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MINI-REVIEW: NEURO FORUM

Control of Movement

Ballet and how it can improve neuromuscular function with age

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Abstract

Ballet shows numerous physiological benefits for dancers, with adaptations in posture, power, strength, stamina, and balance. A recent study from Simpkins and Yang (*J Neurophysiol* 132: 1115–1125, 2024) showed that 45% of ballet-trained dancers experienced a fall during a standing-slip perturbation, compared with 82.6% of nondancers, along with shorter step latencies, durations, and speeds, which were accompanied by shorter electromyographic latencies in several leg muscles. This study demonstrates the viability of ballet training in aiding fall prevention in elderly individuals.

There are various forms of art and expression that have evolved in society, dance, painting, and writing, to name a few. The art of dance is most truly appreciated in the form of ballet, where examples such as Swan Lake use intricate formations and ethereal movements that require great strength and stamina. This alone requires years of training and practice from the involved dancers, in addition to the emotion and story they must express while dancing. These movements require extreme coordination and balance, as one misstep or one change in their operational (balance) leg could not only reflect poorly on the quality of the entire performance but could also cause a fall and potential risk of injury. For these dancers to develop the skills to perform at a high level, they must also undergo significant physical changes to support the repetition and training.

Ballet is considered one of the most demanding forms of dance as the reported necessary attributes of ballet include flexibility, strength, coordination, stability, proportionality, aesthetics, fitness, and miscellaneous (e.g., eyesight). Different combinations of the listed attributes contribute to the greater range of motion seen in the hip, spine, foot, and ankle of ballet dancers (1). Through lifelong training in ballet dancing, enhanced posture and muscular coordination arise through improved neuromuscular control (2). Compared with a control group of nondancers, the dancers showed increased ankle and hip coordination, likely due to enhanced balance from proprioceptive sensitivity and increased neuromuscular responses. Ballet dancers have been proven to have an increased proprioceptive sensitivity increasing their awareness of their movements and allowing for better control at times. In regards to the difference in the amount of control, it is unclear as to what aspect of neuromuscular improvements helps coordinate this in ballet dancers, the speed of the response could be a contributing factor but data show mixed results. Even with little knowledge of what causes it, there is still improved neuromuscular control at least due to increases in proprioceptive sensitivity. Improved neuromuscular control thus offers substantial benefits throughout one's lifetime, when the prevention of injury/physiological stress is also accounted for regardless of what specific adaptations cause this increase in control.

Fall prevention is an urgent public health issue as in 2021 alone falls among adults over 65 yr were the primary cause of more than 38,000 deaths (3). There are many deleterious effects due to the aging process that can impact fall risk, including sarcopenia, frailty, polypharmacy, multimorbidity, vitamin D status, and hazards in the home environment. While some of these factors, such as dietary vitamin deficiency, can be easily addressed, others present a higher risk and require more substantial interventions. For instance, conditions such as frailty and sarcopenia can only be improved through comprehensive physical training and medical care. As people age, there is a dramatic decrease in overall core strength and joint stability, both of which are crucial for maintaining balance and preventing falls. Not only does a loss in core and upper body strength play a role, but also strength deficits in lower limb extremities could help reduce fall risks. In elderly populations, one of the more crucial detriments to balance can occur via hallux valgus; which is a deformity of the foot that causes the big toe to bend inward to the other toes. This is commonly known as bunions, but in elderly populations, it is more common and

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causes more issues with balance and functionality of the foot and lower limb. In a review by Glasoe (4), data showed that strength training of the lower extremities, while not a cure for this deformity, not only decreased pain in the affected area but also showed a decrease in the gait impairments of the limb. This study is just one example of how an increase in strength can be foundational in helping reduce fall risks in elderly populations.

With falls being highly prevalent within the older populations, a significant amount of research has been focused on methods of improving neuromuscular coordination and control in these populations. When thinking of all the physical aspects that ballet dancers have to achieve, in particular balance, it is conceivable that ballet could be used to aid in preventing falls and fall risk measures in the high fall-risk elderly population. A recent study by Simpkins and Yang (5) examined how older recreational ballet dancers respond to a well-controlled, standardized, and large-scale slip perturbation during treadmill standing compared with age- and sex-matched nondancers. Hypothesizing that, ballet dancers would experience fewer falls with better stability, a more effective recovery step, and shorter leg muscle electromyographic latencies following the unexpected standing slip compared with their nondancer counterparts, which could lead to new information in recreational training interventions for high fall-risk populations.

Simpkins and Yang (5) tested a total of 20 dancers and 23 nondancers, of which both groups were primarily females. The individuals in the dancer group practiced ballet for an average of 81 min a day, 2.25 times a week. Those individuals had a wide range of experience, from 6 mo to over 12 yr. The nondancer group did not have any prior dance training, though it is important to note that they were active in many other sports and forms of physical activity. The experimental testing was very novel, as it was designed to induce slipping in a completely controlled and safe environment. Then, with a load cell inline between the harness the subject was wearing and the ceiling, the investigators could determine if the subject reacted sufficiently to recover from the slip. When the load cell force was greater than 30% of the subject's body weight, it was considered a "fall," whereas if the load cell force was less than 30%, they considered that a successful recovery. Another thing that makes this study novel, is that the researchers used large perturbations (maximum belt distance 0.36 m, peak belt speed 1.2 m/s), which would be sufficient to cause falls in most individuals, not just the elderly. Each subject was exposed to a single slip trial while standing on the treadmill. It is important to note that the authors acknowledge this as a potential limitation to the study. However, the protocol was designed so that the perturbation would be unexpected and the subjects would not know how to react, therefore the element of surprise can only be used once. Electromyographic activity of four leg muscles was recorded (rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius) and three-dimensional motion analysis was used to capture kinematics, during the slip trials participants were barefoot to avoid any issues with differences in footwear. The measurements were taken at three characteristic events or time instants – slip onset, recovery foot liftoff, and recovery foot touchdown. In each of these phases, the slip/fall-like sensations, center of mass position, velocity, step length, latency, duration, speed, and distance of the slip were recorded. An additional measurement of dynamic gait stability was used, where the change in the center of mass motion state (position and velocity) is considered relative to the base of support to determine stability in the recovery step.

