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Reactive balance control in older adults with diabetes

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A R T I C L E I N F O

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A B S T R A C T

Diabetes mellitus is a major health problem for older adults worldwide and could be associated with impaired ability to recover balance after postural disturbances. This study compared reactive balance control in three groups of adults, young (YA), healthy non-diabetes older (nonDM-OA) and diabetes older (DM-OA). Twenty participants in each group completed a series of vision, plantar cutaneous sensitivity, grip power and lower limb strength tests. In the reactive balance test, participants stood on a force platform and used the dominant hand to pull the handle of a cord that could be suddenly released to create an imbalancing force. The anteroposterior (AP) and mediolateral (ML) motion of the center of pressure (COP) immediately after the sudden release was calculated to represent the level of imbalance experienced by the participants. Regression analysis entering big toe plantar sensitivity and grip power as independent variable was conducted for COP range for the three groups separately. The results showed that, except for the knee extensor, DM-OA had significantly poorer muscle strength and plantar sensitivity, and greater COP ML motion than YA and nonDM-OA. DM-OA also had significantly greater COP AP motion than YA. Grip power alone and together with plantar sensitivity explained a significant amount of variance in the AP and ML COP motion respectively ($r^2 = 0.334$ and 0.582, respectively) for DM-OA. These findings indicated that diabetes in older adults was associated with declines in reactive balance control, and these changes may be related to muscle weakness and plantar insensitivity.

1. Introduction

Diabetes is one of the major chronic diseases among older adults. The disease affected approximately 100 million older people (60–79 years old) globally in 2010 and the number is expected to double in 20 year [1]. One of the unique problems facing older adults with diabetes is higher rates of falls [2]. Falling or fear of falling is associated with reduced quality of life, hospitalization, disability and institutionalization in older adults [3,4]. Hence, falls prevention is an issue that deserves special attention in the care for older adults with diabetes.

Balance control is the primary underpinning function for maintaining upright and preventing falls, and could be proactive (anticipatory) or reactive (compensatory) in nature. In proactive control, the trunk and leg postural muscles are activated and the body's center of pressure (COP) is moved before the onset of the voluntary movement to minimize the balance disturbances that will accompany the impending movement [4,5]. Impaired proactive balance control although could limit the performance of the intended voluntary movement, it would be less likely to lead to loss of balance because under normal circumstances one could choose to perform the movement more cautiously.

In reactive balance control, unexpected balance disturbances are detected by the peripheral sensory receptors to elicit postural responses for balance recovery. A classical paradigm for the study of reactive balance control uses support surface perturbation to induce body sway and shows that after a short latency the trunk and leg muscles would be activated to reverse the sway [6,7]. This type of balance responses are delayed and result in greater displacement of COP in older adults [8,9] and diabetes patients with neuropathy of non-specified ages [10–12].

The balance responses following support surface perturbations are believed to be triggered or scaled by lower limb somatosensory or vestibular inputs induced by body sway in the anteroposterior direction [13]. However, there are situations in which mediolateral balance is also disrupted and/or sensory inputs about imbalance could be elicited from other parts of the body before body sway begins. These additional inputs may be used for balance control and alter the contribution of the different types of sensory inputs.

During daily activities, imbalancing forces could act upon the upper limb, such as when the object (such as a furniture) one is pulling with one hand suddenly moves, creating balance disturbances in both the anteroposterior and mediolateral directions and generating sensory inputs before the body begins to sway. This type of imbalance although

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is common, our understanding of its balance control is limited. A better understanding in this regard can help to develop strategies for falls prevention and provide suggestions for safety education for this population. This study thus sought to determine the effect of aging and diabetes on reactive balance control and its association with sensorimotor functions. It was hypothesized that aging would be associated with poorer reactive balance control, and diabetes in older adults would be associated with even greater imbalance. It was further hypothesized that the declines in balance control in both healthy and diabetes older adults could be partly explained by poorer sensorimotor function.

2. Methods

2.1. Participants

Three groups of adults (n = 20 each), healthy young (YA), healthy non-diabetes older (nonDM-OA) and diabetes older (DM-OA), participated in this study. The common inclusion criteria were able to stand without person support for more than one minute and follow 3-step commands. The common exclusion criteria were acute inflammation, pain or problems in the neuromuscular or musculoskeletal system affecting handgrip or balance performance, blindness, and lower limb amputation. Young adults were recruited from a university campus. Healthy older adults were recruited by posters placed at the nearby community centers and the volunteer service center in a medical center. This group aged over 65 years and had no history of diabetes. Diabetic older adults aged over 65 years and were recruited from the outpatient clinics in the departments of family medicine and endocrinology in a medical center. This study was approved by the Institutional Review Board of the National Cheng Kung University Hospital. All the participants fully understood the protocol and provided written consents.

