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The influence of high- and low-heeled shoes on balance in young women

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Purpose: To evaluate the influence of two different heel heights on static balance and on limits of stability during functional reach test, with both the eyes open and eyes closed, in young women (age 22–27) who did not wear heeled shoes habitually. *Methods*: Thirty-one young women (age 22–27) performed balance tests on a stabilometric platform without footwear and in shoes with 4 cm and 10 cm heels. The center of pressure (COP) deviations range and velocity in anteroposterior (AP) and mediolateral (ML) directions were assessed. The limits of stability were measured when the subject leaned the body in sagittal plane. *Results*: The ranges of COP deviations in AP and ML directions were already significantly higher in 4 cm heels in comparison to the barefoot condition. COP deviation velocity significantly raised with increasing heel height as well as when the eyes were closed. *Conclusions*: A more pronounced increase of COP deviation velocity than COP deviation range when measurement conditions become more difficult may indicate that young women anticipate postural corrections by stimulation of ankle proprioception when heeled shoes are worn. High-heeled shoes may lead to alterations in velocity feedback balance mechanism, which may increase the risk of musculoskeletal injuries. Observed in our study adverse effect of heeled footwear on balance may predispose women to falls and injuries. Permanent use of stiletto high heels should be avoided by women.

Key words: *heeled shoes, balance, stabilometric platform, proprioception*

1. Introduction

Many women wore high-heeled shoes at some point in their lives and many even wear them on a regular basis. Accordingly, scientists have examined several effects of wearing high-heeled shoes on a body in the recent years [14], [23], [29].

As was reported, postural control is essential for the successful performance of daily movements and activities as well as fall prevention [17]. While the kinematic and kinetic changes of the lower limb during high-heeled gait and their relationship with overuse injuries have been studied extensively [18], [21], [22], [24], [25], [28], balance control of the body has not been studied as widely [2], [19]. The current knowledge is based on the data obtained from clinical tests, swaymeter measurements, or the body's COM motion during gait, which provide limited insights into body balance and postural control [1], [3], [19]. Those studies suggested that the use of high-heeled shoes may lead to abnormal deviations of the center of pressure (COP) locations indicating a lack of body balance [11]. Gerber et al. [12] suggested that high-heeled shoes altered the quality of afferent proprioceptive information from the ankle, influencing the balance and postural control. This may be the reason why they observed the increase in COP sway range in the anteroposterior and mediolateral directions, which was higher with the eyes closed. It is believed that for quiet standing, ankle proprioception is crucial to establish an internal organization necessary to perform a motor task [13]. It was previously reported that certain postural reactions were adapted according to ve-

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locity information [20]. Velocity feedback mechanism plays a crucial role in control of standing posture integrating the multisensory information, especially proprioceptive and plantar cutaneous sensations [20]. Therefore the change of ankle position due to heeled shoes is the factor which modifies the sensory input from proprioceptive receptors and when the foot is in unnatural plantarflexion the velocity of COP displacement may increase as the manifestation of proprioceptive reaction anticipating body posture [13], [20].

The majority of previous studies addressed the influence of heeled shoes on balance in older women [13] or in habitual high-heel wearers [2], [12]. They found that shoes with an elevated heel impaired balance [12] and reduced performance in functional tests [1]. There is a lack of papers which would comprehensively evaluate the influence of heeled footwear on static balance and on limits of stability in the young population without changes due to habitual heeled shoes wearing.

For that reason, in the current study, we have evaluated the influence of two different heel heights on static balance and on limits of stability during functional reach test, with both the eyes open and eyes closed, in young subjects who did not wear heeled shoes habitually. As such, this work is novel for it 1) takes a comprehensive approach by examining the effects of low- and high-heeled shoes on balance utilizing a stabilometric platform which is considered the most reliable and appropriate tool for body balance evaluation and 2) addresses the independent effects of the visual restriction and the height of a heel on changes in the control of balance, which may be important in falls and injuries prevention in women.

2. Methods

Young women (n = 31, age 22–27; 168.6 ± 5.1 cm; 57.1 ± 11.8 kg) were examined in this study. They were healthy and did not have any orthopedic or neurologic disorders. Each subject performed balance tests on a stabilometric platform in all three conditions: (1) barefoot, (2) in low heels (LH – 4 cm), and (3) in high heels (HH – 10 cm). The heels were of the stiletto-heeled type with a base of 1 cm^2. Before the experiment, each subject performed static and dynamic trials with and without shoes to become familiar with all measurements.

