International Journal of Innovative Research in Computer Science & Technology (IJIRCST)
ISSN: 2347-5552, Volume-3, Issue-5, September 2015

Application of Discriminant Analysis in Predicting Fallers and Non-Fallers

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Abstract— **A laboratory study was conducted to discriminate fallers and non-fallers using many fall-related factors including gait parameters, strength, COP, muscle activation rate, and friction demand. The primary objective of this paper was to determine whether fallers and non-fallers differed with regard to the mean of variables, and then was to use those variables to predict if a new person would fall either in fallers or in non-fallers categories. Total of 42 people participated in the study. Fourteen younger (18-35 years old) individuals (7 male and 7 female), 14 middle-age individuals (7 male and 7 female) and 14 older (65 and older) individuals (7 male and 7 female) participated in this experiment. The result indicated that heel contact velocity, step length, RCOF, COP, and isometric strength best-predicted fallers.**

Index Terms— **Fallers, Gait, Non-fallers, Multivariate**

I. INTRODUCTION

It is suggested that *gait characteristics* [1,2,3,4,5], *strength* [2,6,7,8], *postural balance* [10,11,12,13], *muscle activation rate* [14], and *friction demand characteristics* [2,15,16] can be used to predict the likelihood of falls to occur. Yet, no attempt to date to best-predict the characteristics of fallers and non-fallers was performed. Further, information in predicting fallers and non-fallers is not clear. In addition, most study did not attempt to predict the likelihood of falls with all the possible fall-related risk factors; mostly one or two variables were identified and evaluated empirically to predict the fall potential. Therefore, the authors thought that it was essential to evaluate all the possible fall-related risk factors, and to use them to predict a person's fall potential.

This study was conducted to discriminate fallers and non-fallers using all the possible dependent variables including gait parameters, strength, COP, muscle activation rate, and friction demand. The primary objective of this paper was to determine whether fallers and non-fallers differed with regard to the mean of variables, and then was to use those variables to predict if a new person would fall either in fallers or in non-fallers categories.

Manuscript received September 10, 2015.

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II. METHOD

A. *Subject*

Total of 36 people participated in the study. Twelve younger (18-35 years old) individuals (6 male and 6 female), 12 middle-age individuals (6 male and 6 female) and 12 older (65 and older) individuals (6 male and 6 female) participated in this experiment. Each participant completed an inform consent procedure. Participants were excluded from the study if they indicated any physical problems (i.e. hip, knee, ankle problems). A questionnaire was used as an initial screening tool.

B. *Apparatus*

One commonly used floor material (vinyl tile, Armstrong) was used in this experiment to represent a realistic environmental setting. The vinyl tile surface was covered with a soap and water mixture (2:3) to reduce the coefficient of friction (COF); dynamic COF was 0.07. The available dynamic COF (ADCOF) for each surface was measured using a standard 4.54 kg (10 lb.) horizontal pull slip-meter with a rubber sole material on the force platform.

Walking trials were conducted on a walking track using an overhead fall arresting harness system. The entire deck was covered with vinyl tile. While participants were not looking, an experimenter changed the test floor surface so as to provide unexpected slippery conditions. The test surface was mounted on a platform and connected to force plates (BERTEC # K80102, TYPE 45550-08, Bertec Corporation, OH 43212, USA). The overall function of the system was to control the experimental conditions without participants being aware of any floor surface change. A fall-arresting rig was used to protect participants from falling during the experiment and was designed to permit participants to fall approximately 15 cm before arresting the falls and stopping any forward motion. A six-camera ProReflex system (Qualysis) was used to collect three-dimensional posture data of participants as they walked over the test floor surface. Kinematic data were sampled and recorded at 120 Hz. Ground reaction forces of participants walking over the test surfaces were measured using two force plates and sampled at a rate of 1200 Hz. Hamstring muscle activities were measured using electromyography (Noraxon Telemyo System, Noraxon USA, INC Scottsdale, AZ). The Biodex system was used to collect strength data (Biomedical Medical System Inc. New York, USA).

III. Dependent Measures

A. Gait Parameters and EMG data

Submit your manuscript electronically for review. Participants walked across the vinyl floor surface (base line floor) for 20 minutes. Within the 20 minute session, experimenters observed participant's posture, ground reaction force, and EMG and, subsequently, introduced a slippery condition while the participant's posture, ground reaction forces, and EMG data were collected. While walking, participants were instructed to focus their eyes on a screen located on the top of each workstation to ensure that participants did not look at the test floor surface. The participants were asked to count the number of red circles that appeared on the screen. This secondary task was used to ensure that they paid attention to the screens and to disperse their mind from walking. Participants were also supplied with a Walkman during the walking experiment listening to old comedy routines to conceal any sound of the floor changing.

