Correlation Between Sleep Duration, Exercise Time, Toe Flexor Strength, and Balance in Older Adults

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Abstract

The toe flexor strength contributes to maintaining the body's center of gravity and recovering balance in potentially hazardous situations such as slips or falls. This study examined the correlation between sleep duration, exercise time, toe flexor strength, and balance ability in older adults. This study included 59 older adults aged 65 and above (mean age 72.5 ± 5.4 years). Self-reported data on sleep duration and exercise time per week were collected through a structured questionnaire. Toe flexor strength was measured using a handheld dynamometer (Hoggan), and balance parameters were evaluated using the Quiet Stand (closed-eye, 30seconds) test on the Force Decks system (Vald). Sleep duration was significantly associated with the area of the center of pressure (CoP) ellipse, a metric of balance ($r = 0.34$, $p < 0.05$). Exercise time was significantly correlated with right toe flexor strength ($r = 0.33$, $p < 0.05$). In terms of the relationship between toe flexor strength and balance, right toe flexor strength influenced the CoP medial range ($r = 0.33$, $p = 0.12$), while left toe flexor strength showed a non-linear relationship with balance. These findings suggest that while muscle strength naturally decreases with age, exercise time is strongly correlated with toe flexor strength, which significantly impacts balance. Enhancing these factors through targeted interventions may help improve functional health and reduce fall risk in older adults.

Keywords: sleep duration, exercise time, toe flexor, balance, older adults

Introduction

Aging leads to a general decline in physical functions, and especially the decrease in balance ability is directly associated with an increased risk of falls among older adults (Tinetti et al., 1988). Various studies have shown that the deterioration in balance is closely related not only to the decline in muscle strength but also to sleep quality and the level of physical activity (Chennaoui et al., 2015; Smagula et al., 2016). Impaired balance ability makes it difficult for older adults to perform independent daily activities and serves as a major factor in increasing the risk of fractures and long-term functional impairments due to falls. Sleep deprivation can negatively affect postural control by impairing muscle recovery and the nervous system (Chennaoui et al., 2015; Paillard, 2023). Previous studies have reported that older adults with shorter sleep duration show poorer balance and a higher risk of falls (Fu et al., 2017; Smagula et al., 2016). However, the relationship between sleep duration and toe flexor strength has not been clearly established.

Toe flexor strength is a crucial factor in gait and postural stability, and a decrease in toe flexor strength is likely to be directly associated with impaired balance (Mickle et al., 2016; Quinlan et al., 2020). On the other hand, regular physical activity plays an important role in improving lower extremity strength and balance in older adults (Nagai et al., 2012; Quinlan et al., 2020). Lower limb and toe flexor strength have a significant impact on gait stability and balance, and reduced toe flexor strength is linked to altered gait patterns and increased risk of falls (Quinlan et al., 2020). However, studies specifically analyzing the effects of exercise time on toe flexor strength and balance are limited.

Therefore, the purpose of this study is to investigate the relationships among sleep duration, exercise time, toe flexor strength, and balance in older adults and to provide foundational data for developing effective intervention strategies to prevent balance decline and falls.

Methods

59 older adults aged 65 years and above (mean age 72.5 ± 5.4 years) participated in this study. Self-reported data on sleep duration and exercise time per week were collected through a structured questionnaire. Toe flexor strength was measured using a portable handheld dynamometer (Hogan Handheld Dynamometer, USA), and balance ability was assessed using the Quiet Stand (closed-eye, 30seconds) test on the Force Decks System (Vald, Australia).

Results

Correlational analysis was conducted to achieve the study's objectives.

Table 1

Correlations Among Sleep Duration, Exercise Time, and Toe Flexor Strength

	Sleep Duration	Exercise Time	Rt. Toe Max	Lt. Toe Max
Sleep Duration	1			
Exercise Time	0.221	1		
Rt. Toe Max	-0.056	**0.329**	1	
Lt. Toe Max	-0.081	0.259	**0.697**	1
Gap: Rt.Max-Lt.Max	0.076	0.183	**0.455**	-0.112

($N = 59$, $p < 0.05$)

Sleep and exercise time did not significantly affect most variables. However, exercise time showed a significant correlation with right toe flexor strength (r = 0.329), which may reflect the dominant right-hand/right-foot characteristic among older Korean adults. Additionally, stronger toe flexor strength on one side was associated with higher strength on the opposite side (r = 0.69), and the difference in toe flexor strength between the right and left foot (Gap Rt. Max – Lt. Max) was primarily influenced by the right toe flexor strength (Rt. Toe Max: r = 0.46).

Table 2

Correlations of Sleep and Exercise With Balance Variables Based on CoP Measures

	Sleep	Exercise Time	Area of CoP Ellipse	CoP Range: Anterior-Posterior	CoP Range: Medial-Lateral
Sleep Duration	1				
Exercise Time	0.221	1			
Area of CoP Ellipse	**0.343**	0.093	1		
CoP Range: Anterior-Posterior	0.222	0.053	**0.790**	1	1
CoP Range: Medial-Lateral	0.264	0.129	**0.536**	0.374	
Total Excursion	0.248	0.183	**0.662**	0.755	-0.112

(N = 59, p < 0.05)

Sleep duration showed a significant correlation with the CoP (Center of Pressure) ellipse area, a major indicator of balance ability (r = 0.34). The CoP ellipse area also showed strong correlations with the CoP range in the anterior-posterior direction (r = 0.79), the medial-lateral range (r = 0.54), and the total path length (r = 0.66). These findings suggest that the CoP ellipse area is a comprehensive indicator of balance ability, and sleep duration may influence it.

