Supplementary material

Temporal information can influence spatial localization

Femke Maij, Eli Brenner and Jeroen B.J. Smeets

S1. Saccade parameters

The main experiment consisted of five parts, with three or four participants for each part. In order to determine whether the saccades were influenced by the tones, we determined the median saccade duration, peak velocity, latency and amplitude for each participant, part and condition. The values in table 1S are averages of these median values across participants (mean ± standard error). None of the parameters showed any dependency on the timing of the tone. We identified saccades by the tangential velocity exceeding 35°/s. Note that saccade latency differences between conditions within a part are smaller than between the same condition in different parts and much smaller than those between directions (shown for part 2 in figure 4 of the main article).

Condition	part	No tone	-202 ms	-152 ms	-98 ms	-62 ms	-46 ms	-26 ms	-4 ms	42 ms	143 ms
Number of participants	1					4				4	
	2	3				3			3	3	
	3		1	4	4	4			4		
	4					3				3	3
	5					3	3	3	3		
Saccade duration (ms)	1					32±3				33±4	
	2	33±3				33±2			33±1	33±2	
	3		32	33±2	33±3	33±3			34±2		
	4					31±1				33±2	32±2
	5					31±1	31±1	31±1	31±1		
Saccade peak velocity (°/s)	1					370±52				366±49	
	2	327±14				329±12			331±17	329±14	
	3		347	355±24	353±24	350±27			351±29		
	4					359±45				350±35	357±40
	5					373±25	363±20	371±18	369±23		
Saccade latency (ms)	1					179±13				177±12	
	2	186±12				187±8			187±10	182±13	
	3		188	181±7	184±9	185±11			184±9		
	4					178±4				178±1	174±4
	5					184±15	182±14	183±17	180±16		
Saccade amplitude (°)	1					6.9±0.3				6.9±0.3	
	2	6.2±0.3				6.2±0.3			6.2±0.4	6.2±0.4	
	3		6.3	6.7±0.4	6.7±0.3	6.7±0.3			6.7±0.3		
	4					6.3±0.9				6.3±0.6	6.5±0.6
	5					6.8±0.4	6.7±0.4	6.8±0.3	6.7±0.5		

Table 1S. Saccade parameters for each part and condition.

S2. Temporal shift

x	=	*indicated position*
k	=	*trial number*
f	=	*flash location*
i	=	*condition number*
i'	=	*common conditions*
o	=	*participant (observer)*
p	=	*part*
tf	=	*time of flash relative to saccade onset*
t	=	*time of tone relative to time of flash*
Δ_{iop}	=	*single temporal shift*
Δ	=	*set of temporal shifts*
$\mu_{1/2}^{(k)}$	=	*median across all trials k*
M	=	*mislocalization curve*
m	=	*number of participants per part*
n	=	*number of conditions per part*
n'	=	*number of common conditions with part 2*
SS	=	*sum of squares of the difference between the data points and mislocalization curve*

To determine whether the pattern of localization errors is shifted in time between the different conditions (which only differed in the timing of the tone), we determined the temporal shifts for each of the conditions that would produce the smallest deviations around a single mislocalization curve for each session and flash location. We did this by minimizing the median squared difference between all (shifted) data points (considering both flashes at 2/3 and 4/3 of the last displacement of the white dot) and a single mislocalization curve (a curve through all the shifted data points that was created by smoothing the data by averaging the values with weights defined by a moving Gaussian window). We used the median rather than the mean because it is less sensitive to outliers. For each participant in each part:

$$SS_{op}(\Delta) = \sum_{f=1}^{2}\sum_{i=1}^{n} \mu_{1/2}^{(k)}\left(\left(M_{fop}^{(\Delta)}(tf) - x_{kiop}\left(tf + \Delta'_{iop}\right)\right)^{2}\right) \tag{1}$$

where $x_{kiop}\left(tf + \Delta'_{iop}\right)$ is the indicated position on trial *k* attributed to a time that is shifted by Δ'_{iop} and $M_{fop}^{(\Delta)}(tf)$ is the value of the smooth mislocalization curve that takes into account all the temporal shifts in the part. The best fitting temporal shift was determined simultaneously for both flash locations (2/3 and 4/3 of the last displacement of the white dot), but obviously with a different mislocalization curve for each flash location. Adding the same time to all values of Δ does not influence the value of $SS_{op}(\Delta)$. The -62 ms conditions was present in all parts so we considered it as a baseline ($\Delta(t=-62)=0$), but this choice is arbitrarily and does not influence the final values. In Table 2S we show the values of the temporal shift relative to the -62 ms condition for each condition, participant and part (Δ'_{iop}). In the next section we describe how we align the temporal shifts to the no tone condition.

Part.Participant	No tone	-202 ms	-152 ms	-98 ms	-62 ms	-46 ms	-26 ms	-4 ms	42 ms	143 ms
1.1					0				24	
1.2					0				29	
1.3					0				26	
1.4					0				28	
2.1	18				0			12	24	
2.2	25				0			32	34	
2.3	16				0			-5	18	
3.1		26	7	6	0			16		
3.2			10	1	0			9		
3.3			-1	5	0			18		
3.4			-1	-7	0			8		
4.1					0				7	18
4.2					0				-1	13
4.3					0				11	3
5.1					0	-11	0	-4		
5.2					0	3	23	13		
5.3					0	10	8	6		

Table 2S. The temporal shifts as determined by the best fit of the data points to a mislocalization curve (see equation 1) for each part and participant. These values are then aligned across participants and parts (see equations 2 to 4) to obtain the values shown in figure 7 (the change in sign is because having to shift the data points in a certain direction implies that the tone shifted them in the opposite direction).

S3. Aligning the temporal shifts

The method for finding temporal shifts that is described in section S2 only yields differences between conditions within a part. In order to align the different parts, and to relate all the values to the condition with no tone (while not all parts included a no-tone condition), we combined the above-mentioned differences in three steps. We first aligned the shifts of the different participants within each part by minimizing the total between-participant variability across conditions. This was achieved by subtracting the same time from all of each participant's temporal shifts, so that rather than the value for the -62 condition being zero, the average value across all conditions (for every participant in each part) was zero:

$$\Delta''_{iop} = \Delta'_{iop} - \frac{1}{n}\sum_{i=1}^{n}\Delta'_{iop} \tag{2}$$

We then aligned the temporal shifts between parts (without shifting any of the relative positions within each part) on the basis of the overall average values across participants of the common conditions of each part with part 2.

$$\Delta'''_{iop} = \Delta''_{iop} - \frac{1}{m \cdot n'}\sum_{i'=1}^{n'}\sum_{o=1}^{m}\Delta''_{i'op} \tag{3}$$

Finally, we subtracted the average value of the no-tone condition (i = 1 and p = 2) from all temporal shifts so that the average value for the no-tone condition is zero.

$$\Delta_{op}(t) = \Delta'''_{iop} - \frac{1}{m}\sum_{o=1}^{m}\Delta'''_{1o2} \tag{4}$$

The values of $\Delta_{op}(t)$ are shown in figure 7 of the main article for each part (p; each part is represented by a different symbol), condition (t; the position on the ordinate) and participant (o).