B. Postural balance

Participants were asked to stand alone quite on a force plate to measure center of pressure (COP) during subsequent 25 seconds. After a minute break, they were asked to stand quite again with eye closed. Balance capability of each participant was evaluated by calculating eigen values as suggested by Kuo et al [17].

C. Strength data

Isokinetic and isometric knee strengths were measured using BIODEX commercial strength measure device while sitting; isokinetic strength at 30°, 60°, and 90° and isometric strength at 0°, 15°, and 30°.

D. Friction demand(RCOF)

RCOF was measured as the ratio of the horizontal force (Fh) to the vertical force (Fz) while walking over a force plate.

E. Fall definition

Slip distance, sliding heel velocity, the whole body COM velocity, and motion pictures were considered to identify the fall frequency. To be considered as a fall, the slip distance must exceed 10 cm, and peak sliding heel velocity must exceed the whole body COM velocity while slipping [2]. In addition, videos for each slip trials of the participant were analyzed to see if an actual fall had occurred. All of above 3 conditions had to be met to be considered as a fall.

IV. Objective and Choice of Method

The primary objective of this paper was to determine whether fallers and non-fallers differed with regard to the mean of biomechanics variables, and then was to use those variables to predict if a new person will fall either in fallers or in non-fallers. For that purpose, data were collected on numerous variables including strength, weight, height, gait parameters, and EMG. analysis of logistic regression was performed to determine which variable(s) were the best predictors to categorize a new member into fallers or non-fallers

V. Analysis and Interpretation

The logistic regression analysis using all 17 variables was performed. A SAS code "pool=test" was used. The test of homogeneity of variance/covariance indicated that the assumption was violated and the classification table indicated that highest correct was 69.4% with 54.5% sensitivity when accounting all 17 variables. Step-wise forward and backward selection procedures were performed in order to remove insignificant or redundant variables among 17 variables. Five variables (RCOF1, isometric_30, R_HCV, Step_length, and COP_open) were chosen by forward selection and 7 variables (height, R_HCV, RCOF, COP_open, isometric 0, isometric 15, and isometric 30) were chosen by backward selection. After comparing two different variable groups (5 variables from stepwise and 7 variables from backward), the error rate of 5 variable group (0.15) was better than error rate of 7 variable group (0.17). In addition, the homogeneity of variance/covariance assumption was valid using selected 5 variables. Using 5 variable variables selected by stepwise procedure, a new logistic regression analysis was performed. The classification table (table 1) below suggested that highest correct was 91.7% with 81.8% sensitivity. Therefore, a range between 0.480 and 0.520 was selected for cut-off.

Table 1: Classification table

Prob Level	Correct		Incorrect		Corr-ect
	Event	Non-Event	Event	Non-Event	
0.480	9	24	1	2	91.7
0.500	9	24	1	2	91.7
0.520	9	24	1	2	91.7

Prob Level	Percentages			
	Sensiti-vity	Speci-Ficity	False POS	False NEG
0.480	81.8	96.0	10.0	7.7
0.500	81.8	96.0	10.0	7.7
0.520	81.8	96.0	10.0	7.7

In that range, among 11 actual falls, 9 was predicted as fall and 2 was predicted as non-fall. In addition, among 25 non-falls, 24 were predicted as non-fall and 1 was predicted as fall. The table 2 showed odds ratios. The logistic model for fallers was predicted as following:

$$g = 10.5063 + 0.0603\ R\_HCV - 0.6143\ Step\_Length + 150.5\ RCOF1 + 0.0874\ COP\_Open - 0.3458\ isometric\_30$$

The odds ratio of R_HCV, RCOF 1, and COP Open indicated that the probability that a fall occurs was highly increased as the values of R_HCV, RCOF 1, and COP Open was increased, whereas, the odds ratio of step length and isometric_30 indicated that the probability that a fall occurs was decreased as the values of step length and isometric_30 was increased.

