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Original Article

Rhythmic acoustic stimulation and balance in a group of young athletes: a pilot study

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Abstract
Auditory stimulation represents a useful strategy to improve stability without interfering with daily activities in pathological and physiological conditions. However the characteristics of the stimulation are still debated. The aim of this work was to study the effect of different frequencies of auditory stimulation on postural stability in healthy young athletes, in order to examine their effect on reactive control and to verify whether there is a frequency that can best optimise their effect on balance, both under both open and closed eye conditions. A force platform was used to analyse balance and a metronome was employed to administer the auditory frequencies of 30, 60 and 120 bpm, in the open and closed-eye conditions. The results showed that, in the open eyes condition, the 60 and 120 bpm frequencies caused reduced area of the ellipse, indicating a better stability, while the lower one (30 bpm) did not induce any changes. In the case of visual deprivation (i.e. with closed eyes), our results showed reduced area of the ellipse during auditory stimulation at 30 and 60 bpm, but not at 120 bpm, confirming the improvement in stability, even in the case of a condition which involves greater postural instability. In conclusion, this paper underlined the beneficial effect of auditory stimulation on reactive balance control. Among the chosen frequencies, 60 and 120 bpm seem to have a greater beneficial effect on balance in an open-eye condition, whereas in a closed-eye condition even the lowest frequency (30 bpm) is able to improve balance.
Keywords: rhythmic acoustic stimulation, stability, sport, postural control, healthy, sensory reweighting.

Introduction

The process of human evolution involved the transition from the quadrupedal to the bipedal position, causing both structural (i.e., the rotation of the pelvis, or the elongation of the femur) and functional modifications(i.e., the reduction in the area of the base of support and an increase in the centre of mass (CoM)(Takakusaki, 2017). These morpho-functional changes, if on the one hand represented a great evolutionary advantage, on the other hand created a condition of precarious biomechanical balance(Troisi Lopez et al., 2021). From a biomechanical point of view, there are two types of physiological responses for postural adjustments, that are the reactive control and the anticipatory control. The former is a type of compensatory postural control that involves an involuntary muscular response following the occurrence of unforeseen conditions that may compromise balance(Kim et al., 2021). The latter is an anticipatory postural adjustments, which are voluntary movements anticipating actual voluntary movement(Schinkel-Ivy et al., 2016). Schinkel-Ivy et al. analysed the oscillation frequency during standing and identified the frequency ranges of reactive control and anticipatory control from 0.40 to 3.20Hz and from 0.050 to 0.40Hz, respectively, whereas higher frequencies were considered representative of noise (> 3.20Hz)(Schinkel-Ivy et al., 2016).

The ability to maintain balance is managed by a complex system which is able to detect information from the external environment in order to obtain an efficient musculoskeletal response(Fransson et al., 2003). Among the numerous systems that cooperate to maintain balance, the sensory systems play a crucial role.The importance of different sensory systems in maintaining the upright position has been extensively addressed by a large number of studies(Ivanenko & Gurfinkel, 2018). It is widely demonstrated that a reduction in sensory afferents implies less stability, on the contrary an increase in sensory information (e.g. through auditory, vibrotactile or visual stimulation) improves the ability in maintaining balance(Coste et al., 2018; Kanegaonkar et al., 2012; Uimonen et al., 1996).

The auditory system contributes to balance providing information about the three-dimensionality of the surrounding space(Stevens et al., 2016). In particular, the effect of acoustic stimulations on static and dynamic balance has been largely investigated in health(Majewska et al., 2017; Minino et al., 2021; Sienko et al., 2018) and diseases(Fernández-del-Olmo & Cudeiro Mazaira, 2003; Shahraki et al., 2017). Ross et al. analysed the effect of acoustic stimulation on stability in healthy young and old people, with both open and closed eyes(Ross

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et al., 2016). They demonstrated that a white noise (a type of noise characterised by an absence of periodicity and constant amplitude, encompassing the entire frequency spectrum) induces reduction in postural sways variability in healthy older adults in both open and closed eyes conditions. More recently these results have been confirmed by Gandemer et al.(Gandemer et al., 2017). Easton et al. demonstrated that acoustic stimulation is able to improve balance even in congenitally blind people(Easton et al., 1998). Tanaka et al. showed that acoustic stimulation improves balance even when proprioceptive sensitivity is reduced(Tanaka et al., 2001) such as when a sponge under the feet is used. Furthermore, the use of instruments that make use of rhythmicity are significant during the developmental age, improving motor skills and learning(Liparoti & Minino, 2021; Minino et al., 2020). Moreover, the positive effects on both postural control and gait have been shown in several pathological conditions, such as Parkinson's disease(Marchese et al., 2000), multiple sclerosis(Shahraki et al., 2017), hereditary spastic paraplegia(Rucco et al., 2019), Alzheimer’s disease(Yang et al., 2021) and stroke(Cunha et al., 2012; Hayden et al., 2009; Kim et al., 2021), both during stimulus administration and after training or through a biofeedback system(Liparoti, 2021; Liparoti & Lopez, 2021).

