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Experiments to identify the optimal sound to use in a new sound ball to improve recruitment, retention, health, and wellness for blind and visually impaired tennis players

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ABSTRACT

Within the sport of Blind and Visually Impaired (BVI) Tennis, the choice of sound is important in locating the ball. We conducted two experiments to choose a sound that will improve the localizability of the ball, in response to a request for new ball development from the International Blind Tennis Association (IBTA). We screened sounds (freesounds.com) for characteristics that the brain best exploits for sound source localization (Risoud et al, 2018). Sample sounds (23) were tested on an outdoor BVI court in a public park using five Bluetooth speakers, and then replicated in an indoor setting; the environments were otherwise naturalistic and unaltered. Blindfolded-sighted participants (n=29) pointed to where they believed sounds originated, by moving an arrow attached to a large protractor. Degree angles were recorded and converted to absolute degree angle error. The standard BVI tennis rattle ball sound resulted in 9.56 degrees of average angular error at a 30-foot distance. After eliminating sounds that 2 or more people either could not hear in either soundscape or that people had degree angle errors over 15 degrees, we discovered a superior localizable sound that resulted in only 4.00 degrees of average angular error at a 30-foot distance.

Key words: Blind tennis, sound ball, sound source localization, visually impaired athletes

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INTRODUCTION

Blind and Visually Impaired (BVI) Tennis is a growing sport worldwide. Since Mr. Takei Miyoshi invented Blind Tennis in Japan in 1984 (InternationalBlindTennis.org), the sport has grown to be played in at least 30 countries (IBTA) at the tournament level in Ireland, England, Scotland, Poland, Japan, etc., and at the club level in others. The growth potential is large, including expanding the sport to entire countries. In the US the Highland Park Tennis Club (blindtennis.org) is working at the grassroots level in partnership with the United States Tennis Association (USTA) to 'plant' new clinics for BVI players nationally and to improve the ease of learning the sport. Given the existing barriers to exercise faced by people with BVI (Richardson et al, 2022), there is a clear need for research to help enable increased participation.

BVI Tennis has a modified format that adapts the sport to players with different visual acuities, rated as B1-B4 with B1 players being profoundly blind and B2-B3 players having varying degrees of vision (low to high). B2-B4 players use a smaller court than fully sighted players use, with highly visible tape lines and a center-of-net height of 90 cm. Players of all sight classifications must land the first bounce in their opponent's court. B1 and B2 players must strike the ball prior to the fourth bounce, B3 before the third bounce, and B4 before the second bounce. B1 players play on an even smaller

Maggi Ostrowski, Board member of the United States Blind Tennis Association and two-time paralympic B1 athlete, hits a serve from behind a tactile baseline at the 2023 International Blind and Visually Impaired Tennis Education Conference and Tournament at the USTA National Campus in Orlando, Florida. Photo credit: Jennifer Roth / USBTA.

court with tactile lines, with a lower net (center-of-net height: 83 cm) than tennis for players with full vision. All BVI players use a sound ball, and a smaller racquet (B1 players' racquets are up to 23 inches in length; B2-B3 up to 25 inches; B4 up to 27 inches). Court sizes are frequently reviewed, and sometimes change to accommodate the performance of the different balls that have been adopted by the sport (IBTA Technical Manual, 2019).

One challenging aspect of Tennis for no-vision and low-vision athletes that we hope to facilitate with our research, is the need to track a moving ball by sound, determining its trajectory and velocity in a 3-dimensional space. The current standard BVI audible ball contains a 'mechanical' rattle constructed from a hollow plastic dimpled ball containing ball bearings, inserted into a foam outer ball (9 cm circumference, 28-32 grams). This ball only generates a brief, rattle sound whenever the ball changes momentum (hit or bounce) but remains silent at steady velocities or constant spin, making localization and tracking the ball a difficult task to learn. Athletes are challenged to find this mostly-silent ball in the x-, y-, and z-planes while accounting for forward velocity and diminished height with each bounce. With these challenges, a volley is nearly impossible.

