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See no Isotropy, Hear no Isotropy: Perceived Distance Anisotropy in Auditory Space*

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The aim of the present study was to investigate whether the tendency to perceive vertical distances as larger than horizontal ones, called the anisotropy of perceived distance, exists in the auditory modality, too. We performed two experiments in which participants (16+20) had a task to match distances of two sound sources, positioned on horizontal and vertical axes, on three egocentric distances. Besides that, in the second experiment, we varied the head moving towards a sound source (with and without) and sound dispersion around the head (with or without a box-like frame around the head). Results showed that participants managed to differentiate sound source distances, but the effects of head moving (proprioceptive information) and sound dispersion around the head were not obtained. Finally, results showed differences in matched distances between two directions. Distances of the vertical sound source were systematically perceived as larger than physically equal horizontal ones, which coincide with findings from previous studies, related to visual or proprioceptive distance estimates.

Keywords: anisotropy, perceived space, auditory space, distance perception, action and perception

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Data availability. Datasets analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions. 1st, 2nd, and 3rd authors (Anđela Šoškić, Marija Stublinčević, Oliver Tošković) developed the research questions, performed data analysis and contributed equally. The 1st and 2nd author (Anđela Šoškić, Marija Stublinčević) performed and oversaw the experiments. The 3rd author (Oliver Tošković) oversaw the project, integrated both experiments and discussed the results.

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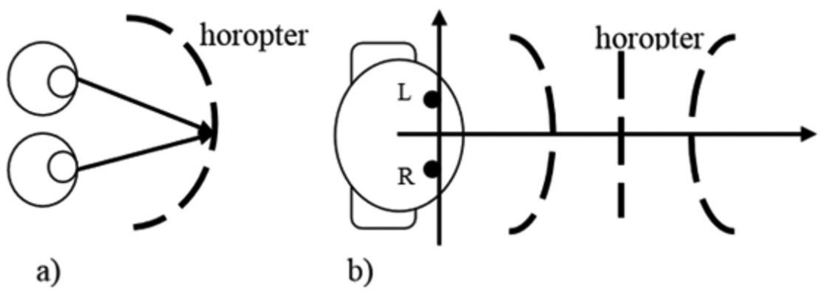
Highlights:

- Perceived distance anisotropy appears in auditory modality, too.
- People perceive vertical distances as larger than physically equal horizontal ones.
- Anisotropy appears regardless of the differences in sound dispersion.
- Interaction with proprioceptive information is not necessary for anisotropy.
- Results are in line with our taking effort into account hypothesis.

One of the first studies that showed that the perceived space geometry differs from the one in the physical space was conducted by Herman Helmholtz (1864). Helmholtz showed that Vieth-Müller horopter circles are actually not geometrical circles, centered at the viewer's standpoint. Instead, they are elliptical: concave (directed towards the viewer) for closer distances and with increasing distance they slowly become linear, and in the end convex for larger distances (see the illustration on Figure 1).

Figure 1
(a) physical horopter (points projecting on corresponding places on the two retinas); (b) perceived horopters at various distances from the viewer (L-left eye, R-right eye)



Similarly, Hillebrand (1902) and Blumenfeld (1913) showed that adjusting two lines to appear parallel at eye level leads to different composition than adjusting them to be equidistant. These and some more recent studies (Doumen et al., 2006; Foley et al., 2004; Levin & Haber, 1993) showed that the perceived space is not Euclidean, and inspired a number of papers discussing its geometry (Erkelens, 2015; Foley, 1972; Luneburg, 1950; Suppes, 1977).

Another example of perceived space deviation from the physical one is anisotropy, which refers to a change of perceived characteristics of an object when it is located in different positions relative to the subject. For example, some researchers report that, during grasping, objects close to the observer are perceived as if they were more elongated than further objects (Campagnoli &

Domini, 2019). Anisotropy of perceived distance would refer to perceiving physically equal egocentric distances (distance between the object and observer) as different on different viewing directions. Horizontal/vertical anisotropy is usually investigated in the assessment of exocentric distances, but it is also detected in the comparison of egocentric distances. Tošković (2009, 2010, 2011) examined the role of visual (e.g. presence of distance cues) and non-visual (e.g. vestibular and proprioceptive information about head and body orientation) factors on the visually perceived distance anisotropy. In these experiments two stimuli (a small light source) were shown to participants, in different directions (horizontal and vertical), and the task was to match their egocentric distances. The factors that were varied in the experiments were viewing direction, permission to move the head, eyes or body, presence of visual depth cues, and participant's body position (e.g., standing straight, laying down or looking between their own legs). The results showed a systematic anisotropy of visual space: subjects perceive objects that are above them as more distant than physically equidistant objects in front of them. This effect arises from an interaction between sensory modalities (visual, proprioceptive and vestibular), and it cannot be attributed to visual depth cues distribution.

