

MECHANISM OF LANDING STRATEGY DURING STEP AEROBICS WITH DIFFERENT BENCH HEIGHTS AND LOADS

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The purpose of this study was to investigate effects of different heights (6inch, 8inch, 10inch) and external loads (0% BW, 10% BW, 15% BW) on lower extremity during step aerobics. Ten college physical education students (age: 23.8 ± 2.1 years, height: 173.5 ± 6.1 cm, weight: 68.5 ± 8.0 kg) participated in this study. A Mega high-speed camera (100 Hz) and an ATMI force plate (1000Hz) were used to record kinematic and kinetic data respectively during step aerobics. Increased vertical ground reaction force, ankle movement, and decreased leg stiffness and ankle joint stiffness were found as the bench height increased to 10 inches which were considered to a high loading rates and shock to the lower extremity, especially at ankle joint. Therefore, people should avoid doing step aerobics at 10-inch bench height for a long time to protect ankle joint and soft tissue from injury.

KEY WORDS: leg stiffness, joint stiffness, ground reaction force.

INTRODUCTION: Step aerobics was the combination of aerobic dance and step training innovating by Gin Miller in 1989. The main effects of step aerobics on its performance included the bench height, stepping rate, body weight and leg length (Stanforth, Stanforth & Velasquez, 1993). Inappropriate bench height was one of the main factors which caused the injury on lower extremities. The peak vertical ground reaction forces were greater in 8 and 10 inch compared with 6-inch bench height (Maybury & Waterfield, 1997) and all of the lower-limb joint moments were increased as the bench height increased (Wu, 2006). The increased of impact force could cause higher risk of injury on lower extremities. Therefore, human might change their landing strategies to prevent higher impact on their joint such as increased knee flexion. Different landing strategies were found in different step-height during stair descent in previous study which showed increased knee flexion, knee and ankle joint moments, ankle power as the step-height increased (Spanjaard, et al., 2008). However, step aerobics requested higher frequency to complete the movement than stair descent. With higher impact force, it might increase joint flexion and leg stiffness to absorb external force. Weighted-vest training was one form of resistance trainings for step aerobics which was considered to improve muscle strength and power of lower limbs (Bean et al., 2002). On the other hand, the extra weighted might increase the joint loadings of lower extremities. Salem et al (2004) demonstrated that wearing 5% and 10% B.W weighted-vest increased knee extension moments and the ankle plantar flexion moments compared to the 0% condition, as well as the impulse of all lower-limb joints, which might increase the risk of injury. Overall, no matter increased bench heights or external loads all had risk of increasing loading rates on lower-limb joints. Little was known about the interaction of different bench heights and weighted-vest training on lower extremities during step aerobics. The purpose of this study was to investigate the effects of different bench heights (6, 8 and 10-inch) and weighted-vest (0%, 10% and 15%) on the lower extremity joint angles, leg stiffness, and joint stiffness during step aerobics to see which kind of condition would affect lower extremity most and has higher risk of injury. We hypothesized that lower extremity joint angles, leg stiffness, and joint stiffness would increase as the bench height increased.

METHODS: Ten college physical education female students (age 19.91 ± 1.14 yr, height 162.95 ± 3.73 cm, mass 54.29 ± 4.82 kg) participated in this study. All participants were physically healthy and right foot dominant. A mega Speed MS25K high speed video camera

(100Hz) and an AMTI force plate (1000Hz) were synchronized to record the subjects' performance of step aerobics in different bench heights (6, 8 and 10-inch) and weighted-vest (0%, 10% and 15%) conditions. The camera was set at 9 meters away from subject in the sagittal plane direction. Nine body landmarks (ear, shoulder, elbow, wrist, hip, knee, ankle, heel and fifth metatarsal head) were attached on the right side of subject's joints. Each subject was asked to perform 1 minute step aerobics at 120 step/min speed in each condition with a specific sequence of steps (Figure 1). There was 2 minutes break for subject between each trail. Experiments conducted with a counterbalanced measures design to avoid fatigue or outside factors changing the behavior of subjects.

For the kinematic data analysis, seven control points were used for direct linear transformation (DLT) calibration. Raw data were filtered using a Butterworth 4th-order low-pass filter with a cut-off frequency of 10 Hz by using APAS motion analysis software. Joint angles were calculated as relative angles. Kinetic data was calculated by DasyLab 6.0 analysis software and filtered with 10 Hz. The joint moments were estimated using an inverse dynamic approach. Calculations were performed using a customized Microsoft Excel spreadsheet. Body segment inertial parameters were referred to the study of human body segment of Taiwanese young people and athletes (Ho, 2002). Ground reaction force and joint moments were normalized by the summation of subject's body weight and the weighted-vest (BW). Leg stiffness (k_{leg}) was calculated from the peak ground reaction (F_{peak}) to the maximum displacement of the leg spring (ΔL) and expressed in BW/m.

