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Hearing Status and Static Postural Control of Collegiate Athletes

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Context: Because of the close proximity of the cochlea, vestibular apparatus, and shared neurovascular structures, the static postural control of athletes who are deaf or hard of hearing (D/HoH) may be different from that of athletes who are hearing. Limited research is available to quantify differences between these athletes.

Objective: To determine the effect of hearing status and stance condition on the static postural control of athletes.

Design: Cross-sectional study.

Setting: Athletic training facilities.

Patients or Other Participants: Fifty-five collegiate varsity athletes who were D/HoH (age = 20.62 ± 1.80 years, height = 1.73 ± 0.08 m, mass = 80.34 ± 18.92 kg) and 100 university club athletes who were hearing (age = 20.11 ± 1.59 years, height = 1.76 ± 0.09 m, mass = 77.66 ± 14.37 kg).

Main Outcome Measure(s): Participants completed the Modified Clinical Test of Sensory Interaction and Balance on a triaxial force plate. Anteroposterior and mediolateral (ML) center-of-pressure (CoP) velocity, anteroposterior and ML CoP amplitude root mean square, and 95% ellipse sway area were calculated.

Results: Athletes who were D/HoH had a larger CoP velocity, larger ML root mean square, and larger sway area than those who were hearing (P values < .01). A significant main effect of stance condition was observed for all postural control variables (P values < .01).

Conclusions: During the Modified Clinical Test of Sensory Interaction and Balance, athletes who were D/HoH demonstrated a larger sway area compared with athletes who were hearing. Therefore, individualized baseline assessments of static postural control may be warranted for athletes who are D/HoH as opposed to comparisons with existing normative data.

Key Words: balance, Modified Clinical Test of Sensory Interaction and Balance, disability

Key Points

- Athletes who were deaf or hard of hearing demonstrated greater postural sway compared with athletes who were hearing.
- Individualized baseline assessments for static postural control may be warranted for athletes who are deaf or hard of hearing because they may differ as compared with norms in athletes who are hearing.

Balance assessments are fundamental tools used to quantify the postural control of athletes preinjury and postinjury. Static assessments have been used to characterize differences in double- and single-legged balance among athletes in various sports[1–3] who are hearing and identify deficits after injury, especially sport-related concussion.[4,5] Although modifiers such as sex, age, and psychological conditions have been established as significant factors that influence the postural control of athletes,[6] hearing status is not well documented as a possible modifier. Characteristics of the postural control of athletes who are deaf or hard of hearing (D/HoH) remain a gap in the literature that should be addressed to better inform injury management and return-to-play decisions for these athletes.[7]

The World Health Organization estimated that approximately 466 million people worldwide are D/HoH.[8] As of 2019 in the United States, 13% of adults had mild to moderate difficulty hearing and 1.6% had significant difficulty hearing or were deaf.[9] Currently, an estimated 692 000 school-aged[10] and 71 000 postsecondary students[11] are D/HoH. Of these students, many participate in athletics through their mainstream school, through residential schools for the deaf, or at the collegiate level through the National Collegiate Athletic Association.[12,13] At the highest level, athletes who are D/HoH can represent their countries in international events such as the Deaflympics.[14] Despite athletic involvement at all levels of competitions, athletes who are D/HoH are not well represented in the literature on postural control; further investigation is warranted to better understand their fundamental performance and guide postinjury management.

Postural control relies on information obtained via the somatosensory, visual, and vestibular systems to influence muscular coordination.[1] Disturbances to these systems have been proposed as possible mechanisms for postural control deficiencies.[1] Athletes who are D/HoH may inherently have vestibular dysfunction because of the proximity of the vestibular apparatus, cochlea, and shared neurovascular supply.[15] Because of the possible vestibular dysfunction, athletes who are D/HoH may use different strategies to maintain postural control compared with athletes who are hearing. Additionally, the cause of the hearing loss (ie, genetics, environmental factors, ototoxic drugs, infections) may negatively affect the vestibular system and, subsequently, postural control.[16] Although hearing loss and postural control are known to be related,[15,17–20] how much the degree of hearing loss influences postural control is not well established in adults. The effects of vestibular dysfunction on postural control are also not well understood, and different postural control characteristics may be present in athletes who are D/HoH compared with hearing populations. It is unclear how the postural control deficiencies of athletes who are D/HoH may influence their injury risk; however, previous authors[21] reported that athletes who are hearing and have postural control deficiencies may be at greater risk of injury.

