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Causes of motor system overload in step aerobics: Literature review

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Summary

Many publications have indicated the positive impact of step aerobics on health. Although step aerobics aims to improve endurance and other health parameters, injuries incurred from overload happen to both instructors and participants. Values of vertical ground reaction force (vGRF) while stepping on and off the bench do not lead to overload on the motor system – they are similar to the values obtained for walking or stair climbing. One reason for injuries may be the step workout technique. Overloads may be caused by incorrect technique of foot positioning on the bench, small knee angle during stepping off, and small angle of trunk flexion. This study presents an overview of current research on the load of the motor system in step aerobics.

Key words: Load – GRF – Technique – Injury

Introduction

In recent years, the problem of motor system overload in different sports activities has been tackled by many studies resulting from the increasing number of people engaging in sports activity which requires physical fitness at a professional level. Overload is a condition which occurs in the process of shifting loads wherein the physical strength of tissues, adaptability, functional capacity of muscles, ligaments, joints and bones is exceeded [35]. Overload and damage to the motor system can be observed when it is subject to large external forces acting in a short time or small external forces over a long period of time. Both may result in injuries. Although step aerobics aims to improve endurance and other health parameters, injuries incurred from overload happen to both instructors and participants. Studies have shown motor organ injuries in 77% of instructors, of whom 52.9% suffer from injuries of the lower extremities, such as ankle joint damage (33%) and knee joint damage (approximately 20%) [7]. Malliou [23] reported that injuries involving the lower extremities are most frequently observed in 33.7% of subjects, 27.5% of which are knee joint injuries and 22.9% lower back pain. Moreover, instructors suffer from Achilles tendonitis, exertional compartment syndrome and ankle sprain. In the 3-year study of aerobics instructors, the researchers observed that approximately 51.7% of the subjects suffered from injuries, of which 69.2% were for the second time and 11% the third the time.

However, many publications have indicated the positive impact of step aerobics on health. Step aerobics has a beneficial influence on the circulatory and respiratory systems [17, 19, 49]. It is considered to improve muscle strength in the lower extremities [18, 22] and increase the resistance of tendons and ligaments to over-extension [51]. Step workout improves postural stability [5, 44]. Cai et al. [4] confirmed that a 10-week, moderate-to-high intensity training program can improve sleep quality and increase melatonin level in sleep-impaired, postmenstrual women. Another significant benefit of step exercise is improvement in bone density, which decreases the risk of osteoporosis [46, 39, 22]. Bone remodeling is observed due to the cyclical loading of bones along the vertical body axis while stepping on and off the bench. The increased amplitude of changes in bone stress likewise increases the flow of fluid in vessels, which stimulates the transport of peptide growth factors between blood and osteocytes, causing an increase in bone mass. This phenomenon is observed in athletes [3] and people participating in recreational sports [10]. Step aerobics is characterized by the number of steps performed during a workout, which ranges from 3500 to approximately 6000 when done 4 to 5 times a week. It has been determined that instructors often conduct up to 20 hours of step aerobics classes a week [21]. The said researchers confirmed that one of the main reasons for their injuries is the number of classes a day. The highest incidence of injuries was reported among male instructors who have 5 or more hours of classes a day. Statistically more injuries were observed in female instructors

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conducting 7 hours of classes a day in comparison to those working up to 6 hours. The same study showed more injuries in step aerobics instructors (32%) in comparison to other fitness instructors (dance 3.2%, body pump 3.8%, and kick boxing 3.8%).

Causes of motor system overload in step aerobics

Body loading may have a positive as well as negative influence on our bodies and result in injuries [29]. Both step aerobics and extreme sports are subject to motor system loading induced by internal and external factors [6, 35]. Internal factors include abnormalities in anatomical structure, friction forces in the motor system, and excessive stretching of tendon anatomy, while external factors include wrong footwear and a bad exercise surface [42]. Other reasons for injuries include excessive volume and intensity of workload, which cause 60% to 80% of injuries in sport. Bruggemann [3], in his study of athletes, showed that extreme loading caused pathological changes in the spine. Such changes can also result from incorrect movement technique – hence the need to find movement techniques which reduce the risk of injury to a minimum but are still effective for winning competitions.

