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Balance impairment is one of the strongest risk factors for falls. Proprioception, cutaneous sensitivity, and muscle strength are three important contributors to older adults' postural control. The relationship between the proprioception, the cutaneous sensitivity, and the muscle strength with the dynamic and static postural control is still unclear. This study was performed to investigate the relationship of these contributors with dynamic and static postural control. A total of 139 older adults were recruited. Each participant's tactile sensation, proprioception, muscle strength and static/dynamic postural control were tested. The results indicated that dynamic postural control was mainly correlated with lower limb muscle strength (r=-0.335-0.212, p<0.05) and proprioception (r=-0.433-0.170, p<0.05), suggesting that the older adults should improve their ankle plantarflexion, hip abduction muscle strength and knee/ankle proprioception to improve dynamic stability; static postural control ability was mainly influenced by tactile sensation (r=0,212-0.311, p<0.05) and proprioception (r=0.210-0.250, p<0.05), suggesting that the older adults should strengthen arch tactile sensation and knee proprioception to improve static stability.

**KEYWORDS:** tactile sensation; proprioception; muscle strength; postural control;

older adult.

**INTRODUCTION:** Postural control integrates information from the musculoskeletal system and sensory input (Susan, 2010). Among them, proprioception, tactile sensation and lower limb muscle strength are three important factors that affect postural control ability. Previous studies reported contradictory correlations between these three factors and postural control (Priplata, 2010; Holmes, 2016; Banu, 2018). They focused on the effects of single joint proprioception and lower limb muscle strength on postural control with limited sample sizes. Furthermore, most studies have not integrated the correlation between static/dynamic postural control and these three factors, and studying this correlation may reveal their different associations in specific situations. This study aimed to investigate the relationship of proprioception, tactile sensation, and muscle strength to static/dynamic postural control in older adults. We hypothesized that proprioception, tactile sensation, and muscle strength are significantly related to dynamic/static postural control.

**METHODS:** A total of 139 participants without previous fractures within six months were recruited for this study (age: 71.24±7.66； height: 162.58±7.59 cm; weight: 64.77±9.84 kg). They were asked to test tactile sensation, proprioception, strength and postural control: these factors were tested during one test session. Tactile sensation measurements were conducted with a set of Semmes–Weinstein monofilaments (SWM) (North Coast Medical, Inc., Morgan Hill, CA, USA) at great toe (GT) , first (1$^{st}$ Met) and, fifth metatarsal (5$^{th}$ Met) heads, arch, and heel; proprioception measurements included the minimum passive ankle movement detection during knee flexion/extension and ankle plantarflexion/dorsiflexion; muscle strength measurements included relative peak torque of ankle plantarflexion/dorsiflexion and hip abduction; static postural control ability measurements included root mean square (RMS) of Center of Pressure (CoP) displacement and CoP mean velocity (V) in the anterior-posterior (ap) and medial-lateral (ml) directions; dynamic postural control ability measurements included Berg Balance Scale(BBS) score, and the time taken to complete the Timed Up and Go (TUG).The Kistler three-dimensional force plate (KISTLER, 9287BA and 9281CA, Switzerland) was used to measure the static postural control ability; the Semmes-Weinstein monofilament tester (SENSE Lab Aesthe siometer, Horby, Sweden) was used to measure the tactile sensation, the proprioception tester was used to measure the proprioception, IsoMed 2000 strength testing system (D. & R. Ferstl GmbH, Hemau, Germany) was used to measure the muscle strength of the lower limbs. A partial correlation was used to determine the relationship of the measured outcomes variables (BBS, CoP-$RMS_{ap}$, and CoP-$RMS_{ml}$) from the category of postural control with each of the proprioception, tactile sensation, and muscle strength variables, while controlling for the covariates, age, height, and weight. The thresholds for the correlation coefficient (r) were as follows: 0~0.1, trivial; 0.1~0.3, weak; 0.3~0.5, moderate; >0.5, strong (Cohen J, 1988).

**RESULTS:**

(1) Correlation analysis results (Table 1):

a. Arch tactile sensation is moderately correlated with CoP-$RMS_{ap}$ (r=0.311, p<0.001), and weakly correlated with CoP-$RMS_{ml}$ (r=0.267, p=0.002), heel tactile sensation (r=0.212, p=0.013) is weakly correlated with CoP-$RMS_{ap}$.

b. Knee flexion proprioception threshold (r=-0.345, p<0.001), knee extension proprioception threshold (r=-0.331, p<0.001), ankle dorsiflexion proprioception threshold (r=-0.321, p< 0.001), and ankle plantarflexion threshold (r=-0.433, p<0.001) are moderately correlated with BBS. Knee flexion proprioception threshold (r=0.171, p=0.047), knee extension proprioception threshold (r=0.170, p=0.048) , ankle dorsiflexion proprioception threshold (r=0.241, p=0.005), ankle plantarflexion proprioception threshold (r=0.209, p=0.014) are weakly correlated with TUG; knee flexion proprioception threshold (r=0.210, p=0.014) is weakly correlated with CoP-$RMS_{ml}$; knee extension proprioception threshold is weakly correlated with CoP-$V_{ap}$ (r=0.223, p=0.009) and CoP-$V_{ml}$ (r=0.250, p=0.003).

