

## REACTION TIME (RT) AS A DEPENDENT VARIABLE FOR SPATIAL TEMPORAL ORDER JUDGMENT (TOJ)

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*We have reported previously that the speed of response (1/RT) of spatial temporal order judgments (TOJ) increases in parallel with the increases in accuracy as a function of increasing inter-stimulus interval (ISI). In the current study we expand the study of parallel changes in RT with accuracy to include the effect of stimulus frequency and stimulus onset asynchrony (SOA). The RT-accuracy parallelism is also found when comparing spatial TOJ to spectral TOJ, when measured either by constant stimuli or by an adaptive staircase procedure. The parallelism between RT and accuracy becomes even more interesting when we compared a population of adult dyslexic readers, showing ISI\*group interaction (i.e., the difference between groups only becomes apparent as ISI = 30 msec or longer) when measured by accuracy, but shows parallel performance when measured by RT, with dyslexic readers yielding longer RTs across all ISIs.*

Temporal order judgment (TOJ) is the ability to correctly perceive the order of at least two stimuli. Studies of TOJ initially focused on the human capacity to judge the order of two tones and then expanded to compare this ability among various sub-populations, such as: 1) aphasic patients (von Steinbuchel, Wittmann, Strasburger, & Szlag, 1999; Fink et al., 2006); 2) dyslexic readers (Ben-Artzi et al., 2005; Fostick, Bar-El, Ben-Artzi, Babkoff, 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). In general, findings from all these studies indicate that individuals in the above mentioned experimental groups need larger separations between the stimuli in order to correctly perceive their order.

The dependent measure used to measure TOJ is the minimal time (threshold) between the two stimuli needed to correctly judge their order. This time interval is either measured from the offset of the first stimulus to the onset of the second (inter-stimulus interval, ISI), or from the onset of the first stimulus to the onset of the second (stimulus-onset asynchrony, SOA). In the present paper we propose the use of reaction time as an additional dependent variable to assess the ability of individuals to judge temporal order (TOJ). Reaction time (RT), or response latency, is the time between the presentation of a stimulus to the response. This measure, although very popular as a dependent variable in the study of human behavior, is not usually reported when studying TOJ. In an attempt to introduce the use of RT in TOJ, we first present some characteristics of reaction or response times in TOJ (Experiments 1 to 4), and then present an example to its use in the study of other sub-populations, by comparing dyslexic and normal readers, using both TOJ ISI and RT thresholds (Experiment 5).

## Experiment 1: The effect of SOA

Twenty-eight undergraduate students (mean age = 22 years, 74% females) performed the spatial TOJ task. Pairs of 15 msec pure 1 kHz tones were presented at 60 dB SPL dichotically (one to each ear). Tone durations were 5, 10, 20, 30 or 40 msec and were presented with an ISI of 5, 10, 15, 30, 60, 90, 120 or 240 msec, yielding SOA values of 10-280 msec. Each ISI value was repeated 16 times, resulting in a total of 1,280 trials (2 stimulus orders of presentation (right ear first/left ear first) x 8 ISIs x 5 stimulus durations x 16). After every 32 trials, participants received a short recess. Participants were required to reproduce the order in which they heard the tones (left ear first, or right ear first). For each response, accuracy and reaction time were recorded. Reaction time is measured from the time elapsed from the offset of the second stimulus to the participant's pressing the first response key. Experimentation followed training in which the participants were familiarized with the stimuli used in the study, and with the appropriate response key for each stimulus order of presentation (For a more detailed description of the paradigm and the training procedure see Ben Artzi et al., 2005; Babkoff, Zukerman, Fostick & Ben-Artzi, 2005).

## Results

The predicting value of SOA for accuracy and for RT was measured using a second order polynomial curve (Figure 1). Plotting accuracy and RT as a function of SOA predicted 97% of the variance for the group average accuracy and RT data. A Fisher r-to-z transformation revealed no difference between the predicting value of the second order polynomial for accuracy and for RT ( $z = -.11$ ,  $p > .05$ ).