Harris and Mander (2014) also stress the importance of interaction of visual and vestibular information for reduction of perceived distance with the change of observer's body position. Tošković (2011, 2012) suggested that this effect is in the function of action, because gravity influences the amount of energy needed to make movements along different axes. For example, a person would use more energy to reach out for an apple which is above her head, than to take it if it was equally far away, but in front of her. In line with this explanation, similar effects were obtained in the domain of proprioceptive space, when participants were matching distances blindfolded and moving stimuli by their own hand (Tošković, 2012). Other authors showed that reachability estimates depend on the environmental context and on the type of reach employed (Lin & Linekenauger, 2021). Also, it is shown that distances above the observer tend to be overestimated, and below the observer tend to be underestimated in regular or hypergravity conditions (Clément et al., 2020). Same authors find that during parabolic flight, in gravity-free condition, these differences in perceived distances disappear. Other findings also stress perception-action matching showing, for example, a tendency of the perceived distance to be larger as a function of task difficulty (Paterson et al., 2019). Same authors stress that perceptual bias may assist in making adaptive action choices. Other authors stress the importance of sensory integration of body-related and visual signals for action specific influences in perception (Kirsch, 2021), or conclude that action's effects on perception are rooted in changes of spatial attention (Kirsch et al., 2021). Durgin and Li (2011) note that explicit misperception of distance might allow accurate spatial action and can be understood as the result of calibration, but they mainly attribute this misperception to the scale expansion of perceived gaze declination.

Given that earlier studies confirmed the presence of anisotropy in visual and proprioceptive space, the next step was to investigate if this effect can be obtained for distance perception in auditory space. Several auditory distance cues vary in their effective ranges in peripersonal and extrapersonal space, such as sound intensity, direct-to-reverberant energy ratio, sound spectrum, interaural time differences (ITDs) and interaural level differences (ILDs), motion– induced intensity rate of change, Doppler effect and motion parallax (Naguib & Wiley, 2001; Zahorik et al., 2005; 0. Importance assigned to two primary distance cues, sound intensity and direct-to-reverberant energy ratio, can vary as a function of sound source type and it's angular position relative to the median plane (Zahorik, 2002). Some authors indicate that reverberation-related distance cue depends on the sound frequency, but it can be considered as direction-independent 0. However, auditory perception of depth results in considerably less accurate and more variable estimates than those gained through visual or combined visual and auditory information (Anderson & Zahorik, 2014). Findings consistently show that listeners tend to underestimate the distance to faraway sources and overestimate the distances to sources closer than 1 m, which can be approximated by a power function (Zahorik et al., 2005). Same authors report that fitted exponents can vary from 0.15 to 0.70 between individual listeners and different stimulus conditions (varying source direction and source signal).

Auditory distance perception received substantially less scientific attention than the directional aspects of auditory localization. Carlille and Pralong (1994) point out the importance of changes in sound frequency due to head and pinnae anatomy, so called head-related transfer function, for sound direction estimation. They conclude that head-related transfer function also can be an important cue for sound source height detection. Findings consistently show that direction estimation is more accurate for sound sources positioned at head level (horizontal plane), while sounds from other azimuth levels are usually localized as closer to the horizontal plane (Makous & Middlebrooks, 1990; Carlile et al., 1997; Best et al. 2011). Makous and Middlebrooks (1990) point out the importance of proprioceptive information from neck muscles for sound source direction localization, since it approves if participants can turn their head toward the sound.

Same as for visual space, findings point to a possibility that the auditory space does not correspond to the physical, either (Maezawa & Kawahara, 2019). For example, a group of researchers (Arthur et al., 2008) showed that participants made systematic misjudgments in sound source localization. If sound direction was estimated verbally or by egocentric pointing task, pattern of distortions was similar to those gained in visual domain, indicating existence of similar anisotropy in auditory space. Also, von Békésy (1949) reports differences in so called auditory image size, perceived from different locations of the listener relative to the sound source, such as listening to concert from ground floor or from the balcony. These differences resemble the change of visually perceived object size appearing on horizon and zenith, such as in Moon illusion.

The goal of our research was to examine whether there is anisotropy of perceived distance in auditory space, analogous to that which was already found in visual and proprioceptive modalities. More specifically, we were interested to investigate if participants would perceive stimuli placed in vertical direction (above their heads) as further than physically equidistant objects that are placed in front of them (horizontal direction).