Second, the rattle sound is not the optimal sound for source localization. Sound source localization is a challenge in the x-, y-, and z- dimensions for a moving object. The cognitive neuroscience of sound source localization informs us that the brain exploits different sound qualities to localize sounds in each of the x-, y-, and z-planes (Grothe, Pecka, & McAlpine, 2010). The horizontal plane provides both interaural time differences and level differences (Møller, Sørensen, Hammershøi, & Jensen, 1995). The vertical plane does not have binaural cues, as human ears are relatively level on the sides of our heads, and therefore relies on spectral cues (Wallis & Lee, 2015) characterized by the head-related or anatomical transfer function specific to an individual. Depth is largely conveyed by intensity (Finnegan, Proulx, & O'Neill, 2016), though reverberation contributes, too. Moreover, sound 'color' such as the varieties of frequencies that convey the meaning or relevance of a sound (Derey, Rauschecker, Formisano, Valente, & de Gelder, 2017), and the bandwidth of frequencies (Yost & Zhong, 2014) are important in a number of dimensions. For each of those sound qualities in those planes, there are optimal sound characteristics of amplitude and frequency of the sound wavelengths to achieve sound source localization (for a review of the physics of sound source localization, see Risoud et al, 2018). Furthermore, ambient sounds such as traffic noise, conversation, dogs barking, and birdsong, heard often on an outdoor tennis court, attenuate the frequencies produced by the sound ball (Docherty, 1972).

Using the current IBTA standard rattle ball, new players work for years to achieve a rally, and international tournament-level players achieve only a short rally. Given that the ball only makes a noise when struck with the racquet and in a brief moment during and after a bounce, new B1 players at our clinic as well as sighted blindfolded players swat at the air where they believe the ball to be. An experienced B1 player from Germany and current IBTA Board member shared:

"I have yet to see a B1 player who manages to consciously hit volleys. The balls currently available are either bouncing too low, moving too fast, or they are not making enough noise to track them easily during all stages of their journey across the net. The ability to track a blind tennis ball is key to delivering quality shots and to being at the right place at the right time. Finding a good sound is difficult, as sound changes as it travels at high speed. There are also noises around the player, and in this sound carpet the tennis ball has to stick out, no matter whether in a one on one or in a noisy tournament environment" (Kaplan, Chris, Personal communication 8/31/2021).

The International Blind Tennis Association (IBTA) requested new ball development (Martin Etheridge, IBTA, personal communication, 2019). The Highland Park Tennis Club's Blind and Visually Impaired (BVI) Tennis program (blindtennis.org), located at public courts in Pittsburgh, in partnership with the USTA, has the potential to expand the health and wellness opportunities that tennis can provide to the over 2 million blind and 7 million visually impaired people living in the US (cdc.gov). We have the potential to revolutionize the sport, increasing the potential for longer rally, possibly introducing volleys altogether, and reaching more athletes by reducing the time to become proficient at 'finding' the ball from years to days. This combination has the potential to increase enjoyment, health, and wellness by maintaining players through the difficult learning phase. Given the correlation between enjoyment and commitment to the sport (Casper et al., 2007), we believe we can improve the potential health benefits of tennis in BVI player by extending their rally (Groppel & DiNubile, 2009; Kovacs et al., 2016; Oja et al., 2017; Pluim et al., 2007), as well as increase cognitive benefits including improved spatial cognition in blind athletes across multiple blind sports that translates to the player's life (Shiota and Tokui, 2017; Velten et al, 2014).

We conducted the experiments described here to optimize the development of a new electronic sound ball that is easier to localize than the standard BVI 'rattle ball.' This optimized ball could allow players to achieve greater proficiency faster, increasing the enjoyment of the sport, increasing the length of points that could improve recruitment, retention, health, and wellness benefits, promoting the love of tennis to new and existing players.

METHODS AND PROCEDURES

We interviewed blind tennis players, board members of the IBTA, and new B1 adult athletes at our BVI Tennis clinic to determine the needs for new ball development, compiled input on the performance of the current ball, generated a 'wish list' of ball features for a new ball (durable, low cost, sound that is easy to localize, bounces well), as well as created a list of a variety of sounds they find to be easily localizable for later assessment.

Sound selection

We screened sounds (freesounds.org) for the characteristics that the brain best exploits for sound source localization (Risoud et al, 2018) via Fourier transformations of the sound wavelengths using a cell phone application (FFT Spectrum Analyzer, version 17). To compare performance to the standard BVI Tennis rattle sound, we recorded the rattle, then normalized this and all sounds to the same peak amplitude. All sounds repeated continuously. We selected 23 sample sounds with different characteristics for our sound localization experiments.

Participants

Participants completed and signed an informed consent form, and 22 sighted participants (ages 18-80 years, mean age 51.0 years; 10 F, 12 M) completed a version of the experiment on an outdoor court; 7 completed the indoor experiment (ages 18-70 years, mean age 35.7 years; 3F, 4M). This research protocol was approved by Carlow University's Institutional Research Review Board.