Furthermore, the mechanism of the acoustic stimulus in determining the appropriate motor response in improving balance is still unclear. It is known that certain characteristics of auditory stimulations, such as rhythmicity, may affect the motor function(Southard & Miracle, 2013). One of the most important mechanisms underlying the ability of rhythm to affect movement are the brain synchronisation processes(Baselice et al., 2019; Elliott et al., 2010; Repp & Keller, 2005). In particular the neural rhythms that enable the coordination of activities between different brain areas, favour the integration of information that underpins movement(Lardone et al., 2022; Sorrentino et al., 2019),suggesting the idea that motor and sensory processes may result from the activity of a synchronised brain network(Buzsáki & Draguhn, 2004). Indeed, several studies have shown that, by exploiting the mechanism of neural oscillations, individuals improve their motor performances through sensory stimulations(Karageorghis, 2020). According to Damm L. et al., listening to a rhythmic stimulus increases the synchronisation between sensory and motor brain areas, resulting in improved rhythmic alternating motor activities, such as walking and running(Damm et al., 2020). In fact, according to the literature, people who practise sport have a greater ability to synchronise to an acoustic stimulus (metronome or musical composition) than an inactive group(Montuori et al., 2019; Romano & Troisi Lopez, 2022; Serra et al., 2021). Akhshabi et al. recently published a literature review article on the effect of music in sport. They have indeed shown that music, and thus acoustic stimulus, has a positive effect not only on the cognitive and mental aspect, reducing fatigue, and improving motivation, but also an improvement related to the physiological aspect and coordination of movement(Akhshabi & Rahimi, 2021).

However, although there is a general agreement on the positive effect of acoustic stimulations on balance and , its features, such as the stimulation frequencies, are still debated.

This study aims to investigate the effect of different frequencies of acoustic stimulation that fall within the frequency range of reactive control on postural stability in young athletes, in order to verify if there is a stimulation frequency capable of maximising the benefits on stability. Specifically, by means of a stereophotogrammetric 3D-motion analysis system and a force platform, we analysed the changes in position of the Centre of Pressure (COP) in conjunction with different frequencies of acoustic stimulation. In addition, given the predominant role of the visual system on stability and the ability to maintain balance, we wanted to observe the effect of these frequencies of acoustic stimulation also in the eyes-closed condition, to investigate whether these frequencies of acoustic stimulation were able to compensate for the lack of visual information.

Methods

Participants

Twenty-five young athletes (14 males and 11 females), aged between 21 and 28 (24,12 ± 2,08), were recruited. The exclusion criteria were: hearing or severe visual impairment, muscular, neurodegenerative and skeletal disorders. All participants were athletes, who practised different types of sports. Each of them also completed the International Physical Activity Questionnaire (IPAQ)(Mannocci et al., 2010; Masala et al., 2010), which assesses the level of physical activity. According to the questionnaire, active people are those who engage in physical activity with an energy expenditure of more than 3.5 METs. People with a lower energy expenditure were excluded.

This study was approved by the local ethics committee (University of Naples Federico II, n. 26/2020) and, prior to participation, all participants read and signed the informed consent, according to the declaration of Helsinki.

Protocol

This study was conducted in the Motion Analysis Laboratory of the University of Naples 'Parthenope'. A force platform (Kistler-9260AA, Winterthur, Switzerland) was used in conjunction with a stereophotogrammetric system(Sorrentino et al., 2016) (ProReflex Unit-Qualisys Inc., Gothenburg, Sweden) to perform a balance analysis(Liparoti et al., 2020; Rucco et al., 2020). Eight passive markers were positioned on the feet (four for each foot), in order to obtain their position on the force platform, and reconstruct the area of the base of support (BoS). Participants were acquired in the basal condition (without any stimulus), and during the acoustic stimulation at different frequencies (30, 60 and 120 bpm) frequencies that, according to Schinkel-Ivy et al., fall in the range of oscillation frequencies related to the reactive control(Schinkel-Ivy et al., 2016). Recordings were repeated with both open (OE) and closed eyes (CE). For each experimental condition (OE and CE at the three frequency), three trials of 20 seconds duration each were recorded(Tanaka et al., 2001; Vitkovic et al., 2016), for a total of 24 recordings for each participant.