Experiment 1

Method

Participants

Since in our previous studies, in the visual and proprioceptive domain, we obtained effects between $\eta^2 = 0.5$ and $\eta^2 = 0.75$, we would need a minimum of 10 participants in order to obtain similar effects in this study, with study power of 0.8 and alpha level of 0.05. Therefore, a convenience sample of 16 first-year students (12 female, all of them aged 19) from the University of Belgrade took part in the study. All participants had normal hearing, according to their own statement. The study was approved by the Institutional Review Board (IRB) of the Department of Psychology, Faculty of Philosophy, University of Belgrade, Serbia, protocol number #2018–022. Informed consent was collected from all subjects prior to their participation in the experiment.

Study Design

The experiment had two factors with repeated measures. The first factor was *distance* of a sound source from the subject, with three levels: 1, 3 and 4 meters. First, we planned to use a 5-meter distance instead of 4, but unfortunately, it was close to the room ceiling and it could lead to measurement biases, e.g., ceiling effect, even literally in this case. The second factor was *a target direction*, with two levels: horizontal and vertical. The dependent variable was *the matched distance* of the second sound source (target).

Apparatus and Stimuli

When assessing perceived distance, two small speakers were used (Esperanza Bluetooth Speaker Fm Ritmo; frequency response 280Hz-16kHz; dimensions 50mm*57mm). Each of them was placed on one of the two threads, with a total length of 7m, along which they could move. The threads were positioned to create vertical and horizontal axes, with a common origin (see Figure 2). Tone Generator (Tolvan Data, http://www.tolvan.com) was used to generate stimuli sounds. There were two types of stimuli, both pure tone sounds calibrated to a comfortable level of approximately 60 dB and frequency of 350 Hz, measured at the participant's head position with the sound source located at 1 m. Sound intensity was similar as in some previous researches (Zahorik, 2002; Zahorik et al., 2005), and frequency level was selected by 9 independent listeners as the most comfortable and detectable sound, for a given intensity level. *Standard* sound was coming from a predefined position (1m, 3m or 4m) from the viewer and it was played for 1 second. *Target* was played continuously during the adjustment of a sound source position. Experiment was performed in a sports hall, with average reverberation time of T60=1.8s, at a given frequency of 350 Hz.

Procedure

After receiving instructions and information about the experiment, participants' eyes were covered and their position was such that their head was next to the origin of the axes.

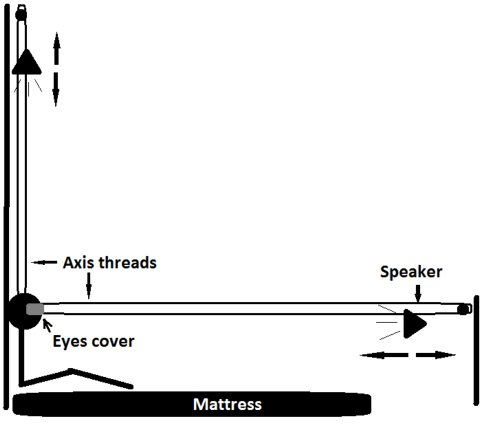
They were instructed not to move their head in any way during the experiment. The horizontal line was perpendicular to participants' body, while the vertical one was parallel to their body. The setting of the experiment is shown in Figure 2.

Each trial started with a brief (1sec.) presentation of the standard. After the participants had confirmed that they had heard it well, the target sound started playing on the second speaker, and the participants would verbally guide the experimenter in tuning the position of the target until they perceived it as equally distant from themselves as the standard. If the participants requested, they were allowed to replay the standard (during this time the target sound was paused), so that they could rely on perception as much as possible compared to the memory of the sound. Once the participant was done with tuning the position of the target, the sound would be stopped and the distance between the target speaker and the participant's ear was recorded. Experimenter who moved the speaker was blind to the aim and the hypothesis of the experiment.

During the task, only the participant gave verbal instructions to the experimenter (*move it closer or further*), while the experimenter was silent. Participants could only hear the experimenter's movements, which were the same in both directions (dragging the ropes) and therefore could not significantly influence the results or produce bias in one of the directions. After each trial, when the experimenter was setting a new standard position, the participant's ears were covered in order to prevent possible additional information on the target position.

Figure 2
The experimental setting for the first experiment

Each participant went through all standard positions twice, and the order of appearance of stimuli followed the principle of the Latin square design, so each participant went through a total of 12 trials in a randomized order. Starting positions of a standard and the target stimuli