Procedures

Twenty-three sample sounds were tested on an outdoor BVI court in a public park using five Bluetooth speakers placed 9.144 meters (30 feet, the approximate baseline to baseline distance on a B1 BVI Tennis court) from the participants at 10-degree increments ranging from 70 to 110 degrees. A convenience sample of blindfolded sighted participants, recruited from the tennis and university communities, were given 3 seconds to point to where they believed sounds originated, using an arrow attached to a large protractor. Degree angles were recorded from the protractor and converted to absolute degree angular error relative to the actual location of the speaker generating the sound. Each participant located 90 sounds selected randomly and played from a randomly selected speaker by a Python script run in an Anaconda environment. The experiment was replicated in an indoor setting, both in unaltered, naturalistic soundscapes. For a video demonstration, visit https://www.youtube.com/watch?v=2UKIGfMdYLA.

Figure 1. *Members of the research team (from left to right Dr. Kaihong Liu, Dr. Jennifer Roth, Christen Rose, and Isabella Liu-Lopez) standing behind the protractor participants used to indicate their best guess as to the location of each sound sampled.*

Data analysis

Before subjecting the data to a t-test to compare the performance on the standard rattle sound to the best-performing sound, we eliminated sounds that 2 or more participants could not hear in either of the soundscapes, and that had average degree angle errors over 15 degrees. We have patent pending status for the process of developing this sound device.

We conducted a brief pilot study on an outdoor tennis court comparing player performance using a foam ball containing the prototype circuit playing the best sound to player performance using the standard BVI Tennis ball. We hit each ball to 2 blindfolded players and asked them to make contact with the ball using their own tennis racquet.

RESULTS

Participants were able to localize 12 of the 23 new sounds better than the standard rattle sound used in BVI Tennis. Participants' performance at localizing the best-performing sound (M = 4.0 degrees of error, SE = 0.92) was significantly better than their performance at localizing the rattle sound (M = 9.56 degrees of error, SE = 1.76) even after making the standard rattle sound continuous ($t(21) = 20.76$, $p < .0001$).

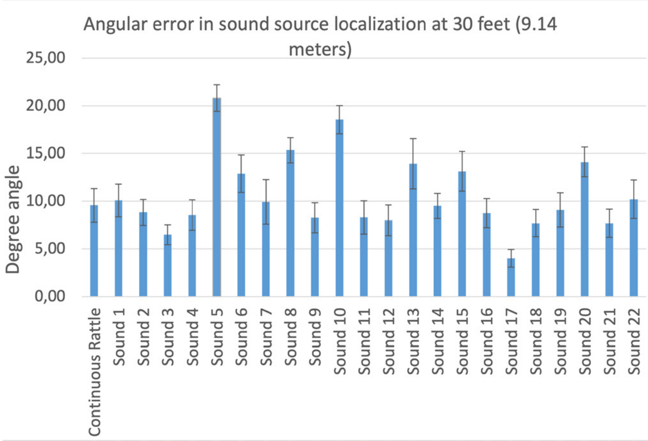

Figure 2. *Average performance across participants in locating the source of 23 sounds. Performance is plotted as average degree angle error from the location of the sound source (average absolute difference between where participants pointed with the arrow on the protractor and where the sound source was located). The Continuous Rattle sound is a recording of the standard sound ball adopted by the International Blind Tennis Association at the time the experiment was conducted.*

In the pilot study on an outdoor tennis court, blindfolded players successfully made contact with the foam ball containing the prototype circuit playing the best sound 100% of the time. They made contact with the standard BVI Tennis ball 50% of the time.

DISCUSSION

The results of the current experiments demonstrate that it is possible to develop an electronic sound ball for BVI tennis players that will lead to greater success in the sport. We identified a sound that blindfolded participants were able to localize with 4.0 degrees of angular error compared to the sound of the standard, BVI Tennis ball at 9.56 degrees of angular error, though both sounds were played continuously. One challenge in BVI Tennis is that the sound of the standard BVI Tennis ball occurs only briefly after a momentum change. This new, better-performing sound was then recorded onto an electronic circuit so that it can play continuously. This circuit was implanted in a foam ball similar to the foam ball used in BVI Tennis. In a brief pilot study, blindfolded tennis players were better able to locate this sound versus the current sound used in BVI tennis in a realistic tennis scenario. Initial testing of the current prototype ball, by hitting the ball at a participant across the net, revealed that players are roughly twice as likely to track the electronic sound ball successfully in a realistic tennis setting compared to the standard ball used currently in Blind/VI tennis. In these preliminary tests, our prototype sound-producing circuit, inserted in a standard foam BVI Tennis ball, is robust to the forces of tennis and bounces similarly to the standard BVI ball. Furthermore, the continuous sound allows B1 players to retrieve their own ball without assistance, adapting the equipment of tennis to the needs of the athletes, rather than asking the athletes to adapt to the equipment.