Biomechanical research may facilitate the development of step aerobics technique. Correct technique would only have a positive impact on the motor system by decreasing the risk of overload and the resulting injuries. If movement is technically correct, loading is absorbed by the muscles. In activities such as walking, running, landing from a drop-jump and standard jumps, loading should be absorbed smoothly through the ankle, knee and hip joints to the spine. Thus, research methods measuring kinematic and kinetic movement parameters would be beneficial in the search for elements of technique which have an impact on the distribution of loading. Such research, supplemented by an assessment of muscle electrical activity, may show the advantages of the motor system correctly absorbing loading. Sports research leads to numerous conclusions which may be applied to minimize motor system loading during physical activity [13]. The research shows higher loading in a drop-jump that lands on flat feet compared to a mid-foot landing [8, 9], while the prevention of knee joint injuries is emphasized by the importance of knee flexion angle [50]. A study of landing in handball and volleyball jumps shows that ground reaction forces for individual joints increase along with a decrease in knee flexion angle [47]. Hip and spinal joint angle are also significant in load prevention. Both the small and large angle of trunk flexion in the sagittal plane, represented by a trunk leaning forward from the vertical axis, may result in back pain. Muscle activity in the spine is highest if trunk flexion equals 60°, meaning spinal joints are subject to lower external forces [52].

Characteristics of motor system loading in step aerobics

An analysis of studies on motor system loading in step aerobics has shown that many researchers examine correlations between ground reaction forces (GRF) and parameters such as types of steps [21, 22, 31, 39, 40], phases of the step movement cycle [24, 34, 40, 45], movement range in joints of the lower extremities [36] or experience level of the people exercising, in particular their mastery of bench stepping [41]. Many publications [1, 11, 38] have described correlations between GRF and the frequency of stepping on and off the bench in time with music. Different studies focus on evaluating motor system loading, conditions and equipment. They concern different types of benches, particularly the height, type of plastic, and type of surface it is placed on. A detailed analysis of the above is presented in the following subchapters. Comparison of the results obtained by different authors, regardless of the body weight of the research subjects, is possible owing to the fact that all values of components of GRF are presented as relative values (BW) [1, 11, 23].

Common methods used in sports biomechanics to evaluate movement have been applied in the assessment of the magnitude of the motor system loading and the risk

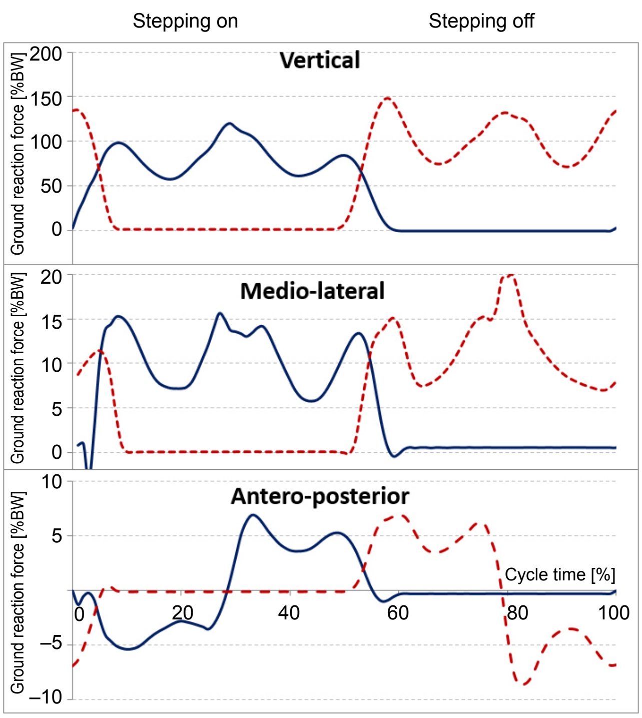

Fig. 1. Ground reaction force (vertical, medio-lateral and antero-posterior) during stepping on (blue line) and stepping off (red line). Author's own research

of injury in step aerobics. Based on this, the following parameters have been computed: GRF components [16, 25], moment force values at the joints of the lower extremities [1, 2, 14], and electrical activity in the muscles of the lower extremities [38, 48]. This also serves to search for correlations between the kinematic parameters of movement [36]. Many of these methods have also been used to assess the risk of injuries in professional sports [12, 15, 33].