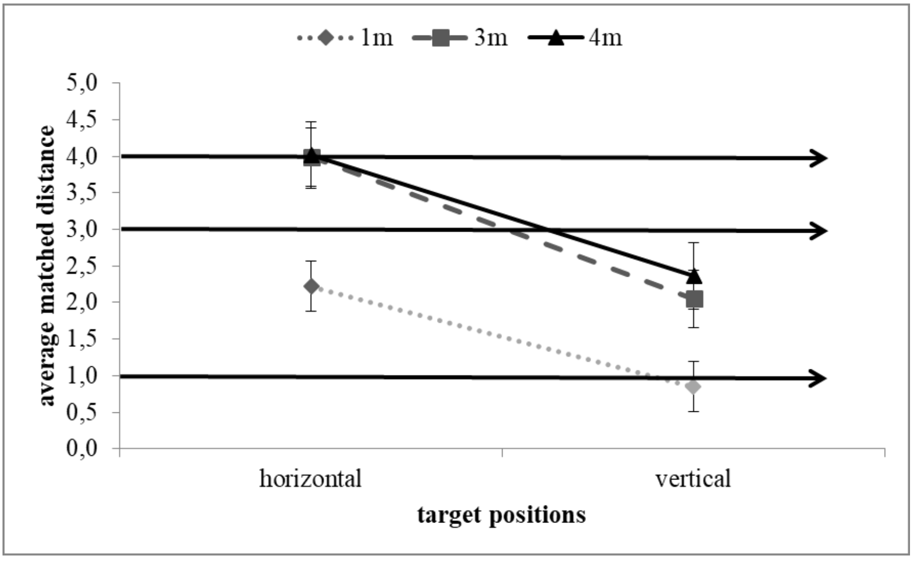
were randomized in each trial, in both directions, for every participant.

Results

As a dependent variable, we used stimuli distances reproduced by participants, in both directions. In order to avoid the inflation of Type I error we decided not to compare each reproduced distance with the standard one. Instead, we compared two sets of matched distances, horizontal matches gained based on a vertical standard and vertical matches gained based on a horizontal standard. So, we compared two target positions in different directions and did not compare the target with the standard stimuli position. Two-factorial ANOVA for repeated measures was used to analyze data, since the dependent variable was normally distributed and the sphericity assumption was satisfied. Figure 3 depicts average distances of the target set to match each standard: horizontal position shows horizontal matches to a vertical standard, while vertical position shows vertical matches to a horizontal standard. Mean distances and their standard deviations can be found in Appendix A (Table A1).

Figure 3
Average matched distances in two directions; horizontal gridline arrows represent standard distances, and error bars represent 95% confidence intervals

ANOVA results showed that the participants were able to differentiate distance of the sound sources within the measured range based on the auditory information available to them (significant effect of the distance, $F(2, 30) = 51.33$,



$p < .001$, $\eta^2 = 0.77$), which was a prerequisite to examine auditory distance perception in this experimental setting. For the research question, a more important finding is the significant effect of direction ($F(1, 15) = 43.19$, $p < .001$, $\eta^2 = 0.74$), which means that there was a difference in the perceived distance when it was presented in vertical and horizontal direction. The participants in most cases matched closer vertical to more distant horizontal distances and vice versa. Or, if they matched the vertical target correctly on 1m, they gave more distant matches for a horizontal target for the same standard distance. Also, on 4m they matched the horizontal target correctly, but they gave closer matches for the vertical target. If we look at ratios of matched distances to standard ones, for horizontal estimates they were ranging from 1 (at 4m distance) to 2.2 (at 1m), and for vertical ones from 0.59 (at 4m) to 0.85 (at 1m). These ratios imply that: (1) on horizontal direction close distances, at 1m, tend to be underestimated while further ones, at 4m, tend to be perceived correctly; (2) on vertical direction all distances were overestimated, but overestimation was larger for closer distances, at 1m. The direction of the effect was in line with the initial expectations: since the participants perceived a closer vertical distance to be equal to a more distant horizontal standard, we may conclude that perceived distance on vertical direction was larger. The interaction between distance and viewing direction was not significant ($F(2, 30) = 2.95$, $p = .07$), meaning that difference in perceived depth on horizontal and vertical direction was similar in all measured distances.

Experiment 2

In Experiment 1 we showed that distance is perceived anisotropically in auditory modality, as well. Namely, vertical distances of a sound source were perceived as longer than physically equal horizontal ones, which resembles the findings in visual and proprioceptive space (Tošković, 2009, 2010, 2011). However, while performing distance estimates, participants were instructed not to move their heads, since they could hear the sound in both directions without moving their heads. Contrary to that, in earlier studies in which a similar task was used, but estimates were done relying on visual information, participants needed to move their head in order to observe stimuli on horizontal and vertical direction. Based on those studies we concluded that anisotropy of perceived distance can be, at least partially, attributed to the interaction of visual and proprioceptive information from the neck muscles. Due to the uniqueness of auditory domain measurements in which head repositioning is not necessary to hear sounds from different directions (participants did not move their heads while switching from horizontal to vertical direction), the interaction with proprioception was omitted in experiment 1. According to that, we might ask, would anisotropy of auditory perceived distance change if we added proprioceptive information during distance matching?

In addition, sound dispersion might differ if it is reaching the ears from the front (horizontal axes) or from above (vertical axes), because of the head and pinane shape (Wolfe et al., 2006). And we might wonder if that could influence previously reported anisotropy effects in auditory modality.