It is important that health care providers be informed on whether the postural control characteristics of athletes who are D/HoH differ from those of athletes who are hearing in order to provide personalized injury management and improve clinical decision-making. Therefore, the purpose of our study was to determine if hearing status and balance condition influenced the static postural control of athletes. We hypothesized that (1) athletes who were D/HoH would demonstrate larger center-of-pressure (CoP) outcome means than athletes who were hearing and (2) CoP means would be larger to a greater extent as the degree of sensory feedback was altered or eliminated via stance conditions.

METHODS

Participants

Fifty-five National Collegiate Athletic Association Division III varsity athletes who were D/HoH (men = 36, women = 19, age = 20.62 ± 1.80 years, height = 1.73 ± 0.08 m, mass = 80.34 ± 18.92 kg) and 100 university club athletes who were hearing (men = 68, women = 32, age = 20.11 ± 1.59 years, height = 1.76 ± 0.09 m, mass = 77.66 ± 14.37 kg) participated in the study. Athletes who were D/HoH were recruited from the world's only university designed to be barrier free for students who are D/HoH. Athletes who were hearing were recruited from a single university.

Individuals aged 18 to 30 years who were participating in varsity or collegiate club athletics at the time of testing were included in this study. Exclusion criteria were as follows: (1) medically diagnosed with a concussion within 6 months of the study, (2) postconcussion syndrome at the time of the study, (3) a medically diagnosed mental health condition, (4) a musculoskeletal injury at the time of the study, (5) a history of lower extremity surgery, (6) pregnancy, or (7) any known balance disorder or neurologic condition that affects balance (excluding hearing-related disorders).

Consent and Communication Considerations. This study was approved by the Institutional Review Board at The Ohio State University.

Athletes who were D/HoH were given an opportunity to view the consent form via video format interpreted in American Sign Language (ASL). All participants were required to sign the paper consent form, regardless of how they viewed it (ie, video or paper consent). A study member who was fluent in ASL and English was present during the consent process and data-collection sessions to answer participants' questions or provide clarification.

Questionnaire. Before the postural control assessments, participants completed a self-reported questionnaire with items regarding their sex, primary sport participation, concussion history, and hearing status.

Static Postural Control Assessment. Height and weight without shoes were collected. All postural control assessments were performed in a quiet environment on a triaxial force plate (model FP4060; Bertec Corp) with all hearing-assistive devices removed. A study member who was fluent in ASL was present for testing to communicate with athletes who were D/HoH. We evaluated unshod participants' static postural control using the Modified Clinical Test of Sensory Interaction and Balance (mCTSIB). The mCTSIB systematically eliminates or alters sensory feedback and consists of 4 stance conditions: (1) standing on a firm surface with eyes open (EO), (2) standing on a firm surface with eyes closed (EC), (3) standing on a foam surface with EO, and (4) standing on a foam surface with EC (Table 1).[22] A medium-density foam pad measuring 19.7 × 16.1 × 2.4 in (50.0 × 40.9 × 6.1 cm; model AirEx Balance Pad Elite; Alcan AirEx AG) was used for conditions 3 and 4. Participants completed three 30-second trials for each condition. We instructed them to keep feet together[23] and arms crossed over their chest during all trials. If an individual was not able to perform a trial for the full 30 seconds without committing an error, that trial was repeated 1 time. If a trial error was committed during a second attempt, the condition was marked as *not completed*. Errors in a trial involved (1) taking a step to regain balance, (2) stepping off the force plate, (3) removing hands from the chest, or (4) opening the eyes during the EC conditions. Each person had at least 30 seconds of rest between trials. During the EC trials, a researcher tapped the participant's shoulder at 30 seconds to indicate completion.

Data Analysis

Kinetic data were collected at 1000 Hz. We calculated and processed the CoP for each data point using a fourth-order, zero–phase lag Butterworth filter with a low-pass filter at 20 Hz. Custom Matlab (MathWorks, Inc) code was used to compute all outcome variables.