All participants reported wearing high-heeled shoes occasionally, but not more frequently than once a month. To familiarize the subjects with high-heeled shoes better, they were all asked to use stiletto type shoes one hour a day during the week prior to the study. The Local Ethical Committee approved the study.

The ALFA stabilometric platform (AC International East, Poland) was used in this study. The acquisition frequency was 62 Hz which was recommended as adequate sampling rate for body balance evaluation [27]. In standard configuration, the platform was equipped with software for data acquisition and analysis and the balance assessment (including Romberg's test) and exercise module. Calibration of the stabilometric platform was conducted prior to the data collection based on the manufacturer's instructions. Subjects were asked to stand upright on the platform with their arms to their sides and remain as still as possible in a relaxed posture. The three successive trials in random order were performed (barefoot, low heels and high heels) with a 1 minute rest between trials.

The static balance (Romberg test) was measured during 2 minutes of quiet standing: 1 minute with the eyes open (EO) and 1 minute with the eyes closed (EC).

Evaluated variables:

– COP deviation range in AP and ML directions (cm),
– COP deviation velocity in AP and ML directions (cm/s),
– Path length (cm),
– Path area (cm^2).

Functional reach test was performed when the subject leaned the body in sagittal plane in anteroposterior direction as far as possible to reach the anterior and posterior limit of stability. The subject leaned forwards and backwards twice.

Evaluated variables:

– Limit of Stability (cm) – the COP distance from anterior to posterior limit of stability in AP direction;
– Dynamic COP deviation range in ML direction (cm) during the body leaning in sagittal plane.

The statistical analysis was conducted using the Statistica 10.0 software. A repeated measurement analysis of variance (RM-ANOVA) was employed for the evaluation of the significance in the differences of the dependent variables (balance parameters) across the independent variables (footwear condition). Significance was set at ($p < 0.05$).

3. Results

Gradual increase in the COP deviation range in AP direction between study conditions was observed with

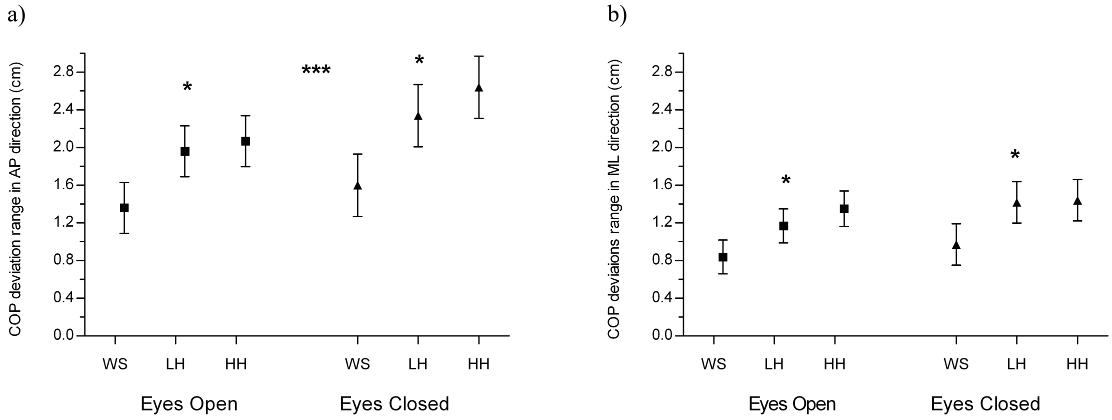

Fig. 1. Effects of heel height on COP deviation range in AP (a) and ML (b) directions.
**p* < 0.05 significantly different value in without shoes vs. low-heel condition
(The *p* value is the post-hoc of study condition main effect)
****p* < 0.05 significantly different value in eyes open vs. eyes closed was noted only in high-heel condition.
WS-without Shoes; LH – Low Heels; HH – High Heels; COP – Center of Pressure; (95% CI)