Having this in mind, the goal of the second experiment was to determine whether differences in perceived distance of a sound source are the result of: (1) proprioceptive information from the neck muscles; (2) differences in sound dispersion; (3) or they just arise from some kind of general anisotropic model of perceived space.

Method

Participants

Since in our previous studies, in the visual and proprioceptive domain, we obtained effects between $\eta^2 = 0.5$ and $\eta^2 = 0.75$, for study power of 0.8 and alpha level of 0.05, in this study we would need a minimum of 10 participants in order to obtain similar effects. Therefore, the study included a convenience sample of 20 first-year students (16 females, all of them aged 19) from the University of Belgrade. All participants had normal hearing, according to their own statement. The study was approved by the Institutional Review Board (IRB) of the Department of Psychology, Faculty of Philosophy, University of Belgrade, Serbia, protocol number #2018–022. Informed consent was collected from all subjects prior to their participation in the experiment.

Apparatus and Stimuli

All equipment (the speakers, apparatus for distance matching and the tone generating software), as well as the stimuli (60dB, 350 Hz pure tone) and room (sports hall), were the same as in the Experiment 1. Additionally, a specially designed frame around the head was used, in order to balance the sound dispersion to the ear from two directions, horizontal (front) and vertical (above). This frame was a handmade cardboard box with the same shape, area and volume towards horizontal and vertical direction (see Figure 4). By wearing it participants had similar artificial head shapes in two directions, from which they were receiving sound, and which should reduce the differences in sound waves propagation (Sataloff & Sataloff, 2006; Piercy et al., 1977).

Study Design

The study had three factors with repeated measures. The first factor was *egocentric distance* of a sound source, with three levels: 1, 2.5 and 4 meters. The second factor was *a target direction*, with two levels: horizontal and vertical. The third factor was the *situation* with three levels:

1) *without the box* and with the *instruction not to move* their head. In this situation there was an unequal sound dispersion, and no proprioceptive information change;
2) *without the box* and with the *instruction to move* their head directing the face towards the sound source (if sound was coming from the horizontal direction, they would "look" upfront, and if it was played from the vertical one, they would "look" above). This situation minimized changes in head-related transfer function (Carlille & Pralong, 1994), since participants were always facing front to the sound source, and included a change of proprioceptive information from the neck muscles;
3) *with the box* and with the *instruction not to move* their head. In this situation head shape was equalized in both directions, and upper parts of the pinnae above the ear canal were covered by the box, which made us assume there was an equal sound dispersion. Participants did not move their head and no proprioceptive information was changed.

Since these three situations were sufficient to draw conclusions about the issues we were interested in, we did not include the fourth situation: with the box and with the instruction to move their head. This potential situation would provide equal sound dispersion and proprioceptive information change, which we already obtained in the second situation. Besides that, with the first three situations the procedure already lasted 45 minutes per participant, and adding another one would make the experiment too long and too tiring for participants. The dependent variable was *the matched distance* of a second sound source (target).