c. The relative peak torque of ankle dorsiflexion (r=-0.24, p=0.005) and hip abduction (r=0.294, p=0.001) are weakly correlated with BBS. The relative peak torque of ankle plantarflexion (r=0.327, p<0.001) is moderately correlated with BBS. The relative peak torque of ankle dorsiflexion (r=0.212, p=0.013) and ankle plantarflexion (r=-0.258, p=0.002) are weakly correlated with TUG. The relative peak torque of hip abduction (r=-0.335, p<0.001) is moderately correlation with TUG.

Table 1: Correlations of proprioception, tactile sensation and muscle strength to postural control

| concomitat variable | | variables | | BBS | TUG | CoP-$RMS_{ap}$ | CoP-$RMS_{ml}$ | CoP-$V_{ap}$ | CoP-$V_{ml}$ |
|---|---|---|---|---|---|---|---|---|---|
| Height, Weight & age | Proprioception (°) | Ankle plantarflexion | r | **-0.433$^{**}$** | **0.209$^{*}$** | 0.090 | 0.158 | 0.110 | 0.130 |
| | | | p | **0.000** | **0.014** | 0.296 | 0.066 | 0.204 | 0.130 |
| | | Ankle dorsiflexion | r | **-0.321$^{**}$** | **0.241$^{**}$** | 0.047 | 0.119 | 0.035 | 0.059 |
| | | | p | **0.000** | **0.005** | 0.591 | 0.167 | 0.682 | 0.496 |
| | | Knee flexion | r | **-0.345$^{**}$** | **0.171$^{*}$** | 0.079 | **0.210$^{*}$** | 0.099 | 0.139 |
| | | | p | **0.000** | **0.047** | 0.363 | **0.014** | 0.250 | 0.107 |
| | | Knee extension | r | **-0.331$^{**}$** | **0.170$^{*}$** | 0.062 | 0.139 | **0.223$^{**}$** | **0.250$^{**}$** |
| | | | p | **0.000** | **0.048** | 0.476 | 0.106 | **0.009** | **0.003** |
| | Tactile sensation (gauge) | Great toe | r | -0.099 | 0.059 | 0.068 | 0.112 | 0.055 | 0.053 |
| | | | p | 0.253 | 0.492 | 0.431 | 0.193 | 0.524 | 0.537 |
| | | 1st metataesal | r | 0.060 | -0.101 | 0.155 | 0.055 | -0.021 | -0.028 |
| | | | p | 0.490 | 0.241 | 0.072 | 0.523 | 0.806 | 0.748 |
| | | 5th metataesal | r | -0.007 | -0.059 | 0.092 | -0.003 | 0.044 | 0.027 |
| | | | p | 0.939 | 0.496 | 0.289 | 0.971 | 0.607 | 0.756 |
| | | Arch | r | 0.007 | -0.027 | **0.311$^{**}$** | **0.267$^{**}$** | -0.114 | -0.116 |
| | | | p | 0.938 | 0.758 | **0.000** | **0.002** | 0.187 | 0.178 |
| | | Heel | r | -0.034 | -0.093 | **0.212$^{*}$** | 0.132 | 0.122 | 0.127 |
| | | | p | 0.694 | 0.283 | **0.013** | 0.125 | 0.156 | 0.141 |
| | Muscle strength (N*m/kg) | Ankle plantarflexion | r | **0.327$^{**}$** | **-0.258$^{**}$** | 0.163 | 0.120 | -0.003 | -0.013 |
| | | | p | **0.000** | **0.002** | 0.058 | 0.163 | 0.977 | 0.885 |
| | | Ankle | r | **-0.240$^{**}$** | **0.212$^{*}$** | -0.174 | -0.173 | 0.154 | 0.153 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| dorsiflexion | p | **0.005** | **0.013** | 0.053 | 0.055 | 0.073 | 0.075 |
| Hip abduction | r | **0.294**** | **-0.335**** | 0.056 | 0.012 | -0.143 | -0.142 |
| | p | **0.001** | **0.000** | 0.518 | 0.887 | 0.098 | 0.099 |

Note: **P<0.01, *P<0.05

(2) Regression equations of fall risk factors (Table 2):

a. BBS=52.946-0.427 ankle plantarflexion proprioception threshold+ 5.443 ankle plantarflexion relative peak torque.

b. TUG=14.657-4.399 hip abduction relative peak torque +0.197 ankle dorsiflexion proprioception threshold+ 7.723 ankle dorsiflexion relative peak torque.