We believe our selection of a new sound to be used in an electronic sound ball for BVI tennis will help to accomplish the USTA's goals of expanding tennis while increasing the health and wellness of new and existing players (Allen, Townsend, & Davies, 2021) through the development of equipment that meets the needs of the players in a way that increases the enjoyment of the sport. This might even provide an interesting inclusive design for training even sighted tennis players, as multisensory cues tend to enhance performance and might make it enjoyable for people playing for the first time (Lloyd-Esenkaya, Lloyd-Esenkaya, O'Neill, & Proulx, 2020), and like other accessible games could allow sighted and visually impaired players to play together (Gonçalves et al, 2021).

This ongoing project has the potential to result in greater recruitment and retention of players to BVI Tennis. This has the potential to expand the health and wellness opportunities that tennis can provide to the over 2 million blind and 7 million visually impaired people living in the US (cdc.gov), and equivalent groups in other countries. This project has the potential to result in longer rally, possibly introducing volleys altogether, and reach more athletes by reducing time and frustration to become proficient at 'finding' the ball. These potential improvements to the sport could increase enjoyment, health, and wellness, given the correlation between enjoyment and commitment to a sport (Casper et al., 2007). The potential health benefits of tennis in BVI players could improve if we do extend their rally (Groppel & DiNubile, 2009; Kovacs et al., 2016; Oja et al., 2017; Pluim et al., 2007). An increase in duration of points, and increased commitment to the sport, could lead to improved spatial cognition (Pasqualotto & Proulx, 2012) that will likely translate to the player's life outside of sport (Shiota & Tokui, 2017; Velten et al, 2014).

CONCLUSION

In conclusion, we identified a new electronic sound to be used in an electronic sound ball for BVI Tennis that is able to be localized more successfully than the rattle noise used currently in the standard BVI tennis ball. We believe that the use of this new, more localizable sound has the potential to increase the duration of rally, decrease the time and frustration involved in becoming proficient at 'finding' the ball, and generally attract and retain more players, allowing more players to experience the health and wellness benefits of tennis.

CONFLICT OF INTEREST AND FUNDING

The authors declare that they do not have any conflict of interest to conduct the research. This research was funded by the United States Tennis Association Research Challenge. M. J. Proulx's research is partly funded by the UKRI Centre for the Analysis of Motion, Entertainment Research and Applications (CAMERA 2.0; EP/T022523/1).