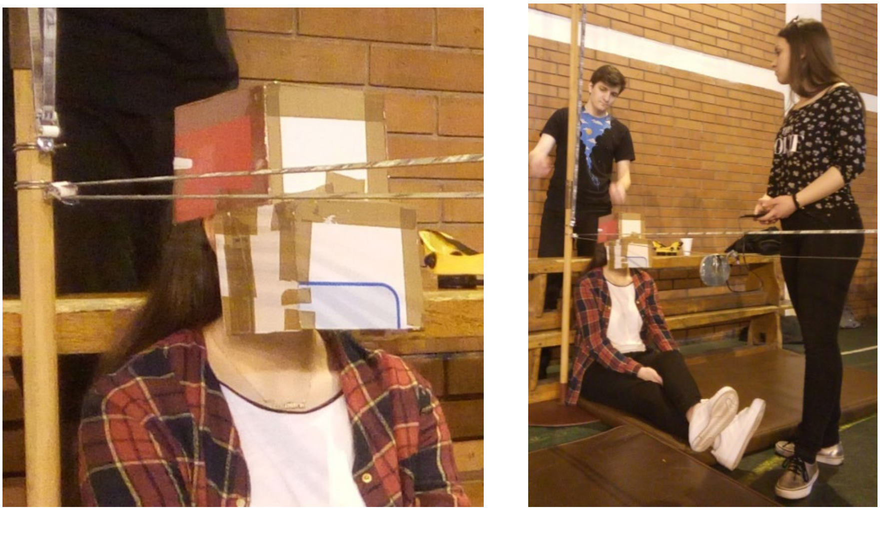
Procedure

As in Experiment 1, the task was to match the distance of two sound sources, in two directions. One of the sounds was considered as standard and participants would verbally guide the experimenter to set the distance of the target positioned in the other direction, until it is perceived as being on the same egocentric distance. Experimenter who moved the speaker was blind to the aim and the hypothesis of the experiment. As in the previous experiment, during the task, only the participant gave verbal instructions while the experimenter was silent. Participants could only hear the experimenter's movements, which were the same in both directions. After each trial, when the experimenter was setting a new standard position, the participant's ears were covered in order to prevent possible additional information on the target position. Participants were sitting blindfolded and positioned in such a way that their ears were equally distant from the floor and the wall behind them, because auditory distance perception can be enriched by surface reverberations (Wolfe et al., 2006). Since side walls show similar Sabine absorption coefficients as ground floor (Cucharero et al., 2019), our setting provided a similar floor sound reflection for horizontal speaker as was wall sound reflection for vertically positioned speaker, and *vice versa*. The setting of the experiment is shown in Figure 4.

Each participant went through all standard positions twice, and the order of appearance of stimuli followed the principle of the Latin square design, so each participant went through a total of 36 trials in a randomized order. This number of trials appeared as sufficient for providing stable estimates in previous experiments in the visual and proprioceptive domain (Tošković, 2009, 2010, 2011). Starting positions of both stimuli (standard and the target) were randomized in each trial, in both directions, for every participant. Also, in order to avoid anchoring appearing in method of adjustment (Shaffer et al., 2014), starting head position was randomized in a situation in which participants moved their head.

Figure 4

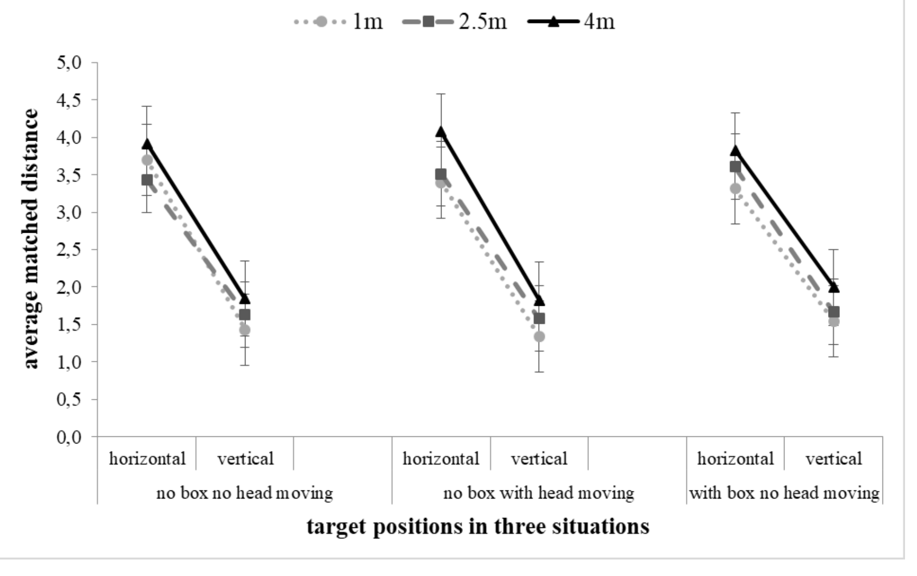
The experimental setting in the second experiment (left) and the frame around the head (right)



Results

Same as in the first experiment, as a dependent variable we used stimuli distances reproduced by participants in both directions, compared two target positions in different directions, and did not compare the target with the standard stimuli position. Three-factorial ANOVA for repeated measures was used to analyze data, since matched distances (dependent variable) were normally distributed and sphericity assumption was satisfied. Figure 5 illustrates average distances of the targets set to match each standard (*horizontal* stands for horizontal matches to a vertical standard, while *vertical* stands for vertical matches to a horizontal standard). Mean distances and their standard deviations can be found in Appendix A (Table A2). Results showed a significant main effect of stimuli distance ($F(2, 38) = 15.7$, $p < .001$, $\eta^2 = 0.45$), showing that subjects were able to differentiate between three distances, 1m, 2.5m and 4m. Furthermore, there was a significant difference between distance estimates obtained in different target directions ($F(1, 19) = 29.28$, $p = .001$, $\eta^2 = 0.61$). Participants matched closer vertical to more distant horizontal distances, and *vice versa*, meaning that vertical distances were perceived as larger.

Figure 5
Average matched distances in two directions, for three experimental situations; horizontal gridline arrows represent standard distances, and error bars represent 95% confidence intervals



In all three situations, ratios of matched distances to standard ones for horizontal estimates ranged from 0.96 (at 4m distance) to 3.7 (at 1m), and for vertical ones they ranged from 0.46 (at 4m) to 1.55 (at 1m). These results show that: (1) on horizontal direction close distances, at1m, tend to be underestimated while further ones, at 4m, tend to be perceived correctly; (2) on vertical direction closer distances, at 1m, were overestimated, while further ones, at 4m, were underestimated.