Table 2: Regression analysis model coefficients

| Model | | Non-standardized coefficient | | Sig. | Covariance statistics | |
|---|---|---|---|---|---|---|
| | | B | S.E | | tolerance | VIF |
| BBS | constants | 52.946 | 0.561 | P<0.001 | | |
| | ankle plantarflexion proprioception threshold | -0.427 | 0.066 | P<0.001 | 0.847 | 1.180 |
| | ankle plantarflexion relative peak torque | 5.443 | 1.125 | P<0.001 | 0.847 | 1.180 |
| TUG | constants | 14.657 | 0.742 | p<0.001 | | |
| | hip abduction relative peak torque | -4.399 | 1.265 | 0.001 | 0.708 | 1.413 |
| | ankle dorsiflexion proprioception threshold | 0.197 | 0.058 | 0.001 | 0.867 | 1.153 |
| | ankle dorsiflexion relative peak torque | 7.723 | 2.885 | 0.008 | 0.746 | 1.341 |

Note: 'threshold': the minimum angle of motion that the participants can perceive during ankle plantarflexion/dorsiflexion

'constants': is the regression analysis model we need to build ($y= a+b_0x_0+b_1x_1+... + b_nx_n$) in a, which is the intercept of the regression line on the vertical axis

**DISCUSSION:** Some studies have suggested a correlation between tactile sensation of the 1st metataesal and dynamic postural control (Cruz-Almeida, 2014). This result is contrary to our findings. This may be due to the different specifications of the monofilaments used in the two experiments. The specifications of the SWM used in the experiment by Yenisel (Cruz-Almeida, 2014) were 5.07 (10g), while the specifications of the SWM used in this experiment were 2.83 (0.07g), 3.61 (0.4g), 4.31 (2g), 4.56 (4g), 5.07 (10g), 6.65 (300g). The five divisions of the foot in this experiment were tested for tactile sensation in order of size, and the data were more comprehensive and the results were more reflective of the correlation between tactile sensation and static postural control.

This study showed that ankle proprioception was more correlated with dynamic postural control than the knee. This result is contrary to the findings of Kokmen (Emre,1978). The reasons may be elucidated: the ankle conditioning strategy is the most commonly used conditioning strategy in postural control by the human body to generate and regulate muscle contractions to maintain the body's upright balance (Goble, 2011), and ankle proprioception is the most complex synaptic center of the human body in locomotion, a combined proprioceptive and balance response with abundant proprioceptors, especially in the lateral collateral ligaments. 93% of these sensors are located distal and proximal to the ligament (Meyer, 2004). Thus lead to the phenomenon of inconsistent conclusions.

In the relationship between muscle strength and static postural control, Satu Pajala (Satu, 2008) contradicted our findings by suggesting that displacement of CoP in the AP direction is associated with a decrease in static postural control in older adults. This may be due to different measurement methods Satu Pajala measured static postural control using the Tandem step standing test (Satu, 2008). Requiring subjects to place one foot in front of the other foot so that the longitudinal axes of both feet remain in the same direction greatly reduces the ground contact area of the subject's foot compared to the present study poses a higher challenge to maintaining static postural control in humans (Speers, 1998).

It can be concluded from the equation that most falls occur due to the interaction of multiple fall risk factors, and when more than one higher fall risk factor exists simultaneously in the elderly, their probability of falling exceeds 80% (Tinetti, 2003). Secondly, the weight of factors affecting the decline of postural balance function in the elderly varies, so the prevention of falls in the elderly should be based on a comprehensive analysis and intervention of multiple factors, and more targeted prevention should be carried out according to the empirical results. Among them, strengthening the muscle strength training of lower limb ankle and hip has a positive effect on maintaining the stability of daily walking of the elderly; strengthening the training of lower limb ankle and hip proprioception has a positive effect on maintaining the stability of daily walking and static standing of the elderly; strengthening the training of arch and heel tactile sensation has a positive effect on maintaining the stability of daily static standing of the elderly.

**CONCLUSION:** The postural control of the older adults is related to the tactile sensation, proprioception, and lower limb muscle strength. Among them, dynamic postural control is mainly correlated with lower limb muscle strength and proprioception, suggesting that trainings to improve the ankle plantarflexion, hip abduction muscle strength and knee and ankle proprioception should be recommended to older adults to improve dynamic postural control. Static postural control is mainly correlated with tactile sensation and proprioception suggesting that trainings to improve the proprioception and planter tactile sensitivity should be recommended to older adults to improve static postural control.

**Limitations and recommendations:** In this paper, only the kinematic indices of the lower limb related to postural control in the older adults were correlated using currently available equipment, not the upper limb and human nerves, thus limiting the scope of application of the final results, but this is one of the future directions in this field.

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