

SPATIAL TEMPORAL ORDER JUDGMENT (TOJ), A META-ANALYSIS: STABILITY ACROSS STIMULUS FREQUENCY, DURATION, LOUDNESS, AND METHODOLOGY.

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Over the past decade, spatial TOJ has become a fairly popular measure of auditory temporal processing and has been used to compare a variety of populations. Researchers have used a wide range of stimulus parameters in determining TOJ threshold. The present meta-analysis includes 14 studies by the present authors over a decade (N=312). The studies analyzed used different stimulus frequencies ranging from 300-1,500Hz, stimulus durations ranging from 3-40msec, click stimuli, and different methodologies (constant stimuli and adaptive procedures). TOJ accuracy increases monotonically with stimulus-onset asynchrony (SOA), regardless of stimulus duration, frequency, or methodology ($r^2=.92$). The estimated population mean threshold over all studies equals 67msec, $SD=26.5msec$ ($COV=.40$) yield a fairly stable estimate of SOA spatial TOJ for young normal adults. These estimated values can then be used as baseline measures against which to compare other populations.

Temporal order judgment (TOJ) refers to the ability to perceive the temporal order of at least two stimuli. The study of the human capacity to judge the temporal order of two stimuli became popular with the classic work of Hirsh (1959) and Hirsh and Sherrick (1961) and recently has become a popular tool for measuring temporal processing in a variety of populations, among whom are: 1) aphasic patients (von Steinbuchel et al., 1999; Fink et al., 2006); 2) dyslexic readers (Ben-Artzi et al., 2005; Fostick et al., 2008; Fostick and Zukerman, 2010; Reed, 1989; Tallal, 1980); 3) sleep deprived young adults (Babkoff et al., 2005; Fostick and Zukerman, 2010); and 4) elderly adults (Fink et al., 2005; Fitzgibbons and Gordon-Salant, 1998; Fostick, Ben-Artzi, Babkoff, 2007; Fostick and Zukerman, 2010; Szymaszek et al., 2006, 2009). The aim of the current study was to test the stability of spatial TOJ, in which the tones to be judged differ in the ear they are presented to, across different stimulus duration, frequency, loudness, and methodology.

Spatial TOJ

Pairs of pure tones were presented dichotically (one to each ear). Participants were required to reproduce the order in which they heard the tones (left ear first then right ear tone, or the reverse order). In all experiments, each ISI value was repeated 16 times, and the participants received a small recess after every 32 trials. Experimentation followed training in which the participants was familiarized with the stimuli used in the study, and with the adequate response key for each stimuli (For more detailed description of the paradigm and its training stages see Ben Artzi et al., 2005; Babkoff et al., 2005).

Experiment 1: Duration

Spatial TOJ with four different stimulus durations (10, 20, 30, and 40 msec) was performed by 80 undergraduate students (20 participants for each duration). Tones were either both 1kHz or 1.5 kHz, and were presented at 60 dB SPL. ISI values for all durations were 5, 10, 15, 30,

60, 90, 120, and 240 msec, resulting in a total of 512 trials (2 tone orders x 2 frequencies x 8 ISIs x 16).

Results

Spatial TOJ thresholds expressed as separation between offset of the first tone to onset of the second tone (inter-stimulus interval, ISI) are plotted for the 80 participants as a function of tone duration (Figure 1). A linear function with a slope of -1.1 significantly accounts for between 13.6% of the variance. These results imply that with an error of 10%, an increase in tone duration results in an equal decrease in spatial TOJ threshold when expressed as the inter-stimulus interval (ISI). Therefore, if the threshold evaluation would incorporate tone duration, i.e., would include the duration of the tone, and be expressed as stimulus onset-to-onset time (SOA), threshold would be indifferent to changes in tone duration. This can be seen in Figure 2, when spatial TOJ threshold data include tone duration (SOA) and are plotted as a function of tone duration. The resulting line appears parallel to the horizontal axis, indicating almost complete independence of the threshold from tone duration.