Step patterns

Step aerobics is characterized by a set of choreographed steps. The complexity of the steps performed in different directions depends on the level of the group and the instructor's creativity. The differing steps were given their own names in order to facilitate teaching, which also makes it easier for researchers to describe them [2, 20]. Moreover, such steps can be performed at low or high impact, which is significant in the evaluation of their influence on motor system loading. Low-impact steps keep one foot on the floor at all times (like walking), while high-impact steps cause both feet to leave the floor (like running). Research confirms statistically significant differences between low- and high-impact stepping based on loading evaluated in vertical ground reaction forces (vGRF) [21]. Components of GRF for low-impact steps are from 1.12 to 1.25 BW, while those for high-impact steps range from 1.50 to 1.54 BW. Ricard & Veatch [31], in their study of aerobic dance, obtained similarly diverse results for low- and high-impact (1.3-2.62 BW) vGRF.

Błażkiewicz et al. [2] presented a different approach to the assessment of motor system loading in step aerobics. The authors analyzed values of muscle torque and the length of the 54 muscles engaged in the "knee up" movement. Their study indicated that the knee joint is the most prone to injuries. Furthermore, their analysis shows that in the "knee up" step the greatest work is performed by the mm. sartorius and mm. tensor fascia lata

Phases of stepping on and off the bench

There are two phases distinguished in step aerobics; the first phase is performed stepping up and forward while the second is stepping down and backwards. Many researchers have observed higher values when stepping off the bench in comparison to those obtained while stepping on it. Machado et al. [21] reported that the ground reaction forces generated in low-impact steps are from 1.12 to 1.25 (BW) while those from high-impact steps range from 1.50 to 1.54 BW. The values of ground reaction forces were shown to be much higher when stepping off the bench, reaching 2.7 BW. Santos-Rocha et al. [40] did not find any statistically significant differences between these two phases. The vGRF values obtained by their research varies from 1.3 to 2 BW for stepping on and from 1.5 to 1.8 BW for stepping off. Ground reaction forces generated while stepping off are similar to those observed in high-impact aerobics [21, 38].

Bench height

A step bench can be adjusted to three different heights. The minimum height is used in workouts performed by people displaying limited motor skills and a low level of physical fitness. It can be presumed that relative values of ground reaction forces can be dramatically changed by bench height, likewise influencing the amount of loading on the motor system. This mainly applies to vGRF while stepping off. This problem has been described by Maybury and Waterfield [24]. They found significant differences for vGRF between the 15 cm and 20 cm bench heights, but not between the 20 and 25 cm heights. Bezner et al. [1] evaluated values of the ground reaction force while stepping off the minimum (1.6 BW) and maximum (1.76 BW) bench height. Fujarczuk et al. [11] analyzed basic steps at bench heights of 15, 20 and 25 cm. No statistically significant differences were observed in the vGRF values; those recorded for minimum height were 0.97 BW and 0.87 BW at maximum height.

Step cadence

Step aerobics is a form of physical activity in which music forms an inseparable part. Music and its tempo (BPM) are selected based on the fitness level of the participants, and thus tempo constitutes a significant factor in the intensity of a workout. Music sets the rhythm for a step workout and has a direct influence on the frequency of the steps performed. It also makes step aerobics classes more interesting and engages the participants. An increase in tempo increases step cadence. Given that an increase in running speed increases ground reaction forces two-fold, it has been hypothesized that a higher stepping frequency would increase ground reaction forces [31]. Research has confirmed that the values of ground reaction forces while stepping on and off the bench are not significantly altered by cadence [1, 11], while the gradient of vGRF does increase with an increase in step frequency [11]. Despite the fact that increased step frequency does not change vGRF values, an analysis of EMG in the lower extremities during workout performed with music of differing BPM shows an increase in muscle activity [38]. Experienced trainers and instructors report that the rhythm of movement and frequency determined by music and its tempo have a positive influence on motor coordination, which is another positive result of step aerobics.

Different types of steps, surfaces and footwear

The landing surface and type of material used to make a bench are two important factors having an influence on loading of the motor system for people performing step aerobics. Skelly et al. [42] compared the properties of three benches made by different manufacturers from different materials. They presented evidence that benches manufactured by different companies have individual suppressing properties which impact loading on the motor system. Recent studies show a correlation between the type of floor and injury rate among instructors. The results indicate that type of floor contributes to the highest number of injuries among instructors. Classes conducted on such a surface lead to statistically more injuries than those performed on a wooden floor [23].

