0. 5957999 E–6 *
5 - 7	|0.1071 – 0.1076|	0.67479 E-10	0. 67479 E-8
7 - 9	|0.1076 – 0.1080|	0.4318734 E-10	0. 4318734 E-8
9 - 11	0.1080 – 0.1080	----constant----	----constant----
11 - 13	0.1080 – 0.1076	0. 4318734 E-10	0. 4318734 E-8
Wolfram global max.	0.00016225 @5.63353	0.448 E-9 **	0.448 E-7 **

*Max local error function ** Global approx. error falls slightly more than data 1-3 local results

Fig. 2. Predicted Results from the Square Root of the Fall/Fear of Falling over the Inverted MFESx10 Ratio Graph for all Participants ((Byrd, Goodbar, Lesley, Martin, 2013)

The results from this study indicated that participants benefited from the interventions at different times during the Stepping On® program, specifically session one, session three, session four, and session five. Prediction results indicated that participants would continue to benefit from continued Stepping On® sessions ten through twenty.

A follow up study conducted approximately 10 months after the completion of the Stepping On® program followed a mixed method design with repeated assessments and an exploration of the fall prevention strategies with three original participants of the Stepping On® program. Mean MFES scores for the participants were highest at the 10-month follow-up (m=7.9) compared to pre-program (m=6.2) and post-program scores (m=7.4) suggesting that the participants' falls self-efficacy continued to increase after completing the program. Interview results indicated all three participants' experienced falls since the completion of the Stepping On® program, but participants were more knowledgeable about fall prevention strategies and were more aware of their surroundings. This result indicates that a follow-up session, or sessions, in fall prevention should be given before a 10 month period has elapsed.

Conclusions

The results of this study suggest that the low-error interpolation method, used with the Stepping On® program, is effective in predicting the results of this fall prevention program. In this study, the implementation of the Stepping On® program resulted in decreased fear of falling and increased falls self efficacy when implemented with community-dwelling older adults in a small group context designed to increase self-efficacy and promote behavior change (Clemson *et al*., 2004). This study can serve as a resource for occupational therapists who are interested in offering a fall prevention program, one time weekly or for future studies that address fear of falling or incidence of falls in community-dwelling older adults. Last, the results of this study will inform occupational therapists and others in the Health and Medical Sciences about the implementation and efficacy of a multifactorial fall prevention program for community dwelling older adults.

Author Contributions

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