Static postural control performance was quantified via anteroposterior (AP) and mediolateral (ML) CoP velocity, AP and ML CoP amplitude root mean square (RMS), and 95% ellipse sway area.[24,25] For each trial, we excluded the first and last 5 seconds to account for any filtering-associated errors.[26] Means from the 3 trials of a stance

Table 1. Modified Clinical Test of Sensory Interaction and Balance

Condition Number	Surface	Vision	Sensory System(s) Compromised	Sensory System(s) Assessed
1	Firm	Eyes open	None	Visual, somatosensory, and vestibular
2	Firm	Eyes closed	Visual	Somatosensory and vestibular
3	Foam	Eyes open	Somatosensory	Visual and vestibular
4	Foam	Eyes closed	Visual and somatosensory	Vestibular

condition were averaged for an overall mean, which was used in the analyses for each person.

Statistical Analysis

Preliminary analyses were conducted to determine if differences in postural control existed between (1) men and women, (2) concussion history groups (self-reported history of concussion versus no concussion history), and (3) deaf and HoH groups. We performed Shapiro-Wilk normality tests for all CoP outcome variables means separated by hearing group. No data fit the normal distribution ($P <$ .001) and, therefore, we applied nonparametric statistical analyses. Wilcoxon signed rank tests were calculated for each outcome variable with the α level set a priori at $P \leq$ .05. Analyses were conducted in RStudio (version 3.6.1) using the shapiro.test() function for normality and wilcox.test() function for mean comparison. Analyses revealed no differences between men and women for any variables ($P >$ .05) except AP RMS (P = .04). No differences were observed for concussion history groups for any variables ($P >$ .05) except ML RMS (P = .04). Thus, we did not include sex and concussion history as main factors in the primary analyses.

Thirty-nine athletes who were deaf (age = 20.31 ± 1.62 years, height = 1.75 ± 0.09 m, mass = 79.26 ± 15.30 kg) and 16 athletes who were HoH (age = 21.5 ± 2.0 years, height = 1.72 ± 0.07 m, mass = 85.47 ± 25.58 kg) were included in the D/HoH group in this study. Overall, no differences in postural control existed between athletes who were deaf and those who were HoH ($P >$ .05). The only difference observed was that athletes who were HoH had a larger sway area (12.06 ± 6.28 cm^2) than athletes who were deaf (10.25 ± 8.67 cm^2) for condition 3 (P = .05). Hence, we combined athletes who were deaf and those who were HoH into a single D/HoH hearing status group.

For primary analyses, mixed-model analyses of variance were conducted to test the effects of mCTSIB stance conditions (4 levels) and hearing status (hearing, D/HoH) on postural control variables. Effect sizes (ESs) were calculated and evaluated according to the Cohen classification of *weak* (<0.50), *moderate* (0.50–0.79), or *strong* (≥0.80).[27] We investigated post hoc paired comparisons of interest for significant interaction effects using Bonferroni-Holm corrections. The α level was set a priori at $P \leq$ .05. All analyses were conducted in RStudio using lm(), anova(), and emmeans() functions for models.

RESULTS

The CoP Velocity

Overall, athletes who were D/HoH had a larger CoP velocity compared with those who were hearing (AP: ES = 0.20, $P <$ .01; ML: ES = 0.22, $P <$ .01). Stance condition also influenced CoP velocity (AP: ES = 0.20–2.78, $P <$ .01; ML: ES = 0.56–2.78, $P <$ .01). All conditions were different from each other ($P <$ .05) except for conditions 2 and 3 for AP velocity (P = .17). Means and SDs of AP velocity and ML velocity for all interactions can be found in Table 2.

Root Mean Square

For the AP RMS, no differences were noted between athletes who were hearing (3.62 ± 1.99 cm) and athletes who were D/HoH (3.59 ± 2.32 cm; P = .85). However, athletes who were D/HoH had a larger ML RMS (0.80 ± 0.51 cm) than those who were hearing (0.33 ± 0.66 cm; ES = 0.33; $P <$ .01). All conditions were different from each other for AP RMS ($P <$ .05) except for condition 1 when compared with condition 2 (P = .56) as well as condition 3 when compared with condition 4 (P = .55). All stance conditions were different from each other for ML RMS (ES = 0.33–2.79, $P <$ .01). No significant interaction effect was observed for AP RMS (P = .69). Means and SDs of ML RMS for all interactions are shown in Table 2.