Footwear is another factor, as it cushions loading when the foot strikes a surface. Cushioning elements arranged in the front (mid-foot) and back (heel) of the sole absorb ground reaction forces. Malliou et al. [23] observed that 75.2% of instructors did not experience any injuries performing step exercises while wearing suitable step aerobic footwear. Studies on injuries in extreme sports and their causes show that worn out footwear, especially the front cushion, may lead to plantar fasciitis or Achilles tendonitis. However, a lack of a back cushion does not contribute to the risk of injuries [28].

Participant level of experience

Research has shown that loading on the motor system is also influenced by the level of experience in step aerobic participants. Motor system injuries may result from the incorrect absorption of ground reaction forces by participants who have recently started aerobics. As supported by research, ground reaction forces generated by novices are much higher in comparison to instructors [41].

Techniques of movement

Placing the foot

The anatomy of the ankle joint exposes it to injury during step aerobics. The technique of placing a foot on the bench can be described by the anteroposterior (a-pGRF) and mediolateral (m-lGRF) ground reaction force, along with range of movement in the sagittal and transverse planes. The technique of placing the foot on the bench has been confirmed to be different than climbing up stairs [36]. Walking up stairs begins with the forefoot striking the ground, followed by heel contact. In step aerobics, it is the heel which strikes the surface first, meaning the a-pGRF is twice as high as climbing up stairs [32].

Analysis of m-lGRF shows that loading while stepping on the bench is put on the midfoot, then transferred towards the lateral part of the foot [36]. Values of m-lGRF range from 0.04 BW to 0.06 BW, while values when climbing up stairs and walking on a flat surface do not usually exceed 0.045 BW [32].

The vGRF is absorbed by ankle joint muscles when the midfoot makes contact with the ground first [8]. Hence, the lower the angle of plantar flexion in ground contact, the smaller is the muscles' ability to absorb the GRF. This is especially significant in stepping off. When vGRF reaches its maximum values in stepping off, both instructors and nonprofessionals place their foot in dorsiflexion (19.7–18.5º), not in plantar flexion [32]. This fact may contribute to the causes of ankle joint injuries.

Analysis of abduction and adduction angles while stepping on and off the bench may be another indicator of

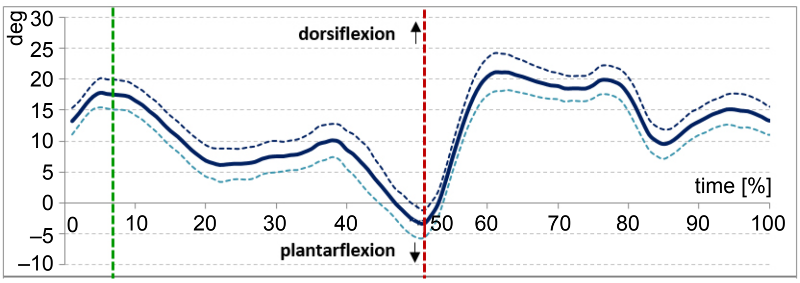

Fig. 2. Angle of foot flexing. Green line – maximal value of vertical GRF during stepping on, red line – vertical GRF during stepping off. Author's own research

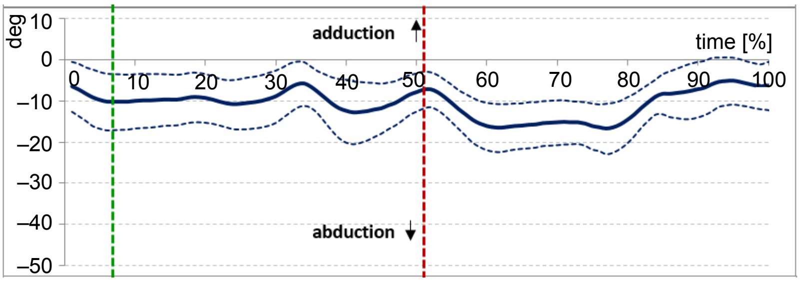

Fig. 3. Angle of foot adduction and abduction. Green line – maximal value of vertical GRF during stepping on, red line – vertical GRF during stepping off. Author's own research

reasons for said injuries. Greater loading on the midfoot joints and medial head of the gastrocnemius muscle may result from placing the foot with greater adduction [27]. The adduction angle while stepping on the bench may value from 10.4 to 1.9 degrees, depending on the level of the participants [32]. The functional maximum range of foot adduction is established at 20 degrees [30]. This fact may also indicate causes of frequent ankle joint injuries. Gait analysis of walking up stairs has shown that when the foot first touches the ground, it is abducted by approximately 17 degrees (maximum range of abduction 35º and adduction 20º) and returns to its neutral position corresponding to gait on a flat surface [26].