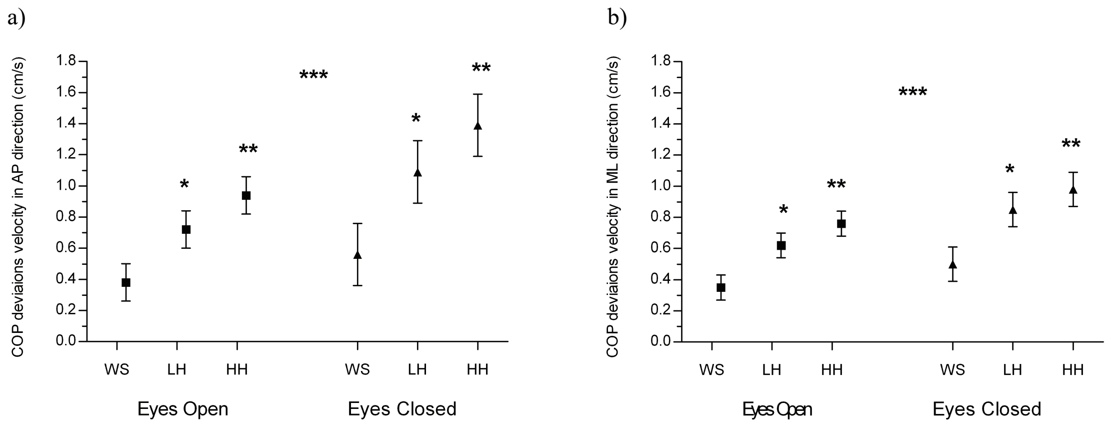

Fig. 2. Effects of heel height on COP deviation velocity in AP (a) and ML (b) directions.
**p* < 0.05 significantly different value in without shoes vs. low-heel condition
***p* < 0.05 significantly different value in low-heel vs. high- heel condition
(The *p*-value is the post-hoc of study condition main effect)
****p* < 0.05significantly different value in eyes open vs. eyes closed was noted in low-heel and in high-heel conditions.
WS – without Shoes; LH – Low Heels; HH – High Heels; COP – Center of Pressure; (95% CI)

EO and EC, but a significant difference was noted between the LH and barefoot condition (Fig. 1a). A significantly higher value of the COP deviation range with EC in comparison to EO was noted only in HH condition (Fig. 1a). Similar variability of this parameter was noted in ML direction (Fig. 1b). No significant differences were observed in COP deviation range in ML directions between EO and EC in all study conditions ($p > 0.05$) (Fig. 1b).

The COP deviation velocity in AP direction was significantly higher in the LH in comparison to the barefoot condition, and an additional significant increase was observed between the LH and HH condition. Those changes were noted in EO as well as EC (Fig. 2a).

COP deviation velocity in ML direction was higher with the increase in heel height with EO as well as with EC, but a significantly higher value was noted only in LH compared to the barefoot condition (Fig. 2b).

A significantly higher value of COP deviation velocity in AP direction with the EC in comparison to EO was noted in both the LH and the HH conditions (Fig. 2a). Similar variability of this parameter was noted in the ML direction (Fig. 2b).

The path length was significantly higher in the LH in comparison to the barefoot condition, as well as in the LH in comparison to the HH condition. This gradual increase in path length was noted both with EO and EC (Fig. 3).

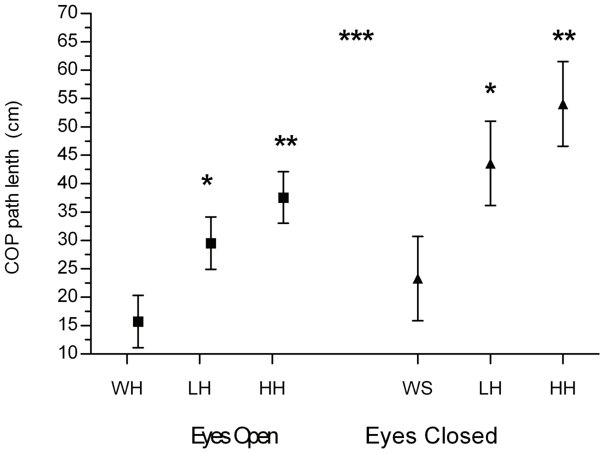

Fig. 3. Effects of heel height on COP path length.
*$p < 0.05$ significantly different value in without shoes vs. low-heel condition **$p < 0.05$ significantly different value in low-heel vs. high- heel condition (The p-value is the post-hoc of study condition main effect) ***$p < 0.05$significantly different value in eyes open vs. eyes closed was noted in low-heel and WS – without Shoes; LH – Low Heels; HH – High Heels; COP – Center of Pressure; (95% CI)