$$k_{leg} = F_{peak} / \Delta L \quad (1)$$

The average joint stiffness (k_{joint}) was calculated from the ratio of the change in net muscle moment (ΔM_{joint}) to joint angular displacement ($\Delta \theta_{joint}$) in the sagittal plane between the beginning of the ground contact phase and the instant when the joints were maximally flexed. The unit of joint stiffness was Nm/kg/deg.

$$k_{joint} = \Delta M_{joint} / \Delta \theta_{joint} \quad (2)$$

Two-way ANOVA with repeated measure was used to examine mean differences among bench height and load conditions for variables with an alpha level of $p < .05$. When an interaction was significant, Fisher's LSD method was selected for the multiple comparisons. All statistical analyses were performed by using SPSS 12.0 software.

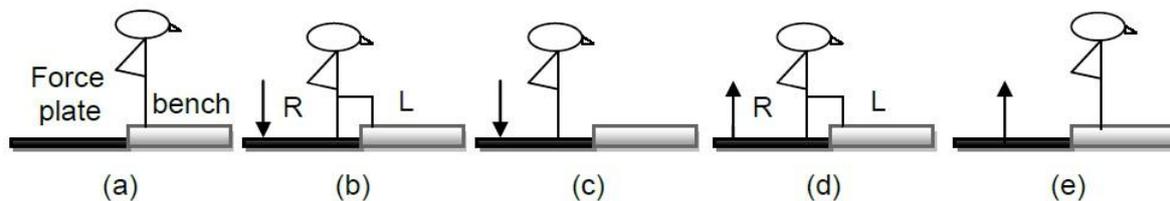


Fig 1: The sequence of steps during a step aerobics cycle: (a) the initial position; (b) descending with right foot; (c) descending with left foot; (d) ascending with left foot; (e) ascending with right foot.

RESULTS: There was no significant interaction between heights and loads in all parameters (Table 1), we further examined the main effect by using one-way ANOVA. For the maximum joint angles, knee extension was found significant difference in loadings which showed larger amount in 15% condition than 0% condition ($F=5.88$, $p < .05$). Ankle plantarflexion and dorsiflexion showed significant difference in bench heights which were significant greater in 10-inch height than 6-inch height (plantarflexion: $F=4.38$, $p < .05$; dorsiflexion: $F=3.54$, $p < .05$). Peak vertical ground reaction force (F_z) was also found greater in 10-inch height than 6-inch height ($F=12.59$, $p < .05$). Leg compression significant increased in 10-inch height compared with 8-inch and 6-inch heights ($F=8.82$, $p < .05$). On the contrary, leg stiffness decreased in 10-inch height compared with 8-inch and 6-inch heights ($F=6.67$, $p < .05$). For the joint stiffness, only ankle joint showed significant larger in 10-inch height than 6-inch height ($F=10.08$, $p < .05$).

Table 1: Summary of maximum joint angles, peak vertical ground reaction force, leg stiffness and joint stiffness data (Mean±SD) during step aerobics (n=10)

variables	6-inch			8-inch			10-inch		
	0%	10%	15%	0%	10%	15%	0%	10%	15%
Hip angle									
Extension (°)	169.97 (6.59)	171.34 (6.44)	171.66 (4.50)	169.73 (5.85)	171.17 (5.75)	171.60 (5.39)	167.66 (6.68)	169.61 (6.50)	171.91 (6.11)
Flexion (°)	148.42 (5.06)	147.21 (4.45)	152.53 (5.38)	149.23 (3.75)	150.78 (5.20)	149.17 (3.31)	146.67 (4.80)	147.95 (4.76)	147.56 (5.13)
Knee angle									
Extension (°) †e	170.51 (4.50)	170.51 (3.52)	172.90 (4.03)	173.33 (4.01)	174.28 (3.86)	174.00 (4.11)	172.61 (7.01)	174.27 (3.20)	178.96 (6.88)
Flexion (°)	136.43 (7.28)	139.51 (7.54)	138.71 (5.12)	135.14 (5.07)	138.18 (5.92)	138.01 (5.53)	133.64 (6.60)	135.56 (6.35)	137.19 (5.88)
Ankle angle									
Plantarflexion(°) ^{†b}	124.63 (4.38)	124.89 (4.36)	126.12 (4.20)	126.33 (4.34)	126.32 (5.85)	128.95 (4.27)	127.19 (5.67)	128.14 (6.19)	131.70 (3.67)
Dorsiflexion (°) ^{†b}	56.25 (5.57)	56.08 (4.66)	53.05 (2.46)	59.07 (5.39)	56.82 (6.33)	58.25 (4.52)	59.93 (5.4)	59.6 (3.70)	60.39 (4.98)
Peak Fz ^{†b} (B.W.)	1.51 (0.22)	1.48 (0.17)	1.45 (0.16)	1.62 (0.24)	1.54 (0.13)	1.55 (0.18)	1.64 (0.26)	1.84 (0.25)	1.89 (0.20)
Leg compression ^{†bc} (m)									
	0.06 (0.01)	0.05 (0.02)	0.05 (0.01)	0.06 (0.01)	0.06 (0.01)	0.06 (0.01)	0.07 (0.01)	0.08 (0.01)	0.08 (0.02)
Leg stiffness ^{†bc} (BW/m)									
	25.17 (0.38)	29.60 (1.01)	29.00 (0.76)	27.00 (0.32)	25.67 (0.19)	25.83 (0.21)	23.43 (0.31)	23.00 (0.16)	23.63 (0.36)
Joint stiffness									
Hip (Nm/kg/deg)	0.092 (0.021)	0.091 (0.016)	0.110 (0.013)	0.093 (0.012)	0.109 (0.023)	0.102 (0.031)	0.104 (0.022)	0.092 (0.031)	0.087 (0.038)
Knee (Nm/kg/deg)	0.062 (0.047)	0.069 (0.044)	0.058 (0.038)	0.057 (0.021)	0.059 (0.091)	0.062 (0.049)	0.060 (0.058)	0.060 (0.057)	0.055 (0.048)
Ankle ^{†b} (Nm/kg/deg)	0.056 (0.083)	0.054 (0.091)	0.047 (0.082)	0.044 (0.044)	0.047 (0.066)	0.043 (0.054)	0.043 (0.068)	0.042 (0.058)	0.040 (0.061)