2.2. Reactive balance task

The participants stood quietly on a force platform (Kistler model 9286A, Winterthur, Switzerland) with the arms at the side and the feet shoulder-width apart in front of a customized compression box (29 × 18 × 33 cm) placed on a table. The box contained a computer-controlled compressor which could be triggered to compress a non-elastic cord connecting to an electronic tensiometer that could indicate the horizontal force exerted onto the cord. The participants held the handle of the cord with the dominant hand and bend the elbow to 90° while maintaining the upper arm vertical to the ground and the wrist at the neutral position. The height and distance of the table would then be adjusted so that the cord was horizontal to the ground without slack (about 1.5 m from the compression box) before the compressor was triggered. While maintaining this initial posture, the participants were instructed to pull the handle and maintain a 2 kg force steadily. After maintaining the pulling force for a variable period of time (less than 8 s), the compressor would be released to create postural disturbance. The participants were instructed to regain upright balance after the release without moving the feet or arms. The task was repeated twice and with a rest of least one minute between trials.

2.3. Physical function assessment

Visual acuity was examined using a standard printed Snellen eye chart 6 m away from the seated participant. Binocular visual contrast sensitivity was examined using the Melbourne Edge Test. If the participant wore corrective glasses during daily activities, they were allowed to do so during the vision tests. Plantar cutaneous sensitivity was examined at bilateral first and fifth metatarsal heads and the center of the heel using the Semmes-Weinstein monofilaments (Patterson Company, IL, USA). This test was conducted in the sitting position with the eyes closed to eliminate visual cues. The thinnest filament that the participant was able to perceive was recorded and for each site, the mean of the two feet was calculated for data analysis.

Bilateral hand-grip strength was assessed using a calibrated JAMAR hand dynamometer (Sammons Preston Rolyan, IL, USA). Participants exerted maximal grip for three seconds in the sitting position with the tested arm at the side, elbow flexion to 90°, and forearm in the neutral position. The maximal isometric strength of bilateral hip flexor, knee extensor, and ankle dorsiflexor was measured using a handheld dynamometer (MicroFET2, HOGGAN Health Industries, UT, USA) following standardized manual muscle testing positions [14]. Handheld dynamometer has been shown to be a reliable and valid method for testing muscle strength [15]. Bilateral ankle plantarflexor strength was tested using the standardized manual muscle testing with a 25-level grade, where participants were instructed to consecutively raise the heel from floor in single-legged standing position [14]. The number of heel rises was recorded to represent the ankle plantarflexor strength. For all the strength measurements, the means of the two sides were used for data analysis.

2.4. Force platform data reduction

Algorithms written in the MATLAB computer language (version R2013a, The MathWorks Inc., Natick, MA) were used for signal processing and data reduction. The data from the force platform were sampled at a rate of 1000 Hz and filtered with a 4th order Butterworth low pass filter at 10 Hz to calculate the COP data. During the reactive balance test with the right hand holding the handle, as the other end of the cord was fixated, the participants consistently reported feeling their body being pulled forward when maintaining the pulling force, and then falling backward when the cord was suddenly released. These postural changes could also be observed by the experimenter. The inspection of the COP patterns confirmed that the COP moved forward and to the left during the pulling period, and immediately after the sudden release, the COP moved backward and to the right (Fig. 1A & B). The COP would then move forward and to the left, and finally reach a stable position near that of the quiet standing. Thus, the COP motion backward and to the right immediately after the sudden release was an indication of imbalance induced. Specifically, the variables of interest in this study included the range and mean and maximal velocity of the COP motion backward and to the right to reflect the different characteristics of the imbalancing motion. The COP range was used to indicate the extent of imbalance. The mean velocity was the averaged instantaneous velocity between cord release and the time when the COP reached the maximal posterior position, and the peak was the maximal instantaneous velocity.

Because the posture at the moment of the sudden release would affect the impact of the postural disturbance, the anteroposterior (AP) and mediolateral (ML) COP initial positions were also calculated in relation to the averaged (300 ms) COP location prior to the onset of the cord release.

2.5. Statistical analysis

For the comparisons of between-group differences in the anthropometrics, sensorimotor functions, and initial posture, one way analysis of variance (ANOVA) with LSD *post-hoc* analysis or Mann-Whitney test was used as indicated. For visual acuity, the better side data were used for analysis. Because the COP motion variables of the same direction were correlated, multivariate ANOVA (MANOVA) was used for the AP and ML directions separately, entering range, and maximal and mean velocity as dependent variable. To determine how the sensorimotor functions contributed to balance performance, stepwise regression analysis was conducted separately for each group. In this model, the independent variable with the smallest p value of F was entered sequentially until no more variables were eligible for inclusion or removal. The rules for entering and removing were $p < 0.05$ and $p > 0.1$, respectively. The rules of thumb suggest that at least 10