Sway Area

Similar to the velocity variables, hearing status had an effect on sway area ($P <$ .01): athletes who were D/HoH had a larger sway area (15.35 ± 23.64 cm^2) than those who were hearing (10.07 ± 11.64 cm^2; ES = 0.32). Stance condition affected sway area ($P <$ .01). All stance conditions were different from each other except for conditions 1 and 2 (P = .07) as well as conditions 1 and 4 (P = .08). The ESs for differences between stance conditions ranged from 0.21 to 1.53. Means and SDs of sway area for all interactions are provided in Table 2.

DISCUSSION

The purpose of our study was to determine if hearing status and balance condition influenced the static postural control of athletes. Understanding the postural control of this population is crucial in guiding rehabilitation programs, concussion management, and return-to-play decisions after injury. Our results suggested consistent group differences between athletes who were D/HoH and athletes who were hearing for conditions 1 and 2 but not for between conditions 3 and 4. Additionally, similar differences were present between conditions within each hearing group.

Previous authors[18] determined that individuals with congenital hearing loss relied more heavily on somatosensory information to maintain postural control compared with individuals who were hearing. In fact, researchers proposed that those who were D/HoH had increased somatosensory reorganization within the primary auditory cortex compared with visual information.[28] However, our findings indicated that athletes who were D/HoH demonstrated overall increased sway for conditions 1 and 2 but not for conditions 3 and 4 versus athletes who were hearing, which reflects reliance on somatosensory information compared

Table 2. **Postural Control Outcome Variables for Each Stance Condition and Hearing Status Group, Mean ± SD[a]**

Variable	Condition 1 Eyes Open, Firm Surface	Condition 2 Eyes Closed, Firm Surface	Condition 3 Eyes Open, Foam Surface	Condition 4 Eyes Closed, Foam Surface
Anterior-posterior velocity, cm/s				
D/HoH group	0.96 ± 0.33[d]	1.41 ± 0.60[b,d]	1.75 ± 0.61[b]	4.60 ± 2.29[b]
Hearing group	0.86 ± 0.21	1.37 ± 0.52[b]	1.34 ± 0.30[b,c]	3.86 ± 1.39[b,c]
Medial-lateral velocity, cm/s				
D/HoH group	1.07 ± 0.30[d]	1.47 ± 0.62[b,d]	2.08 ± 0.66[b,c]	4.61 ± 2.17[b,c]
Hearing group	0.94 ± 0.23	1.46 ± 0.51[b]	1.56 ± 0.34[b,c]	3.94 ± 1.14[b,c]
Medial-lateral root mean square, cm				
D/HoH group	0.46 ± 0.15[d]	0.59 ± 0.27[b,d]	0.74 ± 0.24[b,c]	1.41 ± 0.59[b,c]
Hearing group	0.38 ± 0.09	0.54 ± 0.17[b]	0.54 ± 0.11[b,c]	1.19 ± 0.27[b,c]
Sway area, cm^2				
D/HoH group	3.68 ± 2.62[d]	6.22 ± 7.25[b,d]	10.81 ± 7.99[b]	40.70 ± 35.28[b]
Hearing group	2.44 ± 1.17	5.22 ± 3.51[b]	5.69 ± 2.24[b]	26.95 ± 11.76[b]

Abbreviation: D/HoH, deaf or hard of hearing.

[a] Post hoc comparisons are not presented for anterior-posterior root mean square because of an insignificant interaction effect in the analysis-of-variance model.
[b] Different from condition 1 in same hearing group ($P < .05$).
[c] Different from condition 2 in same hearing group ($P < .05$).
[d] Different from hearing group in same condition ($P < .05$).

with athletes who were hearing. It is important to note, however, that the authors[18] who described an increase in somatosensory reliance did not investigate collegiate athletes but rather middle-aged individuals who were D/HoH. Because of their sport participation and younger age, these athletes may have reweighed sensory input effectively and efficiently during more difficult postural control conditions (eg, conditions 3 and 4 of the mCTSIB), enabling them to perform similarly to athletes who were hearing.

