Stimulus-onset-asynchrony as the main cue in temporal order judgment

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Background

Elderly individuals often complain of difficulties in understanding speech, especially when heard against a background noise or when there are multiple speakers. One of the hypothesized reasons for these complaints is the reported age-related decline in auditory temporal processing (Schneider & Pichora-Fuller, 2001; Schneider, Daneman, & Pichora-Fuller, 2002). The rationale underlying this hypothesis is that the appropriate use of speech cues relies on several types of auditory temporal resolution, which research has shown is age-related (Gordon-Salant, 2005; Pichora-Fuller & Souza, 2003; Schneider & Pichora-Fuller, 2001; Schneider *et al*., 2002). A large number of studies have compared young and elderly subjects on a variety of auditory temporal resolution tasks and reported poorer resolution by the elderly as compared to the younger individuals. Elderly adults perform poorer than younger adults in gap detection tasks and need longer silent intervals to identify the presence of a gap when the marker signal is 250 msec or shorter (Fink, Churan, & Wittmann, 2005; Fitzgibbons & Gordon-Salant, 2001; Grose, Hall, & Buss, 2006; Lister & Roberts, 2005; Lister & Tarver, 2004; Roberts & Lister, 2004; Schneider & Hamstra, 1999; Schneider, Speranza, & Pichora-Fuller, 1998; Snell, 1997; Snell & Frisina, 2000; Snell, Mapes, Hickman, & Frisina, 2002; Strouse, Ashmead, Ohde, & Grantham, 1998). Other studies have reported that older subjects have difficulty in correctly identifying temporal order in a tonal sequence (Fitzgibbons & Gordon-Salant, 1998; Gordon-Salant & Fitzgibons, 1999). Furthermore, a number of studies have reported that older individuals require larger differences in duration between two tones in order to detect a difference (Abel and Hay, 1996; Fitzgibbons & Gordon-Salant, 1994, 1995, 1996). Similar results, indicating poorer discrimination by the elderly, were found when comparing older and younger adults on binaural temporal processing tasks such as locating a tone in the front-back plane (Abel and Hay, 1996), tone localization (Abel, Giguère, Consoli, & Papsin, 2000) and click lateralization (Babkoff, Muchnik, Ben-David, Furst, Even-Zohar, & Hildesheimer, 2002; Strouse *et al*., 1998). Traditionally, most of the studies of age-related decline in temporal resolution have used the gap detection task, in which the duration of the silent interval within a tone is manipulated until the participant (young or elderly adult) is able to detect a non-continuous tone (Ezzatian , Pichora-Fuller , & Schneider, 2010; Fink *et al*., 2005; Fitzgibbons & Gordon-Salant, 2001; Grose, Hall, & Buss, 2006; Lister & Roberts, 2005; Lister & Tarver, 2004; Roberts & Lister, 2004). Other researchers have used the duration discrimination task, in which the duration of a tone is manipulated and changes in duration are detected (Abel and Hay, 1996; Gordon-Salant & Fitzgibbons, 1999; Fitzgibbons & Gordon-Salant, 1994, 1995). Taken together, the results of these studies have shown that the elderly require larger gaps and longer tone durations than the young adults to attain the same levels of discrimination. In general, the common feature in these and other tasks that were used to measure temporal resolution is that the discrimination may be accomplished by one ear only. Consequently, the temporal cue may not necessarily be central, although some evidence points to the involvement of higher order processes in the temporal range associated with gap detection (Ross, Schneider, Snyder, & Alain, 2010). In our studies we have used a different method for studying auditory temporal resolution among the elderly, and other populations of interest, the dichotic temporal order judgment (TOJ) task. This task involves the identification of the order of two sounds that are equal in frequency and intensity (Ben-Artzi, Fostick & Babkoff, 2005; Babkoff, Zukerman, Fostick, & Ben-Artzi, 2005). The tones are delivered to each ear and are separated by a range of inter-stimulus intervals (ISI). The listener is required to judge the order of presentation of the tones to the two ears (left-right or right-left). This paradigm eliminates the possible use of spectral cues for order judgment and depends on central mechanism(s) for the temporal resolution of information received from both ears. The elimination of spectral cues reinforces the conclusion that the judgment is based on the temporal domain. Two temporal parameters are manipulated when a tone is presented to each ear separated by an inter-stimulus interval: i) the silent interval (i.e., the inter-stimulus interval); and ii) the stimulus onset asynchrony (SOA) (i.e., the time from the onset of the tone to the first ear and the onset of the tone to the second ear. The contribution of each of the two parameters to performance level can be studied by manipulating tone duration, while keeping ISI constant. The main purpose of the current study was to identify the temporal parameter that explains most of the variance associated with the judgment of temporal order.