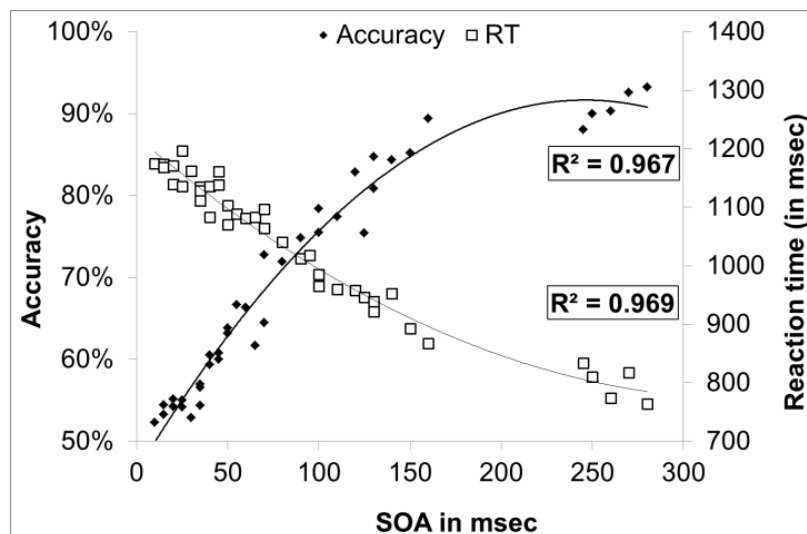


Figure 1. Accuracy and RT by SOA for spatial TOJ

## Experiment 2: The effect of frequency

Twenty undergraduate students (mean age = 23 years, 50% females) performed the spatial TOJ paradigm, similar to the task described in Experiment 1. Tone duration was 10 msec, and tone intensity was 60 dB SPL. ISI values were 5, 10, 15, 30, 60, 90, 120, and 240 msec. Both members of the tone pairs were either 1 kHz or 1.5 kHz. Each ISI value was repeated 16 times, resulting in a total of 512 trials (8 ISIs x 2 stimulus orders of presentation (right ear

first/left ear first) x 2 frequencies x 16 trials). After every 32 trials, participants received a short recess.

## Results

Spatial TOJ accuracy and RT by SOA for 1 and 1.5 kHz are presented in Figures 2 and 3. The data for accuracy and RT by ISI were analyzed separately for each frequency. Two separate Repeated Measures ANOVAs with ISI and frequency as within variables, were performed on the accuracy and RT data and indicated significant effect for ISI ( $F_{(7,133)}=108.16$ ,  $p<.001$  for accuracy and  $F_{(7,133)}=30.16$ ,  $p<.001$  for RT), but not for frequency ( $F_{(1,19)}=1.97$ ,  $p>.05$  for accuracy and  $F_{(1,19)}=.72$ ,  $p>.05$  for RT), and no ISI x frequency interaction, both for accuracy ( $F_{(7,133)}=.75$ ,  $p<.001$ ) and for RT ( $F_{(7,133)}=.32$ ,  $p<.001$ ).

### Experiment 3: The effect of method of measurement

Seventeen female undergraduate students (age 21 to 24) were screened for normal hearing and performed the spatial TOJ task, in the method of constant stimuli (see Experiment 1) and in adaptive staircase procedure. Tone duration was 15 msec. Tones were presented dichotically at 40 dB HL. In the constant stimulus version of the task, tones were presented with an ISI of 5, 15, 30, 60, 90, and 150 msec. Each ISI value was repeated 16 times, resulting in 192 trials (2 stimulus orders of presentation (right ear first/left ear first) x 6 ISIs x 16 trials), presented randomly with a short recess after every 32 trails. ISI threshold was