There were no differences among the three *situations* ($F(2, 38) = 0.1$, $p = .91$), *without the box* and *without head moving, without the box* and *with head moving*, *with the box* and *without head moving*. In addition, all interactions between factors turned out not to be significant, *situation*direction* ($F(2, 38) = 0.65$, $p = .53$), *situation*distance* ($F(4, 76) = 0.79$, $p = .54$), *direction*distance* ($F(2, 38) = 0.64$, $p = .53$) and *situation*direction*distance* ($F(4, 76) = 1.13$, $p = .35$). These findings indicate that results in the Experiments 1 and 2 were similar, and that difference between horizontal and vertical direction in auditory perceived distances could not be attributed to sound dispersion, or to proprioception from the neck muscles.

Discussion

The primary aim of this study was to determine whether perceived distance anisotropy appears in auditory modality, too. The findings of both experiments show that distance of a sound source is perceived anisotropically. Our participants tend to match closer vertical distances to physically more distant horizontal ones, which mean that they perceive vertical distances as larger than physically equal horizontal ones. The same regularity is previously reported in visual and proprioceptive modality. In other words, when people estimate distances relying on visual information, or when they do it blindfolded and relying on proprioception from the hand muscles (distance is estimated by hand movement only), results show that distances above them appear longer than distances in front of them. This study has shown that people behave in the same manner if they are blindfolded, and estimate distances relying only on auditory information – just by hearing and estimating distance of the sound source. Since in both directions various auditory distance cues (sound intensity, direct-to-reverberant energy ratio, sound spectrum, ITDs, ILDs...) were similar, we assume that other factors are responsible for perceived distance anisotropy. Besides that, we noticed a tendency for overestimation of close distances and underestimation of further ones, reported in previous studies (Zahorik et al., 2005).

Besides sensory modality, the other major difference between previous studies (investigating visual and proprioceptive modality) and this one (researching auditory modality), is the fact that in all previous experiments participants needed to move a part of their body in order to perceive stimuli distance in two directions, while in the present study they did not do so. If participants should look at the stimuli on horizontal, and then on vertical direction, they must move their head in order to do so. Similarly, if participants use their hand to move the stimuli in two directions, they must change the position of the hand. But, if participants listen to the stimuli from two directions, neither head nor hand movement is necessary. This difference between studies appears as significant, given that one of the possible explanations of perceived distance anisotropy in the visual domain was the interaction of visual and proprioceptive modality. Since in auditory modality, perceiving distance in various directions does not require head moving, and no proprioceptive and vestibular information change, anisotropy in this sensory modality can have significant impact on questioning the multisensory nature of this phenomena. Another important issue for perceived distance anisotropy in auditory modality is a difference in sound dispersion on horizontal and vertical direction. Namely, the shape of the head differs if the sound reaches ears from the front (horizontal axes) or from above (vertical axes), which creates different trajectory shapes and possible different sound dispersion. In order to investigate the role of proprioception from neck muscles and head-related transfer functions in perceived distance anisotropy, in auditory modality, we performed the second experiment.

Variations of artificial head shape gained through the handmade box-like frame did not affect anisotropy of perceived distance. Additionally, differences between vertical and horizontal distances remained the same, regardless of the head moving. In the situation in which participants listened to sounds from two directions without moving their head, we obtained the same anisotropy effects as in the situation in which they moved their head directing their face towards a sound source. Similar effects across three experimental situations suggest that head-related transfer functions (Carlile & Pralong, 1994) were not responsible for perceived distance anisotropy. The only effect which was constant throughout all of the situations was the difference between perceived distances in vertical and horizontal direction.

The finding that variations of possible sound dispersion did not affect perceived distance anisotropy is not related to our understanding and possible explanations of this regularity. However, the finding that proprioception from the neck muscles did not affect it, can be related to those explanations. Results from previous studies, performed mainly on visually matched distances, indicated that anisotropy appears in the interaction of visual, vestibular and proprioceptive information. Those results showed that perceived distance anisotropy is the largest when both the proprioception from the neck muscles and vestibular information change. If just one of those information changes and the other one remains constant, perceived distance anisotropy still appears but it is reduced. If none of those information changes, as in the situation when participants are lying on the left side of their body and they are turned by the experimenter, anisotropy of visually perceived distance is significantly decreased (Tošković, 2011). On the other hand, results from present study, in which we measured auditory perceived distances, did not show any interaction with proprioceptive information from the neck muscles. We might argue that such interaction, with proprioceptive and vestibular information, can be specific for visual modality, since the change of viewing direction requires the head or body position change. For auditory modality, such interaction is not necessary, since we can hear sounds from different directions without moving the head or body. On one hand, results from this study can raise doubt on multisensory nature of perceived distance anisotropy, since change in proprioception did not affect results. On the other hand, we can assume that difference in perceived distances in horizontal and vertical direction describes a model of perceived space, a kind of heuristic which is used as a starting point for distance estimation. Since other findings show the importance of proprioceptive information for anisotropies in depth perception (Clément et al., 2020), it might be that vestibular and proprioceptive information are used during formation of such a perceived space model, and once it is formed, they are no longer necessary for its activation. This is especially important if we have in mind that during our experiments participants rely on memory, since they need to remember standard position while trying to match the target distance with it. However, both lines of interpretation are plausible, and require further research.