Experiment 2: Frequency

Spatial TOJ was performed by 87 undergraduate students. For each pair, both tones were either 300Hz (N=13), 600Hz (N=13), 1kHz (N=30), 1.5kHz (N=19), or Gaussian Noise (GN) (N=12). Stimulus duration, level, and ISI values for each frequency are described in Table 1.

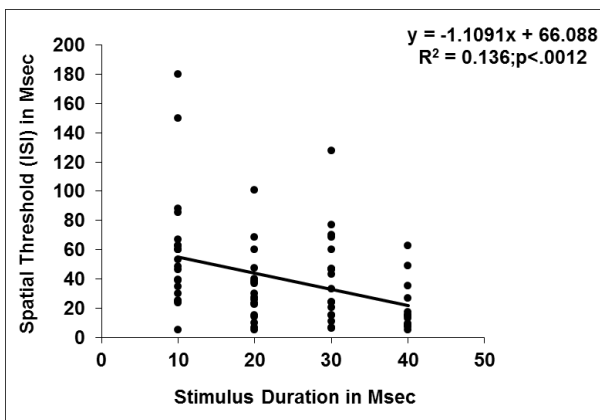


Figure 1. Spatial TOJ ISI threshold by stimulus duration

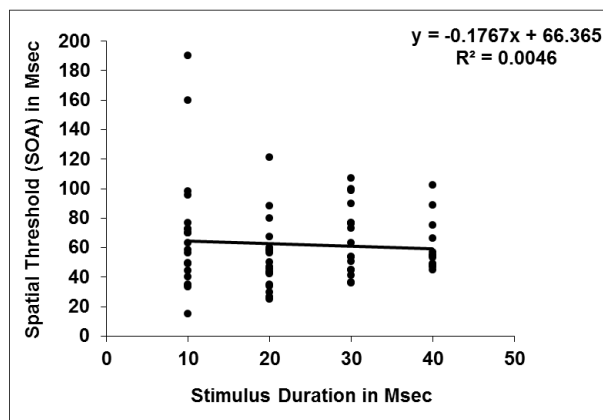


Figure 2. Spatial TOJ SOA threshold by stimulus duration

Table 1. Stimulus duration, level, and ISI values for spatial TOJ in four frequencies

	Stimulus duration	Stimulus level	ISI value
300Hz	15 msec	60 dB SPL	8 - 400 msec
600Hz	15 msec	60 dB SPL	8 - 400 msec
1kHz	15 msec	40 dB SL	5 - 240 msec
1.5kHz	10 msec	60 dB SPL	5 - 400 msec
GN	3, 6, 12, 24 msec	40 dB SL (Equal loudness ¹)	5 - 240 msec