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REFERENCES

Allen, J., Townsend, J., & Davies, K. (2021). Attracting and retaining new tennis players: A review of the literature. *Journal of Medicine and Science in Tennis.* Journal of Medicine and Science in Tennis, 26(2), 6-12.
Casper, J. M., Gray, D. P., & Stellino, M. B. (2007). A Sport Commitment Model Perspective on Adult Tennis Players' Participation Frequency and Purchase Intention. Una perspectiva del modelo de ompromise depotivo en adultos freecuencia de participación e intención de compra. *Sport Management Review*, *10*(3), 253–278. https://doi.org/10.1016/S1441-3523(07)70014-1
Centers for Disease Control (2021, September 9). Fast Facts of common eye disorders. https://www.cdc.gov/visionhealth/basics/ced/fastfacts.htm
Derey, K., Rauschecker, J. P., Formisano, E., Valente, G., & de Gelder, B. (2017). Localization of complex sounds is modulated by behavioral relevance and sound category. The Journal of the Acoustical Society of America, 142(4), 1757. https://doi.org/10.1121/1.5003779
Docherty, E. M. H. (1972). The effects of reducing and masking the auditory cues accompanying performance of select gross motor tasks on the performance of those tasks. [Doctoral Dissertation, The Ohio State University]. Ohio
Etheridge, M. (2019). IBTA, personal communication, 2019
Finnegan, D. J., O'Neill, E., & Proulx, M. J. (2016, May). Compensating for distance compression in audiovisual virtual environments using incongruence. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (pp. 200-212). https://doi.org/10.1145/2858036.2858065
Gleeson, M., & McFarland, S. (2020). Working together to increase playing opportunities for the blind and visually impaired. International Blind Tennis Association presentation to the International Tennis Federation.
Gonçalves, D., Rodrigues, A., Richardson, M. L., de Sousa, A. A., Proulx, M. J., & Guerreiro, T. (2021, May). Exploring asymmetric roles in mixed-ability gaming. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (pp. 1-14). https://doi.org/10.1145/3411764.3445494
Groppel, J., & DiNubile, N. (2009). Tennis: For the health of it! *The Physician and Sports Medicine*, *37*(2), 40–50. https://doi.org/10.3810/psm.2009.06.1708
Grothe, B., Pecka, M., & McAlpine, D. (2010). Mechanisms of sound localization in mammals. Physiological Reviews, 90(3), 983-1012. https://doi.org/10.1152/physrev.00026.2009
International Blind Tennis Association. https://www.facebook.com/groups/129804027216963/
Highland Park Tennis Club Blind and Visually Impaired Tennis Program (n.d.) Blindtennis.org
International Blind Tennis Association. (2019). IBTA Technical Manual 2019. IBTA. https://www.internationalblindtennis.org/technical-manual
Kaplan, Chris, Personal communication 8/31/2021.
Kovacs, M., Pluim, B., Groppel, J., Crespo, M., Roetert, P., Hainline, B., Miller, S., Reid, M., Pestre, B., De Vylder, M., Dunn, N., Miley, D., & Jones, T. (2016). Health, Wellness and Cognitive Performance Benefits of Tennis. *Medicine & Science in Tennis*, *21*(3), 14–21. https://www.researchgate.net/publication/313064586_Health_Wellness_and_Cognitive_Performance_Benefits_of_Tennis#fullTextFileContent
Lloyd-Esenkaya, T., Lloyd-Esenkaya, V., O'Neill, E., & Proulx, M. J. (2020). Multisensory inclusive design with sensory substitution. Cognitive Research: Principles and Implications, 5(1), 1-15. https://doi.org/10.1186/s41235-020-00240-7
Møller, H., Sørensen, M. F., Hammershøi, D., & Jensen, C. B. (1995). Head-related transfer functions of human subjects. Journal of the Audio Engineering Society, 43(5), 300-321.
Oja, P., Kelly, P., Pedisic, Z., Titze, S., Bauman, A., Foster, C., Hamer, M., Hillsdon, M., & Stamatkis, E. (2017). Associations of specific types of sports and exercise with all-cause and cardiovascular-disease mortality: a cohort study of 80 306 British adults. *British Journal of Sports Medicine*, *51*(10), 812–817. https://doi.org/10.1136/bjsports-2016-096822
Pasqualotto, A., & Proulx, M. J. (2012). The role of visual experience for the neural basis of spatial cognition. Neuroscience & Biobehavioral Reviews, 36(4), 1179-1187. https://doi.org/10.1016/j.neubiorev.2012.01.008

Pluim, B., Staal, J., Marks, B., Miller, S., & Miley, D. (2007). Health benefits of tennis. *British Journal of Sports Medicine*, *41*(11), 760–768. https://doi.org/10.1136/bjsm.2006.034967

Richardson, M., Petrini, K., & Proulx, M. J. (2022). Access to exercise for people with visual impairments during the Coronavirus-19 pandemic. British Journal of Visual Impairment. https://doi.org/10.1177/02646196211067356.

Risoud, M., Hanson, J. –N., Gauvrit, F., Renard, C., Lemesre, P.-E., Bonne, N.-X. & Vincent, C. (2018). Sound source localization. European Annals of Otorhinolaryngology, Head and Neck Diseases, 135 (4), 259-264. https://doi.org/10.1016/j.anorl.2018.04.009.

Shiota, K., & Tokui, A. (2017). Audiospatial cognitive ability of visually impaired athletes in static and dynamic spatial cognitive tasks. Journal of Physical Therapy Science, 29(11), 1981–1986. https://doi.org/10.1589/jpts.29.1981

Velten MC, Blasing B, Portes L, et al. (2014). Cognitive representation of auditory space in blind football experts. Psychology of Sport and Exercise, 15, 441–445. https://doi.org/10.1016/j.psychsport.2014.04.010

Wallis, R., & Lee, H. (2015). The effect of interchannel time difference on localization in vertical stereophony. Journal of the Audio Engineering Society, 63(10), 767-776. https://doi.org/10.17743/jaes.2015.0069

Yost, W. A., & Zhong, X. (2014). Sound source localization identification accuracy: Bandwidth dependencies. The Journal of the Acoustical Society of America, 136(5), 2737-2746. https://doi.org/10.1121/1.4898045