Though only mCTSIB conditions 1 and 2 were different between groups, it should be noted that the SDs for conditions 3 and 4 among athletes who were D/HoH were approximately twice those of athletes who were hearing. This substantially larger variation of athletes who were D/HoH in conditions 3 and 4 may result from the heterogeneity of hearing loss, a history of cochlear implantation, or cause of deafness. A more homogeneous sample of athletes who are D/HoH might decrease the postural control variability.

The lack of differences between hearing groups in condition 4 may signify vestibular compensation of the D/HoH group. It is well established that some individuals who are D/HoH have vestibular dysfunction[29,30]; yet performing tasks that involve vestibular input, such as postural control, may not demonstrate deficits in the same way as for individuals who are hearing. Tamaki et al[20] studied individuals who were deaf, examining both vestibular function and postural control via vestibular evoked myogenic potentials (VEMPs) and the mCTSIB, respectively. Despite vestibular dysfunction as noted in the VEMPs, many participants performed similarly in condition 4 as their hearing counterparts, which was also apparent in our study. Vestibular compensation may occur in individuals who are D/HoH through reweighting or unweighting input from other more dependable sensory systems.[31,32] Though we did not assess VEMPs, this may explain our current study's results.

The only static postural control outcome that was not different between athletes who were D/HoH and athletes who were hearing for any condition was AP RMS, which may indicate greater sensitivity to AP perturbations compared with ML perturbations when the feet are placed together.[33] Nonsignificant findings for AP RMS may suggest a lack of sensitivity of this variable in differentiating static postural control between athletes who are D/HoH and athletes who are hearing. Dynamic postural control measures may be more appropriate or sensitive in detecting changes in postural control between hearing groups.

Overall, similar differences between conditions within each group were observed. Previous researchers[1] determined that athletes who were hearing had faster sway speed during the EC and foam surface conditions than the EO and firm surface conditions, respectively. Our results were consistent for both athletes who were hearing and athletes who were D/HoH, implying that implementing the mCTSIB for athletes who are D/HoH would lead to comparable outcomes between conditions as those of athletes who are hearing. However, it is important to note that the differences in means between hearing groups for each stance condition were significant; thus, performance under each stance condition for athletes who are hearing may not represent that of athletes who are D/HoH.

Clinically, sports medicine professionals should recognize possible postural control differences between athletes who are D/HoH and athletes who are hearing to help guide rehabilitation and return-to-play decisions. For example, according to the National Collegiate Athletic Association's Concussion Safety Protocol Checklist,[34] all varsity athletes should undergo baseline concussion assessments, including postural control. Baseline postural control assessments may be especially beneficial for athletes who are D/HoH, providing valuable information for the interpretation of postconcussive evaluations and allowing for a more informed return-to-play decision. If athletes who are D/HoH demonstrate different baseline postural control, then comparing postconcussive symptoms with population norms may not be the best practice, as this could negatively influence the management, return-to-play decisions, and overall safety of the athlete.

This study supplied evidence of static postural control differences between athletes who were D/HoH and those who were hearing. Nonetheless, certain limitations should be considered. The level of collegiate competition between athletes who were D/HoH and athletes who were hearing differed, which could have influenced the results. Additionally, participants self-reported their hearing status; future investigators may find it useful to confirm hearing status, the severity of the hearing loss via an audiologist, and the cause and length of hearing loss. We did not control for a history of cochlear implant surgery; this may have influenced vestibular function, and therefore the postural control, of these athletes. Future researchers should examine dynamic postural control assessments of athletes who are D/HoH and the influence of a history of cochlear implantation surgery on postural control. Lastly, postinjury assessments and recovery trajectories should be considered.

CONCLUSIONS

We compared the static postural control of athletes who were D/HoH with that of athletes who were hearing. Overall, athletes who were D/HoH demonstrated greater postural sway in stance conditions on a firm surface during the mCTSIB than athletes who were hearing. These findings may be secondary to vestibular dysfunction in some athletes who were D/HoH, which could have led to increased reliance on somatosensory information, an increased somatosensory reliance independent of vestibular status, or both. These outcomes highlight that hearing loss may be a modifying factor in individualized baseline and postinjury assessments, which is crucial for health care providers to acknowledge when working with athletes who are D/HoH. The postural control of athletes who are D/HoH may differ compared with their hearing counterparts, and this might influence rehabilitation and return-to-play decisions.

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