The main finding of the study by Simpkins and Yang (5) was that of the 20 dancers, only nine of them experienced a fall (45%) during the standing-slip experiment. In contrast, 19 of the 23 nondancers (82.6%) experienced a fall during the same experiment. After taking their recovery steps, it was found that the dynamic gait stability at lift-off and foot touchdown was higher among the trained dancers signifying a more stable state of backward balance loss or slipping. The center of mass was more anterior to the base of support in that of dancers compared to non-dancers during the onset of slip. Dancers were also found to have a significantly shorter step latency, a smaller step duration, and a faster step speed. The final outcome measure found that dancers had significantly shorter electromyographic latencies for their standing-side rectus femoris, stepping-side biceps femoris, standing tibialis anterior, and stepping medial gastrocnemius. Taken together, these results demonstrate that trained dancers are less likely to fall in response to a severe perturbation, or what would be considered a slip-out in a natural environment. Furthermore, if a slip does occur, the trained dancers exhibit much quicker muscle activation, ultimately leading to more efficient recovery and regaining of balance.

Ballet training has significant practical applications, as it enhances key neuromuscular and biomechanical responses to unexpected slips and potential falls. The results of the present study show that ballet's emphasis on full-body coordination, lower limb strength, postural control, and balance resulted in better stability, quicker recovery steps, and faster muscle activation in response to a slip, all of which are critical in fall prevention [Simpkins and Yang (5)]. These results were even more robust since the duration of ballet training varied between 6 mo and 12 yr for the dancer group. It would have been interesting if the researchers had correlated the duration and frequency of ballet training with the fall risk, though we acknowledge this would have required significantly more subjects in the dancer group. Similarly, if all of the dancer group had 10+ years of ballet experience, would that have eliminated all falls observed in the experiment? These are pertinent questions that arise from the experiment by Simpkins and Yang (5) and could lead to additional research in the future.

There are alternative forms of exercise for the elderly, such as Tai Chi and yoga, that can improve balance, stability, and muscle control. Subjects in the nondancer group participated in activities like these, and others such as pilates, golf, and strength training. However, ballet training has the added benefit of incorporating complex and multidirectional movements and postural adjustments, which are particularly beneficial for improving dynamic stability. Dynamic stability is less emphasized in other exercise forms, since most of the movements are fairly stationary (6). In addition, these other exercise interventions lack the need for faster muscle activation. This was a key finding in the study by Simpkins and Yang (5), where dancers were able to activate the leg muscles milliseconds quicker than nondancers. Though only a few milliseconds of muscle onset latency seems too short to have a beneficial effect, when you combine the activation latencies of all leg muscles and potentially the postural muscles, this adds up to an overall much quicker stabilization of the body. Previous research has shown that reflexes in the lower limb are actually suppressed in professionally trained ballet dancers (7), so this suggests that the results observed in the present study are more likely due to the optimal amount of ballet training (80 min, 2–3 times/wk) contributing to faster muscle activations. While the research shows that ballet can enhance neuromuscular responses such as faster muscle activation, it also needs to be determined what the minimum and maximum amounts of ballet training are required to achieve these benefits (1).

The reviewed article leaves room for many questions to be asked about dance interventions in older adults and how these interventions can affect an individual's ability to avoid slips. Dance as an intervention with older adults is not the most typical form. There is usually more of a gym-based approach recommended or utilized in general populations, whether that is resistance training or a flexibility and cardio-based program. Part of the reason for dance being the non-typical form of exercise could be the limited access to dance studios and trained dance teachers. However, we must also acknowledge that ballet, itself, carries with it a different and potentially higher injury risk (including falling) if the right progression is not used or if enough oversight is not available. The study by Simpkins and Yang (5) demonstrates that one of the driving factors for reduced falls is quicker muscle activation. Consequently, it may be the general act of dancing, with fast movements in different planes, that is responsible for the observed benefits. A couple of studies from the same research group have already demonstrated the benefit of ballet practice in reducing fall risk to unexpected and repeated slips in younger adults (8, 9), which only further highlights the clinical potential of this type of dance. Future research could examine the neuromuscular adaptation differences between dancers, nondancers, and between types of dance. Another major factor when considering dance as an intervention is the social aspect in which, as one gets older it becomes more difficult to find individuals with similar interests. In addition, the mental rehearsal of movements could provide a cognitive benefit to elderly adults. Exploring the unique benefits of dance interventions in older adults, particularly its combined physical and social components, could provide valuable insights into effective strategies for improving balance, preventing falls, and enhancing overall well-being.

DATA AVAILABILITY

Data will be made available upon reasonable request.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

A.A., D.B., W.H., and B.B. drafted manuscript; A.A., L.R., D.B., W.H., and B.B. edited and revised manuscript; A.A., L.R., D.B., and W.H. approved final version of manuscript.

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