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Methods

Participants

Twenty-eight young adults (mean age = 25 years, 64% females). All were native Hebrew speakers and had normal hearing.

Tasks and stimuli

Dichotic

Two 1kHz pure tones were delivered to each ear, separated by a range of temporal intervals. The participants were required to report the order of the tones (right-left, or left-right). Tone durations were 5, 10, 20, 30 or 40 msec. Tones were separated by ISIs of 5, 10, 15, 30, 60, 90, 120, or 240 msec. Tone durations and ISIs were randomly presented and were repeated 16 times, creating 1,280 pairs (5 durations X 8 ISIs X 2 orders X 16 repetitions). After every 32 trials subjects received a short recess. Percent correct was recorded for each trial.

To familiarize the participants with the tones, participants were first presented with five examples of the tone presented to one ear, then five examples of the tone to the other ear. Training then proceeded with 24 trials of single stimuli, 12 stimuli for each ear, randomly intermixed. On each trial, the participant was required to identify the ear to which the tone was presented by pressing the correct key. Visual feedback (*right/wrong*) was provided for each response. In the last stage of stimulus familiarization, the stimuli were presented in random order, with no feedback, until the participant met the criterion of 20 correct responses in 24 consecutive trials. Testing was programmed to be terminated for participants who did not meet the criterion within 30 trials, but no such cases were present. After being successful in the familiarization phase, participants were presented with pairs of tones in two possible orders: left-right, right-left, with an ISI of 240 and 60 msec. Each ISI was repeated 16 times, randomly intermixed, resulting in 64 tone pairs. Participants were to identify which order the tones were presented by pressing the key for the location of the first tone followed by the key for the location of the second tone. Visual feedback (*right/wrong*) was provided for each response during training, but no feedback was provided during the experimental session

Results

Figure 1 shows dichotic TOJ percent correct for each of the five stimulus durations, plotted as a function of ISI. Repeated measures analysis of variance (ANOVA) revealed main effects for both duration and ISI ($F_{(4,108)}$=61.86, P<.001 and $F_{(7,189)}$=121.06, P<0.001, respectively), with the left most curve representing accuracy as a function of ISI for the stimulus duration of 40 msec and the right most curve representing the 5-msec stimulus duration. Figure 2 presents mean TOJ threshold for each stimulus duration. Repeated measures ANOVA showed significant effect for stimulus duration ($F_{(4,72)}$=44.55, P<.001).

The R^2 for predicting dichotic TOJ performance by ISI for different tone durations is .88 (Figure 3). Figure 4 shows the dichotic TOJ accuracy plotted as a function of SOA. In contrast to predicting TOJ performance by ISI, 97 % of the variance (R^2=.97) is accounted for when dichotic TOJ is plotted as a function of SOA. Based on Fisher r-to-z transformation, the difference between the predicting value of ISI and the SOA is significant (z=–1.98, P<.05).

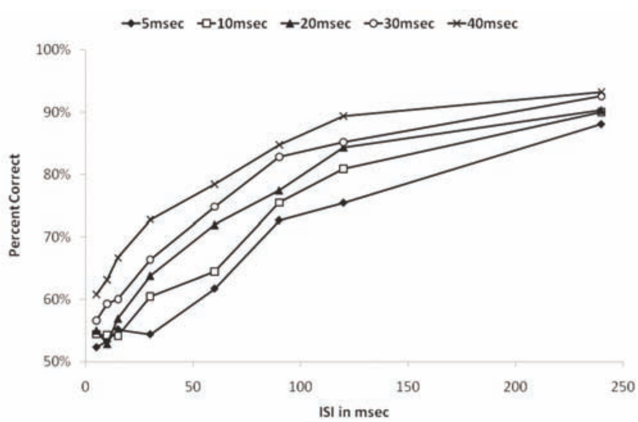

Figure 1. Dichotic temporal order judgment percent correct by ISI for five stimulus durations.