Regardless of the interaction between sensory modalities, the findings of the present, as well as from all previous studies are in line with our *taking effort into account* hypothesis (Tošković, 2010, 2012). Since upward action or movement requires more effort, we assume that elongation of upward distances increases precision of those movements. If reaching for something above us is more effortful, then enlarging its perceived distance would suggest investing more strength than in reaching for something in front of us. Durgin and Li (2011) also conclude that biases in space perception may have more general functional significance, and attribute them mainly to visual depth cues, such as perceived gaze declination But, since anisotropy is shown in various sensotry modalities, it can hardly be attributed to visual depth cues. *Taking effort into account* hypothesis assumes the existence of anisotropic model of perceived space, and suggests that such a model increases the preciseness of our actions. Contrary to our intuition, in this case a bias in the perceptual representation would lead to more precise actions. If it is true, it would further mean that perceptual representation of space is designed not to be a verbatim copy of physical space, but to be a most adequate heuristic for future actions. We believe this might be the case, given that vertical distances are perceived as larger in all studies, regardless of the sensory modality, visual, proprioceptive or auditory.

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Ne vidim izotropiju, ne čujem izotropiju: anizotropija opažene udaljenosti u slušnom prostoru

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Cilj ovog istraživanja je bio da se istraži da li tendencija da se vertikalne udaljenosti opažaju kao veće od horizontalnih, zvana anizotropija opažene udaljenosti, postoji i u slušnom modalitetu. Sproveli smo dva ekspermenta u kojima su ispitanici (16+20) imali zadatak da izjednače udaljenosti dva izvora zvuka, postavljena na horizontalnoj i vertikalnoj osi, na tri egocentrične udaljenosti. Sem toga, u drugom eksperimentu smo varirali pokrete glave prema izvoru zvuka (sa i bez) i raspršenje zvuka oko glave (sa ili bez kutijastog okvira oko glave). Rezultati pokazuju da su ispitanici uspeli da razlikuju udaljenosti izvora zvuka, ali da efekti pomeranja glave (proprioceptivna informacija) i raspršenja zvuka oko glave nisu dobijeni. Na kraju, rezultati ukazuju na razliku u proceni udaljenosti između dva pravca. Udaljenosti vertikalnog izvora zvuka su bile dosledno opažane kao veće nego fizički jednake horizontalne udaljenosti, što se poklapa sa nalazima prethodnih studija, povezanim sa procenama udaljenosti na osnovu vizuelnih ili proprioceptivnih informacija.

Ključne reči: anizotropija, opaženi prostor, slušni prostor, opažanje udaljenosti, akcija i opažanje

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Appendix A

Table A1

Average distances set to match standards in Experiment 1 (N = 16)

Standard axis	St. distance	*M*	*SD*	*SE*
horizontal	4m	4.01	1.13	0.28
	3m	3.99	1.02	0.26
	1m	2.22	0.98	0.25
vertical	4m	2.36	0.73	0.18
	3m	2.05	0.60	0.15
	1m	0.85	0.41	0.10

Table A2

Average distances set to match standards in Experiment 2 (N = 20)

Situation	*Standard axis*	St. distance	*M*	*SD*	*SE*
No frame, no head moving	horizontal	4m	3.91	1.26	0.28
		2.5m	3.43	1.16	0.26
		1m	3.70	1.68	0.38
	vertical	4m	1.85	0.65	0.14
		2.5m	1.63	0.53	0.12
		1m	1.43	0.47	0.10
No frame, with head moving	horizontal	4m	4.08	1.49	0.33
		2.5m	3.51	1.53	0.20
		1m	3.40	1.71	0.34
	vertical	4m	1.83	0.88	0.12
		2.5m	1.58	0.53	0.38
		1m	1.34	0.44	0.10
With frame, no head moving	horizontal	4m	3.83	1.65	0.37
		2.5m	3.61	1.45	0.22
		1m	3.32	1.55	0.32
	vertical	4m	2.00	1.00	0.17
		2.5m	1.67	0.76	0.35
		1m	1.55	0.64	0.14