Before the acquisition phase, participants were instructed to remain on the force platform, stationary, looking at a fixed point ahead of them (OE condition) or with their eyes closed (CE condition) until the end of the recording, indicated by the operator. After each recording, participants took a short break, allowing the operator to set the next frequency stimulation, and avoiding the fatigue effect. Furthermore, to avoid the learning effect, the order of the experimental conditions was randomised. The acoustic stimulation was set at 440Hz(Coste et al., 2018), emitted by a metronome (MA-1 Solo Metronome, Korg - UK) positioned behind the participants, with an easily audible volume(Almarwani et al., 2019). The operators were positioned to the sides, in order to record the acquisitions and to modify the frequencies of acoustic stimulation when necessary.

Balance Assessment

The analysis of static balance was carried out by assessing the following parameters: 1) distance from the ideal centre of pressure on medio-lateral axis (COP dist. X axis ideal); 2) distance from the ideal centre of pressure on the antero-posterior axis (COP dist. Y axis ideal); 3) area of the ellipse of the centre of pressure with 90% confidence (90%COP area); 4) length of the centre of pressure path (COP path length); 5) the mean speed of the displacement of the average centre of pressure (COP mean); 6) the maximum speed of the displacement of the average centre of pressure (COP max. speed); 7) the curve/area ratio of the COP (COP curve/area).

Statistical Analysis

The statistical analysis was carried out in Matlab (MathWorks, version R2018b). The analysis was performed by comparing the baseline open-eye (OE) condition with all experimental conditions (three acoustic frequencies) with open eyes, and the baseline closed-eye (CE) condition with the other experimental closed-eye conditions. The Shapiro-Wilk test was performed, in order to check the normal distribution of the variables. Given the heterogeneous distribution of the parameters, a non-parametric statistical test was carried out. The Friedman test was used as omnibus test, while a two-sided Wilcoxon signed rank test was used to perform pairwise comparisons. For each comparison, the test statistic (W) and effect size (ESr) were reported. The statistical significance was set at $p < 0.05$.

Results

Open Eyes (OE)

The parameters obtained in the OE basal condition were compared with those recorded at each frequency (30, 60 and 120 bpm) of acoustic stimulation.

These comparisons highlighted significant differences in the area of the ellipse, at 60 bpm ($W = 249$, $p = 0.0008$, $ESr = 0.77$) and 120 bpm frequencies ($W = 177$, $p = 0.017$, $ESr = 0.55$), showing a reduced ellipse area, with respect to the basal OE, but no differences were shown in the comparison between OE and 30 bpm condition (as indicated in Figure 1). The other parameters investigated, did not show statistically significant difference.

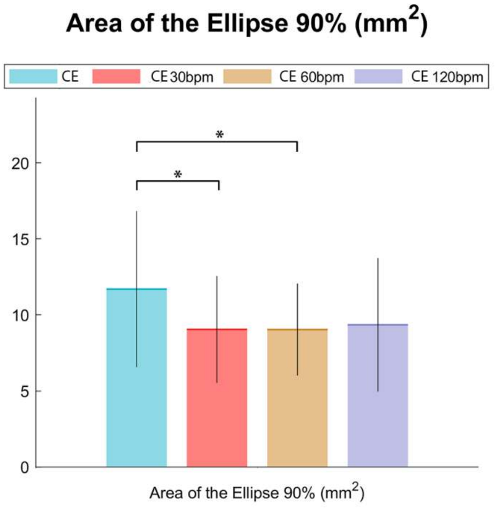

Figure 1: Histogram of the Area of the Ellipse 90% when comparing the baseline open eyes (OE) condition and the acoustic stimulation frequencies set at 30, 60 and 120 bpm. Significance p value: * $p < 0.05$, ** $p < 0.01$, ***

Closed Eyes (CE)

The comparison between the parameters recorded in the CE condition and the those obtained with different stimulation frequencies showed significant differences in the area of the ellipse, in the case of the 30 bpm (W = 159, p = 0.032, ESr = 0.49) and 60 bpm (W = 157, p = 0.034, ESr = 0.48) frequencies, again showing a reduced area of the ellipse, compared to the basal condition (as indicated in Figure 2). No difference was shown in the comparison between CE basal condition and the 120 bpm frequency.