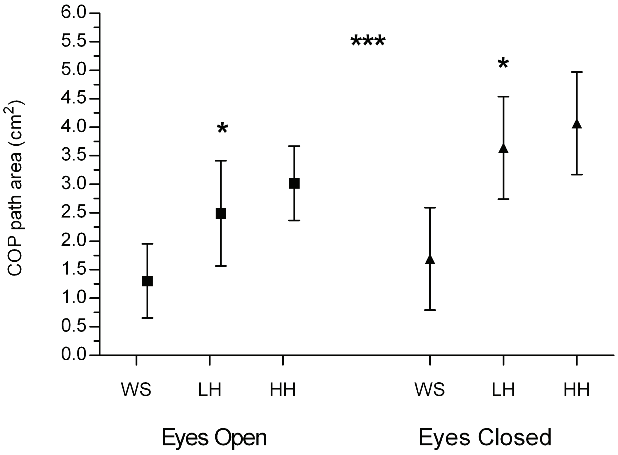

Fig. 4. Effects of heel height on COP path area.
*$p < 0.05$ significantly different value in without shoes vs. low-heel condition (The p-value is the post-hoc of study condition main effect)
***$p < 0.05$significantly different value in eyes open vs. eyes closed was noted in low-heel and in high-heel conditions.
WS –without Shoes; LH – Low Heels; HH – High Heels; COP – Center of Pressure; (95% CI)

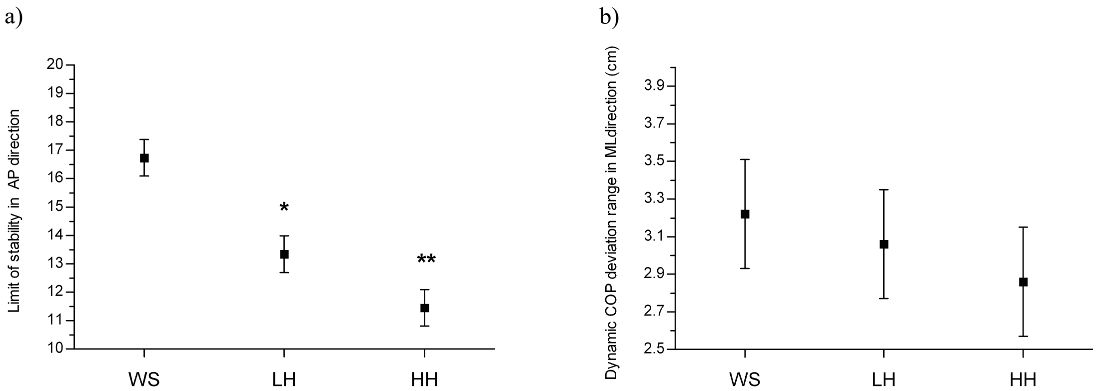

Fig. 5. Effects of heel height on limit of stability in AP direction (a) and on dynamic COP deviation range in ML direction (b).
*$p < 0.05$ significantly different value in without shoes vs. low-heel condition
(The p-value is the post-hoc of study condition main effect) **$p < 0.05$ significantly different value in low-heel vs. high-heel condition.
WS – without Shoes; LH – Low Heels; HH – High Heels; COP – Center of Pressure; (95% CI)

A significantly higher value of path length measured with EC than with EO was noted in both the LH and the HH conditions (Fig. 3).

A gradual increase in path area between study conditions was observed with EO and EC, however, a significant difference was noted only between the LH and barefoot condition (Fig. 4). A significantly higher value of path area in the measurement with EC than with EO was noted only in the LH condition (Fig. 4).

A gradual significant decrease in path length indicating the unfavorable influence of heeled shoes on limits of stability was noted between all three study conditions (Fig. 5a).

No significant differences were observed in COP deviations in ML directions between all study conditions $p > 0.05$) (Fig. 5b).