Table 3

Associations Between Toe Flexor Strength and Balance Parameters

	Rt. Toe Max	Lt. Toe Max	Gap: Rt.Max-Lt.Max
Rt. Toe Max	1		
Lt. Toe Max	**0.697**	1	
Gap: Rt.Max-Lt.Max	**0.455**	-0.112	1
Area of CoP Ellipse	0.021	-0.105	0.214
CoP Range: Anterior-Posterior	0.077	-0.079	**0.386**
CoP Range: Medial-Lateral	**0.326**	0.290	0.228
Total Excursion	0.065	-0.117	**0.320**

(N = 59, p < 0.05)

Right toe flexor strength showed a significant correlation with the medial-lateral range of CoP (r = 0.33), indicating that toe flexor strength can influence lateral balance. The difference in toe flexor strength between both feet was also significantly correlated with the anterior-posterior CoP range (r = 0.39) and the total path length (r = 0.32), suggesting that imbalance in toe flexor strength may affect overall balance control.

Table 4
Correlation Between Age and Toe Flexor Strength Asymmetry

	Age	Rt. Toe Max	Lt. Toe Max	Gap: Rt.Max-Lt.Max
Age	1			
Rt. Toe Max	0.153	1		
Lt. Toe Max	-0.044	**0.700**	1	
Gap: Rt.Max-Lt.Max	**0.408**	**0.455**	-0.112	1

(N = 59, p < 0.05)

There was also a significant correlation between age and the difference in toe flexor strength between both feet (Gap: Rt Max - Lt Max, r = 0.34), indicating a tendency for the strength difference to increase with age. This may imply that the strength of the more frequently used foot is better preserved, while the less used foot experiences a greater decline in strength.

Discussion

Sleep Duration and Toe Flexor Strength

Sleep duration did not show a significant correlation with toe flexor strength. This suggests that sleep duration may not directly affect the toe flexor strength, or other physiological factors may mediate the relationship. This result is consistent with Fu et al. (2017), who also reported that while sleep affects general physical function, its influence on isolated muscular strength such as toe flexors may be limited. Sleep may affect overall function or balance more than isolated muscular strength.

Exercise Time and Right Toe Flexor Strength

Exercise time was significantly correlated with right toe flexor strength, which may be related to the dominant side characteristic among Korean older adults. This finding aligns with previous studies (Mickle et al., 2016; Nagai et al., 2012), which emphasize that regular physical activity contributes to the preservation of muscular strength, particularly in the dominant limbs. These studies support the notion that exercise enhances strength asymmetrically in favor of the dominant side.

Correlation Between Both Feet's Toe Flexor Strength

There was a strong correlation between the toe flexor strength of both feet. This indicates that greater strength in one foot is likely accompanied by greater strength in the other, reflecting the tendency for symmetrical development or decline in muscle strength. This finding agrees with Mickle et al. (2016), who observed bilateral symmetry in foot muscle strength decline with aging, implying systemic factors in muscle degeneration.

Effect of the Right Foot on Toe Flexor Strength Asymmetry

The difference in toe flexor strength between both feet was mainly influenced by the strength of the right foot. This suggests that higher usage frequency of the dominant foot may help preserve its strength, while the non-dominant foot experiences more significant decline. This asymmetry has been noted in prior literature (Mickle et al., 2016), which also reported that habitual loading on the dominant foot leads to relatively better preservation of muscle mass and function.

Correlation Between Sleep Duration and Balance Ability

Sleep duration showed a significant correlation with the CoP ellipse area, indicating that sleep may positively affect balance maintenance (Fu et al., 2017; Paillard, 2023). This result reinforces the conclusions drawn by Fu et al. (2017) and Paillard (2023), both of whom reported that inadequate sleep negatively affects neuromuscular control and postural stability. The CoP ellipse area demonstrated a strong correlation with both anterior-posterior and medial-lateral sway, indicating that the various components of postural balance are functionally interrelated. This interdependence is further supported by the quantitative analysis of sway dynamics conducted by Quinlan et al. (2020).

Conclusion

This study examined the correlations among toe flexor strength, balance indicators, exercise time, and sleep duration in older adults. The findings revealed that, overall, sleep and exercise time were not significantly associated with toe flexor strength. However, exercise time showed a significant positive correlation with right toe flexor strength, which may reflect dominant-side usage patterns in this population. Sleep duration was significantly correlated with balance-related indicators, particularly the CoP ellipse area, underscoring the potential role of sleep in postural control. In addition, asymmetry in toe flexor strength between both feet emerged as a possible factor influencing balance ability.

These results suggest that balance control in older adults is shaped by a multifaceted and dynamic interplay of physiological, behavioral, and lifestyle factors. The observed associations align with existing literature emphasizing the multifactorial nature of balance decline in aging populations (Mickle et al., 2016; Paillard, 2023; Quinlan et al., 2020). Specifically, previous studies have demonstrated that muscle strength, sleep quality, and neuromuscular coordination are key components in maintaining postural stability and preventing falls.

Given these findings, future research should employ more comprehensive models that account for individual characteristics such as age, sex, physical activity level, and habitual asymmetries. Moreover, intervention strategies targeting toe flexor muscle strengthening and promoting adequate sleep duration may serve as practical and effective approaches for improving balance and mitigating fall risk in older adults. Such strategies are consistent with preventive frameworks proposed in prior studies and may contribute meaningfully to aging-in-place and fall prevention efforts in community and clinical settings.

However, this study has several limitations that should be considered when interpreting the results. First, the cross-sectional design precludes causal inferences regarding the relationships among variables. Second, the relatively small and homogeneous sample limits the generalizability of the findings to broader older adult populations. Additionally, self-reported data on exercise time and sleep duration may be subject to recall bias and may not fully capture behavioral patterns. Future studies employing longitudinal or experimental designs with larger and more diverse populations, along with objective measurements of sleep and physical activity, are warranted to validate and extend the current findings.

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