*Significant interaction between height and loading: $p < .05$

†Significant simple main effect

‡Significant main effect in height

‡ Significant main effect in loading

^a Significant difference in height between 6-inch and 8-inch

^b Significant difference in height between 6-inch and 10-inch

^c Significant difference in height between 8-inch and 10-inch

^d Significant difference in loading between 0% and 10%

^e Significant difference in loading between 0% and 15%

^f Significant difference in loading between 10% and 15%

DISCUSSION:

According to the result, we found that bench height was the main effect on the landing strategy during step aerobics, except the knee extension which was mainly affected by weighted-vest loads. The increased knee extension might be due to the greater anticipatory control of the lower-limb muscles when participants sustained external loads. A greater co-contraction of the thigh muscles could allow participants to generate knee extension force, increase knee joint stability, and avoid knee buckling at impact phase (Gollhofer, Schmidtbleicher, & Dietz, 1984). However, there was no investigation of muscle activities in this study, the mechanism of knee extension might need to be examined by using

electromyography in the further study. Furthermore, no effect on lower extremity while wearing weighted-vest might be due to the extra load was supported by the trailing leg during touch-down, which resulted in the leading leg being loaded as in the normal situation. This result was similar to a previous experiment which adding 20% body mass loads on participant during stair descent and showed no difference to non-loaded condition (Spanjaard et al., 2008).

Ground reaction force was found greater in 10-inch than in 6-inch height condition which resulted in the increased ankle plantarflexion and dorsiflexion during the landing phase. These data highlighted the important role of the ankle as the bench height increased. Previous studies indicated that people would increase knee flexion and ankle dorsiflexion to absorb the higher impact force as the landing height increased (Yeow, Lee & Goh, 2009). There was no knee flexion increasing in the present study might be due to the higher cadence of step aerobics compared to the landing task. The contact time of the ground might be too short for knee to accomplish the whole flexion movement to absorb the external force.

Increased leg stiffness was associated with reduced lower extremity excursions and increased peak forces. With this combination of factors, it denoted to have increased loading rates and shock to the lower extremity (Hennig & Lafortune, 1991). In this study, the ground reaction force increased but the leg stiffness decreased which showed participants has changed their landing strategy into larger leg compression by increasing ankle flexion. However, it has been demonstrated that too little stiffness might allow for excessive joint motion leading to soft tissue injury (Granata et al., 2001). Thus, we should prevent ankle joint from overusing as the bench height increased to 10 inches. For the joint stiffness, ankle joint was found smaller in 10-inch height condition than the 6-inch condition. Farley and Morgenroth (1999) have reported that the primary mechanism for leg stiffness adjustment was the adjustment of ankle stiffness during hopping which was similar with the result of this study. Increased joint stiffness was associated with improved functional joint stability, as stiffer structures tended to resist sudden joint displacements more quickly and effectively. Therefore, decreased ankle joint stiffness in this study might be considered as an unstable movement due to the increased bench height. Participants required more muscle activities or ankle dorsiflexion to maintain their stability.

CONCLUSION:

Ground reaction force, ankle movement, leg stiffness and ankle joint stiffness changed as the bench height increased to 10 inches which were considered to a high loading rates and shock to the lower extremity, especially at ankle joint. Therefore, people should avoid doing step aerobics at 10-inch bench height for a long time to protect ankle joint and soft tissue from injury.

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