4. Discussion

The most novel finding of this study is that during the static balance evaluation the range of COP deviations in AP and ML directions and path area were already significantly higher in 4 cm heels in comparison to the barefoot condition, and even increased but not significantly in 10 cm heeled shoes. What is interesting, with eyes closed, compared to eyes open, the deterioration in the COP deviation range was observed only in high-heeled shoes and only in AP directions suggesting a mild influence of the absence of vision on static balance. Despite no significant changes in COP deviation range in some of the study conditions, the COP deviation velocity gradually and significantly increased with increasing heel height as well as with the absence of vision when the eyes were closed. Thus, more pronounced increase of COP deviation velocity than COP deviation range when measurement conditions become more difficult indicates that young women anticipate postural corrections by stimulation of ankle proprioception when heeled shoes are worn. As was reported by some authors the change of ankle position due to heeled shoes is the factor which modifies the sensory input from proprioceptive receptors. Therefore when the foot is in unnatural plantarflexion the velocity of COP displacement may increase as the manifestation of proprioceptive reaction anticipating body posture [13], [20]. Observed in our study, with eyes closed an increase in COP deviation velocity without simultaneously increasing COP deviation range is in contrast to other authors' observations [12], who have reported that the wearing of heeled shoes deteriorated static balance in young women, increasing the range of COP sway range, regardless of visual restriction.

There are some suggestions in literature [11]–[13], [16], [20] that foot plantarflexion in heeled shoes causes changes in the proper positioning of proprioceptive receptors which may change the proprioceptive information from the ankle region and affect the maintenance of posture and balance. Gerber et al. [12] reported that when the foot is in plantarflexion the oscillations of the body COP were higher when compared to the barefoot condition. The following deterioration in static balance was observed with the eyes closed, when the absence of vision interfered with the altered ankle proprioception. All women being examined were accustomed to wearing heeled footwear but as they underlined, noted oscillations on the ML and AP axes. They suggested that the foot plantarflexion which changes the ankle proprioception is a sufficient factor to induce the increase in COP oscillations [12]. Nonetheless, they did not take into account the role of COP velocity oscillation in anticipation of body position or the detrimental effect of long term heeled-shoes wearing on calf muscles. Therefore, their observations are not supported by data from our study and we suggest that with the absence of alterations due to long term wearing of heeled shoes, the anticipatory postural reactions work properly, even in 10-cm heels and the velocity feedback mechanism which is triggered mainly by ankle proprioceptors compensates the uncontrolled deterioration in COP oscillation range. We hypothesized that the prolonged wearing of shoes with high heels probably may disrupt this anticipatory mechanism leading to more unstable posture when heeled shoes are worn.

Furthermore, a strong coupling of visual information with body sway has been previously reported [5], [12], [26]. Some studies have noted an increase in postural instability with EC in comparison to EO, demonstrating that the interruption of the visual system causes a specific directional oscillation in posture [4], [30]. The results of Gerber et al. [12] revealed significant differences between tests without shoes and when wearing high-heels as well as with EO and EC. They also reported that in high-heeled condition, there was a significant increase in ML oscillation with EC in comparison to EO. But the results of our study did not confirm those observations. The range of COP oscillation in ML direction in our study was not statistically different in high-heeled shoes in comparison to low-heeled shoes indicating that the oscillations in ML direction did not increase significantly with the increase in heel height. Moreover, in our study, the oscillations in ML directions with the eyes closed did not differ significantly from those with the eyes open as well as without shoes as in low- and high-heeled shoes. Also, in the dynamic condition, the change in ML deviation range was not significant. Our observations may suggest that vision restriction may not have as strong influence on balance parameters as was postulated by other authors [12]. As reported by Fitzpatrick and McCloskey [9] and by Hazime et al. [13], the main mechanism controlling balance is proprioception, thus, when working properly, the anticipatory postural reactions from proprioceptors may compensate the absence of vision. The situation in which the range of COP oscillations did not increase significantly with the eyes closed, but simultaneously, a significant increase in COP oscillations velocity occurred was observed in our study. The range of COP displacement was only significantly higher with the eyes closed in high-heeled shoes and only in AP direction. The loss of visual information did not influence the range of ML or AP oscillations in low-heeled shoes.