Table 2. Parameter Estimates

Term	Estimate	Odds Ratio
Intercept	10.5071799	.
R_HCV	0.06027686	353088.761
Step_Length	-0.6143279	2.9988e-12
RCOF1	150.542247	1422831289
COP_Open	0.08737999	81.8448314
isometric_30	-0.3458315	1.74312e-7

VI. DISCUSSION

The purpose of this study was to evaluate if fallers were different from non-fallers when comparing the means of biomechanical variables between two groups and to predict fallers with the biomechanical variables. The study suggested that in order to best-predict fallers, weight, height, hamstring muscle activation rate, A-P heel contact velocity, heel deceleration angle, walking velocity, and transitional walking velocity were removed from the model. This may indicated that those variables may be redundant variables or not related to fall occurrence.

In agreement with previous findings [2,3,4,7,8,14,15,16], heel dynamics (i.e. HCV), friction demand characteristics (i.e. RCOF), and balance characteristics (i.e. COP Open) were positively associated with the likelihood of slip-induced falls, whereas, strength (i.e. isometric_30) was negatively associated with the likelihood of slip-induced falls. In other words, higher heel contact velocity and friction demand, more instability, and weaker muscle strength were considered to be major characteristics for fallers in comparison to nonfallers. A study by Lockhart et al. [2] suggested that heel velocity at heel contact was a good indicator to predict slip-induced falls due impulse-momentum relationship. In this paper, they suggested that an increase in heel velocity due to aging process led to an increase in horizontal force components. Furthermore, the increased horizontal shear force due to an increase in heel velocity at the heel contact was suggested to increase RCOF which was demanded coefficient of friction in order for walkers to veer away from slipping [2,4,16]. It was surprising that heel contact velocity and RCOF were used in predicting fallers although they were suggested to be correlated [2, 14]. This may suggest that there were more factors that influenced RCOF besides heel contact velocity such as step length [6,18] and transitional walking velocity (Kim et al., 2005; Lockhart et al., 2003). Commonly, static balance characteristics (i.e. center of pressure) had been evaluated to predict fall potential among older adults although falls usually occurred while in motion. However, static balance characteristics had been a good evaluation measure for sensory organization, especially, when wanting to control inputs from visual, vestibular, and proprioceptive sensory modalities and to evaluate the effects of each modality [6]. Therefore, static balance characteristics (i.e. center of pressure) measure in this study could be selected to predict fallers. In addition to sensory modalities, strength had been indicated to contribute to the likelihood of slips and falls [19]. With intact integration of sensory systems, it was suggested that adequate muscle forces must be generated to ensure adequate motor output when regaining balance from slipping [19]. A fall starts suddenly requiring explosive muscle force generation in order to recover from it. Inability to produce adequate muscle force while loosing balance would lead to falls.

Height, weight, hamstring muscle activation rate, A-P heel contact velocity, heel deceleration angle, walking velocity, transitional walking velocity, and most of strength measures besides isometric_30 were disregarded for predicting fallers in the present study. Slips and falls related studies did not account for anthropometric data such as height and weight [2,14,20]. As the results indicated in the present study, height and weight may not be critical factors in predicting fallers. Muscle activation rate has been indicated to influence heel contact velocity since hamstring play a role in reducing the forward leg momentum [14]. Slips usually start 70-120 ms after the heel contact while the whole body is in forward progression with heel is in the contact with floor. The activation of hamstring muscle has a major impact before the heel contact, not while in motion with heel on the ground. A-P heel velocity was suggested to a better measure for evaluating heel velocity at heel contact because it accounted the linkage model of segments in the lower extremity when measuring the heel velocity. However, it was not found to be useful in predicting for fallers in the present study. This could be probably due to the redundancy effects between heel contact velocity and A-P heel contact velocity when drawing a logistic model for fallers. It was surprising that walking velocity and the transitional walking velocity were not selected for predicting the model for fallers. As suggested [2,14], walking velocity and the transitional walking velocity should have been accounted for predicting fallers in the present study. However, they were removed from the model. This may be due to the redundancy effects of heel contact velocity and the RCOF on walking velocity and the transitional walking velocity. Heel contact velocity was highly corrected to walking velocity [14] and the RCOF was suggested to be highly influenced by the transitional walking velocity [2,6], respectively. In the present study, because the values in RCOF and heel contact velocity were partially the function of walking velocity and transitional walking velocity, they were probably removed during the selection procedure.

VII. ACKNOWLEDGEMENT

This research was supported by “Research Base Construction Fund Support Program” funded by Chonbuk National University in 2015.

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