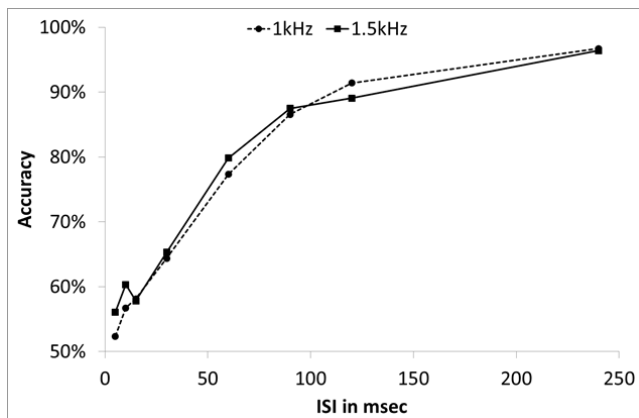


Figure 2. Spatial TOJ accuracy by SOA for 1 and 1.5 kHz

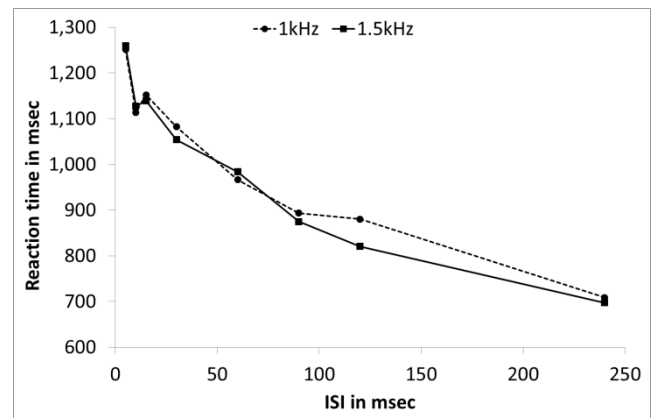


Figure 3. Spatial TOJ accuracy by SOA for 1 and 1.5 kHz

calculated using a 2nd order polynomial curve for accuracy plotted as a function of ISI. The ISI value that corresponded to 75% correct responses was considered the TOJ ISI threshold. TOJ RT threshold was also calculated by fitting a 2nd order polynomial curve to RT plotted as a function of ISI. RT threshold was defined as the RT value corresponding to the TOJ ISI

threshold, determined as described previously. For example, if a participant's ISI threshold was assessed to be 60 msec, then RT threshold was the RT corresponding to the ISI=60 msec. In the adaptive staircase procedure, tones were presented in a random order using a two alternative forced choice 2-down-1-up adaptive staircase procedure, with an initial ISI=150 msec. The experiment was terminated after 10 reversals, and ISI threshold was calculated as the average of the last eight reversals. RT threshold was the average of RT values of the same last eight reversals. Half of the participants performed the method of constant stimuli first, and the other half performed the adaptive staircase procedure first.

## Results

RT and ISI threshold data from the method of constant stimuli and from the adaptive staircase procedure are shown in Table 1. Two separate paired t-tests indicated no significant differences between thresholds calculated by ISI or by RT (Table 1).

### Experiment 4: The effect of population (dyslexic vs. normal readers)

Fifty dyslexic readers (mean age = 26, 36% females) and 47 normal readers (mean age = 24, 38% females) who were screened for normal hearing performed the spatial TOJ task using the method of constant stimuli, as described in Experiment 1. Stimulus duration was 15 msec. Tones were presented at 40 dB SL. Threshold calculation followed the same procedure as described in Experiment 3.

## Results

The results shown in Table 2 indicate that TOJ thresholds measured as the ISI necessary for 75% accuracy are significantly longer for adult dyslexic readers than for normal adult readers. However, if TOJ threshold is measured as the RT corresponding to the ISI necessary for 75% accuracy, there is no significant difference between the dyslexic readers and the normal adult readers.

Table1. ISI and RT spatial TOJ threshold for method of constant stimuli and adaptive staircase procedure

	Method of constant stimuli		Adaptive staircase procedure		t
	M	SD	M	SD	
RT threshold	780.14	156.05	778.55	276.33	-.026
ISI threshold	43.47	24.45	44.33	22.97	.186

Table 2. ISI and RT spatial TOJ threshold for dyslexic and normal readers

	Dyslexic readers		Normal readers		t
	M	SD	M	SD	
RT threshold	896.18	322.51	851.02	321.28	.51
ISI threshold	121.88	78.68	78.31	59.57	-3.04**

\*\*p<.01

## Discussion

In the present paper we introduced the use of RT as an additional variable for measuring the ability to correctly perceive spatial TOJ. We compared accuracy as a dependent variable with RT as a dependent variable and noted that both variables plot as a quadratic function of stimulus onset asynchrony (SOA) with almost all of the variance accounted for. In a second experiment, we compared spatial TOJ for two tone frequencies, 1kHz and 1.5 kHz and noted that for both dependent variables, accuracy and RT plotted as a function of ISI, the curves overlap completely, indicating that both variables reflect the same mechanisms of spatial temporal judgments. We also noted that different methodologies of measurement yield the same thresholds whether measured by accuracy or by RT. These findings suggest that RT is an equivalent measure to accuracy and RT threshold corresponds to ISI threshold.

Moreover, in an attempt to examine the use of RT as a measure, we compared both RT and ISI thresholds among dyslexic and normal readers. The results showed that although RT and ISI thresholds were similar when measured on normal controls, the comparison between dyslexic and normal readers revealed a difference between these measures. While significant difference was found in ISI threshold between dyslexic and normal readers, no such difference was found in RT. The difference between dyslexic and normal readers in ISI threshold has been reported earlier in the literature (Ben-Artzi et al., 2005; Fostick et al., 2008; Fostick and Zukerman, 2010), but RT thresholds have never been compared in the two populations.

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