¹see Experiment 3

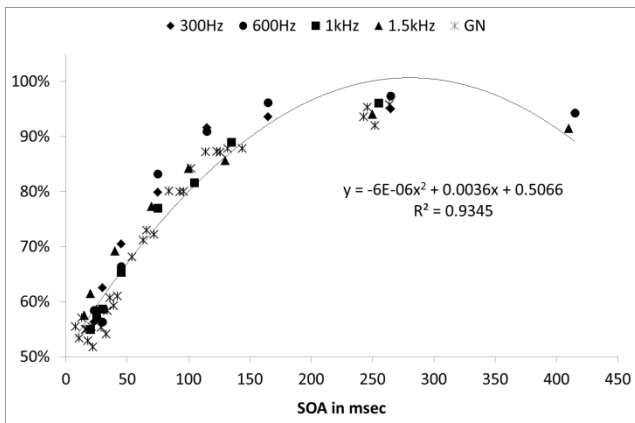


Figure 3. spatial TOJ accuracy by SOA for four frequencies

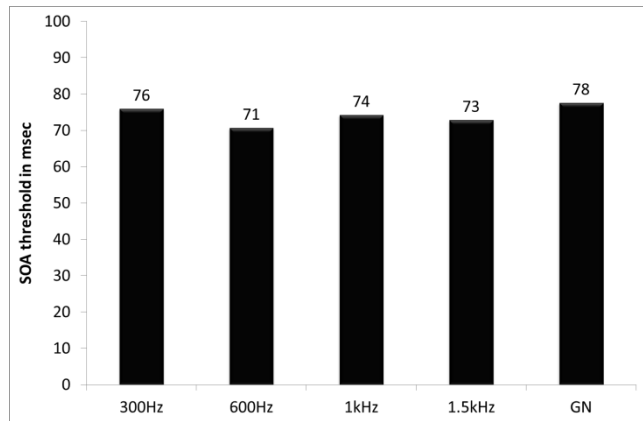


Figure 4. Spatial TOJ SOA threshold for four frequencies

Results

Spatial TOJ accuracy by SOA and thresholds for the different frequencies are presented in Figure 3 and 4. One-way ANOVA revealed no difference between SOA thresholds of the different frequencies ($F_{(4,75)}=.102$, $p>.05$). A second-order polynomial fit obtained by accuracy data from all frequencies predicted 93.5% of the variance.

Experiment 3: Loudness

Spatial TOJ was performed by 68 undergraduate students for three different sound levels: 60 dB SPL (N=26); 40 dB SL (N=30); and equal loudness of 40 dB SL for all stimuli (N=12). Stimulus duration for the 60 dB SPL and the 40 dB SL conditions was 15 msec. For the equal loudness condition, stimulus duration was 3, 6, 12, and 24 msec. Therefore, this condition was preceded by an equal loudness test in which participants evaluated the loudness of each stimulus duration. Based on this test, different durations were delivered for each participant in equal loudness of 40 dB SL.

Results

Spatial TOJ accuracy by SOA and thresholds for different stimulus loudness are presented in Figure 5 and 6. One-way ANOVA revealed no difference between SOA

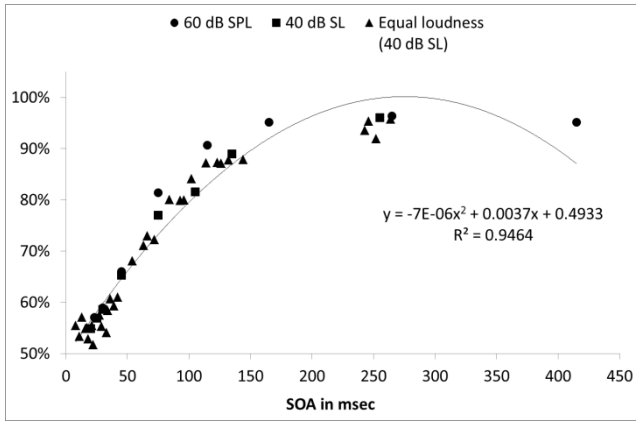


Figure 5. Spatial TOJ accuracy by SOA for different loudness

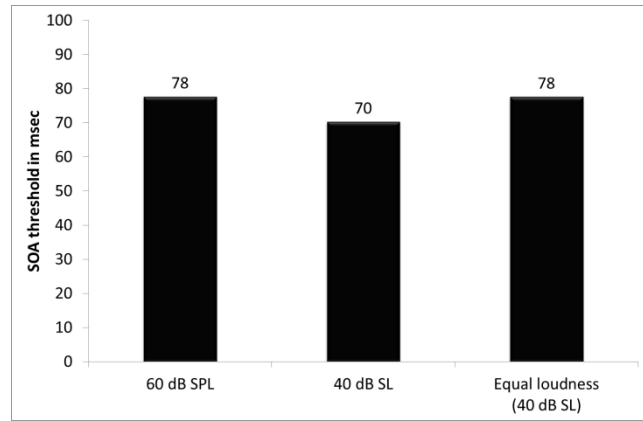


Figure 7. Spatial TOJ SOA threshold for different loudness

thresholds of different stimulus loudness ($F_{(2,64)}=.557, p>.05$). A second-order polynomial fit obtained by accuracy data from all stimulus loudness predicted 93.1% of the variance.

Experiment 4: Summary of current data

Spatial TOJ was performed by 312 undergraduate students in 14 studies with different stimulus duration, level, ISI, and method. Table 2 summarizes the studies different parameters.