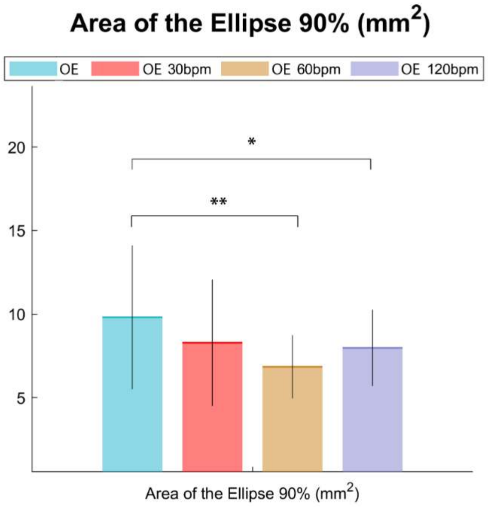

Figure 2: Histogram of the Area of the Ellipse 90% when comparing the baseline closed eyes (CE) condition and the acoustic stimulation frequencies set at 30, 60 and 120 bpm. Significance p value: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Discussion

The aim of this work was to investigate the best frequency (among those responsible for reactive control) of an acoustic stimulation to obtain an improvement in balance in athletes. Furthermore, we wanted to find out if the reduction of the sensory information (closed eyes condition) interfered with specific stimulation frequencies.

Our results showed that, in the OE condition, the 60 and 120 bpm frequencies caused a reduction in postural oscillations, while the lower one (30 bpm) did not induce changes. These results are partly in line with the literature, confirming an improvement in stability following acoustic stimuli. Many studies have evaluated the effectiveness of the acoustic stimulation in controlling balance(Majewska et al., 2017; Siedlecka et al., 2015). However, most of them used high frequencies stimuli that commonly are considered as noise (white or pink noise)(Maheu et al., 2017; Seiwerth et al., 2018). Since our aim was to evaluate the frequencies that are associated with reactive control, the acoustic stimulation at lower frequencies within the aforementioned range was utilised. Our results highlighted an improvement in stability even with lower stimulation frequencies (60 and 120 bpm) than those previously investigated. Intuitively, reducing the stimulation frequency (30 bpm), the positive effect on reactive postural control is cancelled out, probably due to the fact that the stimulation is not sufficient to induce a postural response. Indeed, several studies showed that reduced auditory information causes a worsening of balance. Vitkovic et al., investigating the effect of the sound environment on balance, found greater oscillations in the absence of sound in individuals with normal hearing(Vitkovic et al., 2016).

In the closed eyes condition, our data showed better stability during acoustic stimulation at 30 and 60 bpm, but not at 120 bpm. This result seems to indicate different mechanisms between the OE and CE conditions, showing that, whereas the former necessitates higher stimulation frequencies, the latter requires lower ones. As participants lack visual information, which is one of the fundamental sensory systems for maintaining balance (in addition to the vestibular and somatosensory ones), they are able to compensate when sensory stimulation is taking place. Indeed, Vitkovic et al., analysing sensory interference, demonstrated that an acoustic stimulus improves stability during sensory deprivation (i.e. eyes closed as regards the visual system and the use of a foam under the feet as regard the somatosensory system)(Vitkovic et al., 2016).

Even the stimulation frequency set at 120 bpm, although not statistically significant, showed a tendency toward the statistical significance (p=0.057). Speculatively, we can argue that it is possible that this stimulation frequency also causes an improvement in stability, but that in our case, it did not show up due to the high standard deviation. We cautiously suppose that the sample size could be the reason for the non-effect of this stimulation frequency.

In fact, we believe that one of the main limitations of this work is the small sample size. In addition to the sample size, our population consisted of 25 healthy and athletic young people, aged between 21 and 28, who have a stable balance. Furthermore, in order to carry out a clear analysis of the effect of acoustic stimulation on balance in an athlete population, it is necessary to compare them with a young population that does not practise sport.

Conclusions

This paper highlighted the positive effect of acoustic stimulations on balance and stability in athletes. In particular, stimuli set at 60 and 120 bpm were able to improve the stability, as suggested by the reduced area of the ellipse described by the CoP displacement. A similar effect was evident in the eyes-closed condition, particularly with the 30 and 60 bpm frequencies, and with a trend towards improvement even at 120 bpm. Our results underlined the importance of Rhythmic Acoustic Stimulation in improving postural stability, especially when the sensory information is reduced. Specifically our paper pointed out that, frequencies included in the range frequency of reactive control, promote an improvement of balance also in young athletes. Future analyses could be useful to evaluate the effect of these stimulation frequencies in our sample, comparing them to a group that do not practise any sport. It would also be interesting to compare other stimulation frequencies in order to identify the optimal frequencies that maximise sports performance. Furthermore, by increasing the sample, it would be interesting to assess the differences between different types of sports, which are able to differently influence the balance and synchronisation process.

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