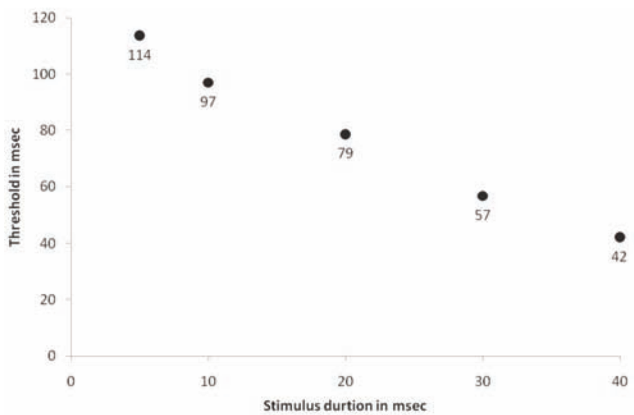

Figure 2. Dichotic temporal order judgment thresholds for five stimulus durations.

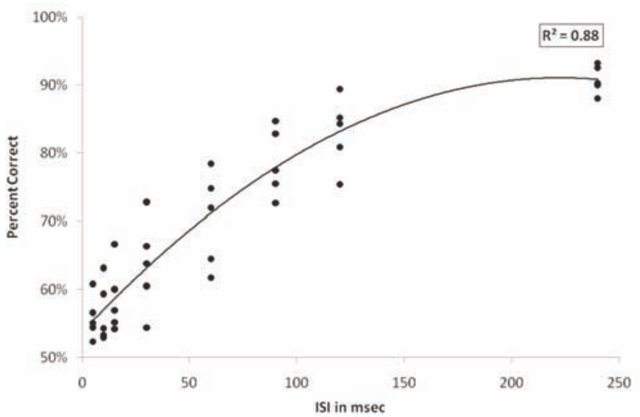

Figure 3. Predicting performance of dichotic temporal order judgment by inter-stimulus intervals for five tone durations.

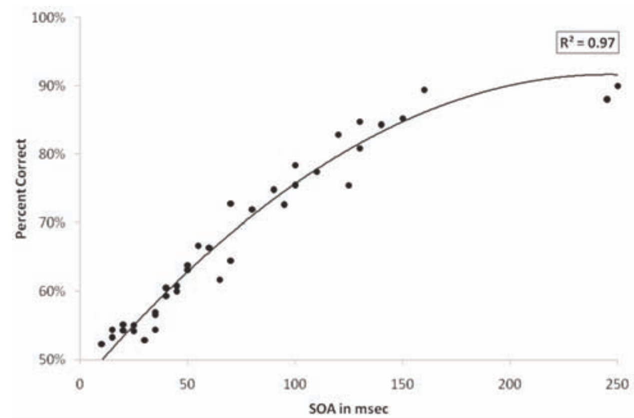

Figure 4. Predicting performance of dichotic temporal order judgment by stimulus onset asynchrony.

Discussion

The data of the current study show that the parameter that explains most of the variance of dichotic TOJ performance level is the SOA, i.e., the time from the onset of the tone to one ear and the onset of the tone to the other ear. When performance level is plotted as a function of ISI for the different durations, ISI explains 88% of the variance. However, the alternative data plotting of performance level by SOA collapsed over the 5 durations, ranging from 5-40 msec, produces a function that explains 97% of the variance. The significant increase in the amount of explained variance when the data are plotted as a function of onset-to-onset asynchrony provides the more parsimonious explanation and evidence that SOA is the temporal parameter of interest when required to judge the order of arrival of stimuli to the two ears. The dichotic temporal order judgment paradigm thus can provide a very well controlled instrument for measuring auditory temporal resolution and comparing various groups suspected of deficit in this function with normal controls. The temporal resolution thresholds found in the current study were in the range of 42 to 114 msec. This range is similar to the time range of phonemes and other cues for speech perception, like formant transition and VOT (Belin, Zilbovicius, Crozier, Thivard, Fontaine, Masure, *et al*., 1998; Nooteboom & Doodeman, 1980; Ohde & Ochs, 1996). Along this line, several studies, using the dichotic TOJ task, have shown the paradigm to be associated with other aspects of language, such as reading and speech (Ben-Artzi *et al*., 2005; von Steinbuchel, 1998). Taken together, the current findings when using a paradigm that: i) depends solely on temporal cues; ii) is dependent on central mechanism(s) (since the task requires the receipt, coding and use of information from each of the two ears for the judgment of order); and iii) whose temporal range of SOAs conform to temporal ranges of certain components of speech, the dichotic TOJ paradigm may be considered an appropriate tool for studying and screening auditory temporal processing among the elderly.

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