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Auditory and visual localization accuracy in young children and adults

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ABSTRACT

Objective: This study aimed to measure and compare sound and light source localization ability in young children and adults who have normal hearing and normal/corrected vision in order to determine the extent to which age, type of stimuli, and stimulus order affects sound localization accuracy.
Methods: Two experiments were conducted. The first involved a group of adults only. The second involved a group of 30 children aged 3 to 5 years. Testing occurred in a sound-treated booth containing a semi-circular array of 15 loudspeakers set at 10° intervals from −70° to 70° azimuth. Each loudspeaker had a tiny light bulb and a small picture fastened underneath. Seven of the loudspeakers were used to randomly test sound and light source identification. The sound stimulus was the word "baseball". The light stimulus was a flashing of a light bulb triggered by the digital signal of the word "baseball". Each participant was asked to face 0° azimuth, and identify the location of the test stimulus upon presentation. Adults used a computer mouse to click on an icon; children responded by verbally naming or walking toward the picture underneath the corresponding loudspeaker or light. A mixed experimental design using repeated measures was used to determine the effect of age and stimulus type on localization accuracy in children and adults. A mixed experimental design was used to compare the effect of stimulus order (light first/last) and varying or fixed intensity sound on localization accuracy in children and adults.
Results: Localization accuracy was significantly better for light stimuli than sound stimuli for children and adults. Children, compared to adults, showed significantly greater localization errors for audition. Three-year-old children had significantly greater sound localization errors compared to 4- and 5-year olds. Adults performed better on the sound localization task when the light localization task occurred first.
Conclusions: Young children can understand and attend to localization tasks, but show poorer localization accuracy than adults in sound localization. This may be a reflection of differences in sensory modality development and/or central processes in young children, compared to adults.

1. Introduction

During the past decade research has shown a close functional relationship between auditory and visual spatial localization processes in animals and humans [1]. Spatial localization processes enable one to detect/localize objects or events that may or may not be very close [2]. Auditory spatial localization is thought to "complement" visual spatial localization in several important ways. First, compared to vision, the greater range of directional information from the auditory system allows one to assess events that might occur out-of-sight or from behind the head [2]. This attribute of the auditory system is critical for safety and survival, allowing one to locate a source of potential danger well in advance. Second, attentive and orientation movements of the eye, head, and body in response to a visual stimulus are dramatically enhanced by an auditory stimulus that occurs in the same location and these same visual orientation behaviors are suppressed by an auditory stimulus that is medially displaced 15–60° to the visual cue [3]. In mammals, visual and auditory spatial maps are in rough topographic relation with one another in the superior colliculus, a region of the central nervous system thought to mediate reflexive orientation behaviors [4–6]. Consequently, a spatially coincident multisensory stimulus located within the excitatory region of the receptive field of one modality will also fall within the excitatory region of the other modality, and the responses they evoke will enhance one another [3]. In real-life situations, the process of sound localization is usually accompanied by eye and head movements [7]. Orienting the head and eyes towards a sound

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source allows the auditory system to exploit binaural cues to improve listening in complex acoustic environments [8]; this in turn leads to bimodal integration of auditory and visual perceptual cues to further enhance localization [9–11]. Finally, recent evidence suggests that a large portion of central auditory processes is associated with spatial attention [12,13]. As such, spatial attention assists in orienting the subject towards the location of goal-directed events or objects in the presence of competing sources [12–14]. It is also possible that spatial attention develops throughout childhood starting primarily as stimuli-directed and becoming more goal-directed during adolescence and early adulthood [15].

A major difference between visual and auditory spatial processing is that the location of visual objects can be derived directly from the retinotopic organization of the visual system. When light enters the pupil of the eye it is focused onto a specific region of the retina (an extension of the white matter of the brain). The location of the rods and cones on the retina creates an instant image of the object or event signaling to the brain the exact spatial location of the image. In the retinal image of the world, objects and events are characterized in the simplest form: by a change in luminance or luminance direction and as such is a "first order attribute" [16]. Without further central processing the spatial location of a visual object can be immediately extracted from the retinal image [17]. As a result, visual spatial localization develops early and with precision. Visual first order attributes, such as spatial orientation to a single light source, reach adult values (less than 1° mean absolute error) by 40 weeks of age in human infants [18].