Knee-joint angle

Knee-joint mechanics show that the joint angle of knee flexion and extension is related to the muscle moment arm of the knee joint flexor and extensors [50]. This is why knee joint muscles performing a certain range of motion develop a higher or lower moment of muscle force. This means that when the angle of knee joint flexion is either large or small, the muscle moment arm is very short and the moment of force of knee flexors and extensors is also smal l. Stepping down with straight knees decreases muscles' ability to absorb ground reaction forces. This function is then performed by the ankle and hip joint muscles. The findings indicate that small knee joint angles while stepping off may be a reason for knee joint injuries [36].

Angle of trunk flexion

The last body segment participating in suppressing vGRF is the spine. Research shows that the peak moment of force for the spine extensor is reached when the angle of trunk flexion in the sagittal plane equals 60º [52]. This indicates that the smaller is the angle of trunk flexion in the sagittal plane, the greater are the forces acting on the surface of the spinal joints and the greater the load on the paraspinal muscles. The angle of trunk flexion equals approximately 5º for stepping on and 10º for stepping off the bench [36]. Back pain in step aerobics may result from a trunk position that is practically straight. The angle of trunk flexion depends on specific traits of aerobics classes. When conducting the class, instructors watch the participants in the mirror and maintain verbal and eye contact with them, and the participants follow their movements.

Conclusion

The movement structure of a basic step in step aerobics resembles that of the natural gait of climbing up stairs [43]. Many studies broadly describe human gait using kinetic, kinematic and electromyographic parameters. The evidence shows that values of vGRF while stepping on the bench do not lead to overload on the motor system. Correspondingly, vGRF values obtained for stepping off the bench do not result in overload since they are similar to the values obtained for walking. However, comparison of maximum joint forces

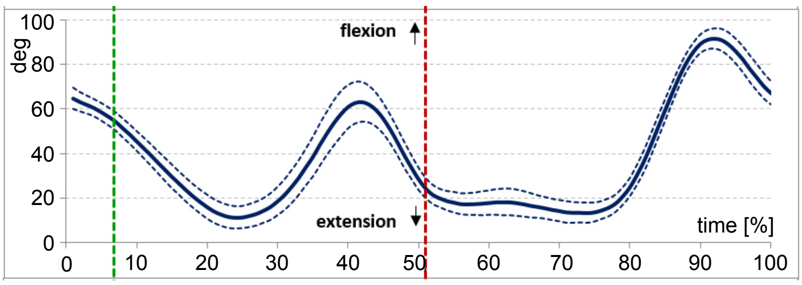

Fig. 4. Angle of knee flexion. Green line – maximal value of vertical GRF during stepping on, red line – vertical GRF during stepping off. Author's own research

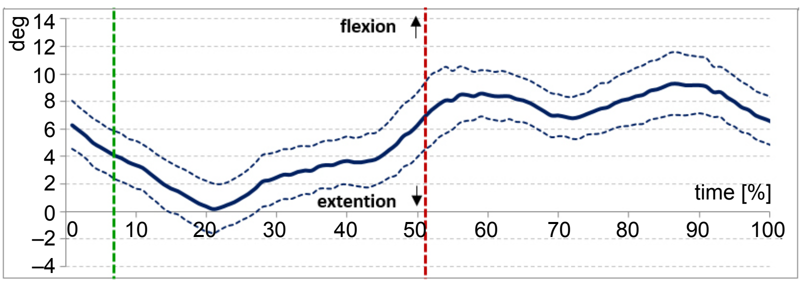

Fig. 5. Angle of trunk flexion-extension. Green line – maximal value of vertical GRF during stepping on, red line – vertical GRF during stepping off. Author's own research

and joint movements shows 2-10 times higher loading in step aerobics than in stair climbing [14]. Overload of the motor system with instructors, similar to professional athletes, should be seen in the number of hours spent exercising. Regarding participants, overloads are caused by incorrect technique of foot positioning on the bench and the unadjusted intensity of step workouts to suit strength and endurance abilities of their motor systems. This problem mainly concerns elderly people and fast step aerobics classes.

Conflict of interest: Authors state no conflict of interest.

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