The importance of velocity information in controlling balance during quiet stance was reported by some authors who suggested that certain postural reactions were adapted according to velocity information [6], [8], [13]. Masani et al. [20] investigated whether a velocity feedback mechanism makes a significant contribution in an anticipatory modulation of ankle extensor activities during quiet stance, and they found that the ankle extensors are controlled in anticipation of the change in the COM displacement. Additionally, Gatev et al. [10] reported a significant correlation between COM displacement during spontaneous body sway and the activity of the lateral gastrocnemius muscle (LG). Moreover, they discovered that the LG activity temporally preceded COM displacement and hypothesized that the CNS applies feedforward control, which anticipates the body position change and activates the LG in advance in order to regulate balance during quiet stance.

The study of Gefen et al. [11] showed that women who often use heeled footwear experience fatigue of the medial and lateral gastrocnemius and peroneus longus muscles. What is more, in habitual high-heeled shoe wearers under fatigue conditions, imbalanced EMG activities of the gastrocnemius medialis versus the gastrocnemius lateralis were observed. They concluded that the lateral tendency of the COP in high-heeled shoe wearers is probably related to the imbalanced activity of the fatigued gastrocnemius lateralis and gastrocnemius medialis. Additionally, they suggested that prolonged raising of the hind foot greater than 5 cm leads to a decrease in the activity of medial gastrocnemius and to increased activity of the lateral gastrocnemius, resulting in instability of the ankle [11], [12]. Also, other authors supported the observation that the factor accelerating fatigue of the muscles may affect the balance control during high-heeled gait, and may limit the ability to control foot stability and COM in response to postural perturbations, leading to an increased risk of ankle sprains and/or falls [2], [7]. This may indicate that the feedforward mechanism from the gastrocnemius lateralis muscle induces the COP displacement and stimulates the ankle proprioception increase in COP velocity oscillation which is the natural reaction anticipating body position change. Therefore we hypothesized that in non-habitual high-heel wearers, this velocity feedback mechanism may play a crucial role in the control of balance. Due to the fact that in women who do not wear heels regularly the alterations in gastrocnemius muscles fibers, or pronounced fatigue of those muscles should not be present. Moreover, the feedforward strategy from gastrocnemius lateralis, which is important in correct activation of velocity feedback, anticipatory reaction should be unaffected. By increasing the COP velocity oscillation the body prevents an increase in the range of COP oscillation. The changes in gastrocnemius muscles due to prolonged foot plantarflexion, which were observed in habitual wearers, are likely to lead to alterations in this mechanism [12]. Therefore, in women for whom the heeled shoes impair balance, the velocity feedback mechanism may not work properly and this may be the reason why the range in COP oscillations increased in both ML and AP directions and deteriorated subsequently with the eyes closed. Probably in habitual wearers, the velocity feedback cannot work properly because of changes in calf muscles, and this may be the reason for the increase in COP oscillation range reported by some authors [8], [10], [12], [20]. These women may be more vulnerable to falls or injury. In our study, all participants used heeled shoes only occasionally, therefore the velocity feedback mechanism worked properly anticipating body position in heeled shoes. We noted a significant increase in COP oscillation velocity in low and in high-heeled shoes in both MP and AP directions.

The limitation of this study was the fact that the study population consisted of healthy, young women, thus it may not be possible to extrapolate these findings to all populations of different ages and health status. Also in current study all evaluated women did not wear high-heeled shoes habitually, and for this reason, future research directly comparing the influence of heeled shoes on balance in habitual and non-habitual wearers is needed.

Recent studies suggest that wearing high-heeled shoes deteriorates balance in healthy young women, increasing the range of COP oscillations, regardless of visual restriction. Our most notable observation is that the more pronounced increase of COP deviation velocity than COP deviation range when measurement conditions become more difficult may indicate that young women who do not use heeled shoes habitually anticipate postural corrections by stimulation of ankle proprioception when heeled shoes are worn.

Based on these observations, when considered in combination with other recent findings, we postulate that permanent wearing of heeled footwear may lead to alterations in the velocity feedback mechanism and deterioration in balance, which may predispose women to falls and injury. However, in women who used heeled shoes only occasionally, the velocity feedback mechanism works properly anticipating body position in heeled shoes.

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