Table 2. Parameters of 14 spatial TOJ studies

Year	N	Stimulus Duration	ISI	Stimulus level	SOA threshold (SD)
2000a	26	15 msec	8 – 400 msec	60 dB SPL	78 (28) msec
2000b	6	25 msec	8 – 400 msec	60 dB SPL	62 (21) msec
2001a	20	10 msec	5 – 240 msec	60 dB SPL	57 (16) msec
2001b	20	20 msec	5 – 240 msec	60 dB SPL	53 (22) msec
2001c	20	30 msec	5 – 240 msec	60 dB SPL	66 (22) msec
2001d	20	40 msec	5 – 240 msec	60 dB SPL	60 (21) msec
2002	28	10 – 40 msec	5 – 240 msec	60 dB SPL	81 (21) msec
2003a	19	10 msec	5 – 400 msec	40 dB SL	72 (34) msec
2003b	23	15 msec	5 – 240 msec	60 dB SPL	93 (28) msec
2004a	30	15 msec	5 – 240 msec	40 dB SL	72 (23) msec
2004b	64	15 msec	5 – 240 msec	40 dB SL	76 (28) msec
2004c	12	3 – 24 msec	5 – 240 msec	40 dB SL ¹	78 (29) msec
2011a	17	15 msec	5 – 150 msec	40 dB SL	58 (24) msec
2011b	7	15 msec	²	40 dB SL	62 (21) msec

¹Equal loudness; ²Adaptive staircase procedure, longest ISI = 150 msec

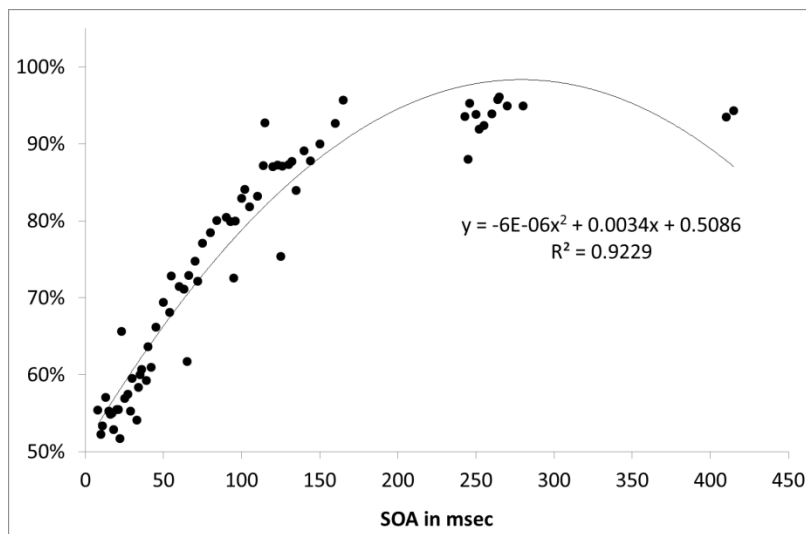


Figure 7. Spatial TOJ mean accuracy by SOA obtained from 13 studies with 305 participants

Results

Figure 7 presents mean spatial TOJ accuracy by SOA. SOA predicted 93% of the variance in accuracy, regardless of stimulus duration, level, or ISI. Mean SOA thresholds for each study are presented in Table 2. Overall Mean SOA threshold for the 312 participants in the 14 studies was 67 msec (SD = 29 msec). The COV= 0.43. COV represents the ratio of the standard deviation to the mean of a distribution. It can be a useful statistic for comparing the degree of variation from one data series (e.g., young normal controls) to another (e.g., dyslexic readers) even when the means are expected to differ.

Discussion

The current study summarizes data obtained from 14 studies and include 312 healthy young participants. The data showed that (1) stimulus duration combined with the ISI (stimulus-onset asynchrony, SOA) are the main predictor for TOJ performance; (2) spatial TOJ increase monotonically with SOA, regardless of stimulus frequency and loudness; and (3) spatial TOJ thresholds was stable across different frequencies and loudness. These results suggest that spatial TOJ is a stable measure across different parameters and methodologies, and the values obtained can be compared across different sub-populations in order to assess their TOJ ability.

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