In contrast, the auditory system uses a different, more slowly developing mechanism to locate the origin of a sound source. In the auditory system, sound receptors (hair cells) in the cochlea *cannot* code spatial location via the tonotopic organization of the auditory system. Instead, hair cells by virtue of their location on the basilar membrane, encode only the frequency, amplitude, and duration of a sound. Therefore, sound spatial localization (unlike light spatial localization) is a second or third order approximation that is dependent entirely upon central auditory computation of inter-aural differences in sound level, arrival time, and spectrum. The mammalian auditory system requires much practice in early years to learn to localize to sound accurately. Consequently adult performance in localization of a single, azimuthal sound source is not reached until age 5 years or later in humans [19].

Localization ability is essential for safety and communication. For instance, one needs to be able to detect an approaching vehicle when crossing the street [19] or locate the source of a potentially dangerous situation [20] such as an approaching animal or a fire alarm. In the classroom setting, children need to be able to localize the specific talker – the teacher or another student who is answering a question – above other environmental noises such as chatter among the other students or air-conditioning units. The same applies when children are in the school cafeteria. Such environments are more difficult for children than for adults [21,22]. Knowing where to listen in such challenging environments improves speech intelligibility [23], thus further justifying the importance of maximizing localization abilities. The results of such studies as this current study could therefore contribute vital information regarding enhancing sound source localization capabilities in children.

Few localization accuracy studies involving young children exist currently. As a consequence, data regarding sound source localization abilities in young children are lacking [19,20,24]. Four localization accuracy studies, which involved normal hearing children and utilized similar methodology, were reviewed. None of these studies focused solely on localization accuracy in normal hearing children, but the data relevant to normal hearing children were extracted for comparison purposes in order to set a foundation for this current study.

A summary of the information extracted from the four studies is shown in Table 1. Van Deun et al. [19] examined localization accuracy in a total of 33 children who were 4, 5 and 6 years old; and 5 adults (mean age 24 yr). In this study the root-mean-square error (RMS error) was 10°, 6° and 4° respectively in children and 0° in adults. Litovsky and Godar [25] examined a total of 9 children between the ages of 4–5 years (mean age 5.14) and 10 adults (mean age 22 year). Mean RMS errors were obtained at 10.2° in children and 3.6° in adults. Grieco-Calub and Litovsky [26] examined 7 children who were 5 years old and obtained an RMS error of 18.3°. Lastly, Johnstone et al. [20] examined two groups of 12 children who were between the ages of 6–9 year and 10–14 year. RMS error scores in this study was 7.04° for the 6–9 year olds and 2.57° for the 10–14 year olds. None of these studies examined localization accuracy in 3 year olds. Each of the aforementioned studies employed similar methods and the stimuli used were ecologically relevant. All of the studies used stimuli with sound intensity levels randomly varied (with a rove) on a trial-by-trial basis.

The overall performance in children in each of these studies shows an improvement in localization accuracy with age but there is some variability. While the skills appear to be emerging, they are not yet fully mature. Development, task comprehension, "attention" and "testing conditions" were among the possible explanations for the differences in localization accuracy with age [19]. The present study aimed to determine which of these explanations best describes the differences in localization accuracy with age.

This study investigated localization accuracy in two sensory modalities: vision and audition. The intent was to separate non-auditory attention and task comprehension factors from the developmental central auditory processing factors that may affect sound localization accuracy in young children (and adults) by comparing performance on a light localization task to a sound localization task. Two experiments were performed. The first experiment was conducted with a group of 12 adults who were between the ages of 23 and 31 years. The second experiment was conducted with a group of 30 children who were between the ages of 3 and 5 years. The stimuli and method of testing was exactly the

Table 1
Results from four studies involving normal hearing children and adults. The number of participants, their age range, the type of stimuli/set up used, and the average root-mean-square error (RMS error) in degrees are shown for comparison.

Study	No subjects	Age	Avg RMS error	Stimuli/set up
Van Deun et al. [19]	33 children 5 adults	4-, 5-, 6-yo (N=21, 6, 6) Avg age 24 yr	10°, 6°, 4° 0°	• Broadband bell ring (1 s) • 9 loudspeakers 15° apart
Litovsky and Godar [25]	9 children 10 adults	4–5-yo Avg age 22 yr	10.2° 3.6°	• 3-pink-noise-burst • 15 loudspeakers 10° apart
Grieco-Calub and Litovsky [26]	7 children	5-yo	18.3°	• Spondaic word "baseball" • 15 loudspeakers 10° apart
Johnstone et al. [20]	12 children	6–9-yo (N=6) 10 to 14-yo (N=6)	7.04° 2.57°	• Spondaic word "baseball" • 15 loudspeakers 10° apart