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Sequential streaming of speech sounds based on position cues: Effect of head position and spatial attention.

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This scientific report has been written during the visiting period of Nicolas Grimault at ASU from January the 1st to March the 29th 2018. The purpose of this document is to report preliminary data about sequential streaming based on position cues and spatial attention.

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I. INTRODUCTION

David et al [1–3] have already designed several experiments that reported an effect of position cues (ITD/ILD and perceived position) to segregate sequences of noise bursts first and, more recently, sequences of consonant/vowel syllables. For example, to quickly summarize the most recent data [3], David and colleagues have presented sequences of phonemes, **Tha**/Sa/**Fi**/Shu/... with the bold syllables coming from azimuth ϕ_1 and the other syllables coming from a different azimuth ϕ_2 . These sequences can be segregated based only on the azimuth difference $\Delta = (\phi_2 - \phi_1)$. For voluntary segregation in the azimuthal plan, performances start around $d' = 1.8$ and grow up to $d' = 3$ for $\Delta = 30^\circ$. A Δ around 8° leads to intermediate performances (cf figure 5, panel 1 and figure 6 panel 1 in [3]). The experimental procedure was to detect a repetition within a stream of syllables interleaved with an other stream of syllables and these experiments were realized using headphones and virtual angular positions (ϕ_2 and ϕ_1) using HRTF. The authors suggest that this effect of position cues on stream segregation of speech sounds probably contributes to the spatial release from masking. In these experiments, virtual environments were used and the position of the reference stream was fixed and always equal to 0° ($\alpha = \phi_1 = 0^\circ$ in figure 1). Recently, Grange and Culling [4] have suggested that head orientation could benefit to speech intelligibility in noise. Consequently, the first aim of this project is to test the hypothesis that head orientation (i.e. variable α with fixed Δ in figure 1, panel A) could also benefit to stream segregation of speech sounds.

In the previous experiment, the use of a virtual environment prevents also to visually locate the sound sources and probably reduces the potential effect of spatial attention. The second aim of this project is then to evaluate the effect of spatial attention for voluntary segregation of speech sequences. Such cues have been already reported to enhance speech intelligibility for simultaneous talkers [5]. The experiments are conducted in Bill Yost psychoacoustic laboratory, at ASU in Arizona in a sound booth with low reverberation and equipped with a stimulation system involving several loudspeakers (every 15°) and a revolving chair at the middle of the booth.

II. RATIONAL

As the rotations of the chair can be controlled, the proposed experiment would be either to rotate the listeners at random (changing α at random and keeping ϕ_1 and ϕ_2 constant in figure 1, panel A) or to rotate the sounds at random around the listeners while always maintaining constant the angular difference between sources (changing ϕ_1 at random and ϕ_2 accordingly and keeping α constant in figure 1, panel B). Due to experimental constraints, the constant angular distance between loudspeakers (Δ) is equal to 15° . In the rotated-sound condition, ϕ_1 would go at random from 0° to 90° by steps of 15° and α would be fixed to 0° . In this condition, the couple of speakers are then selected at random for each sequence presentation and the listener is fixed. As such, the listener does not know *a priori* where to listen at the beginning of the sequence and spatial attention is potentially reduced. In the rotated-listener condition, ϕ_1 is fixed to 0° and the listener (i.e. the chair) goes from α

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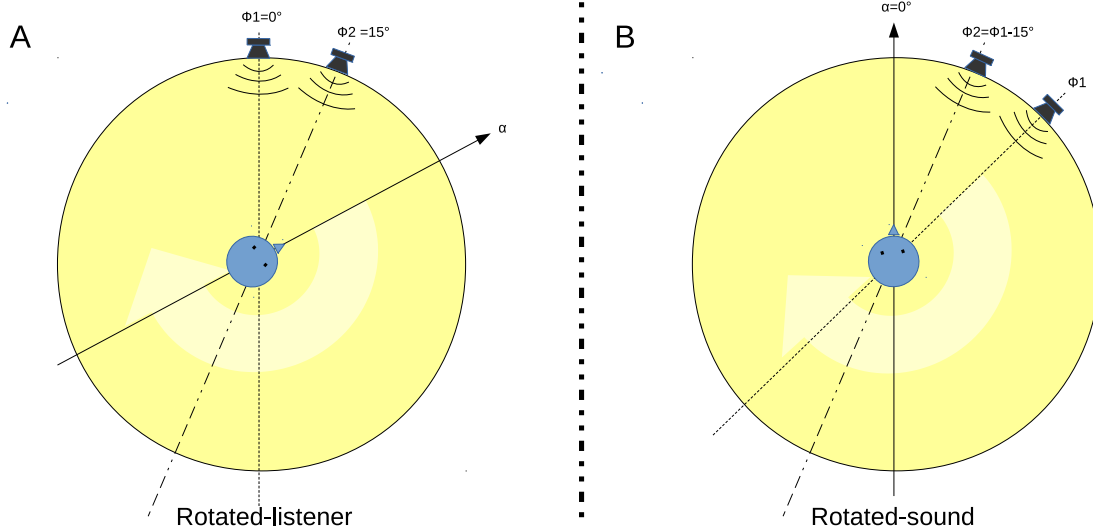


FIG. 1. schematic relative position of the head (α) and of the two loudspeakers (ϕ_1, ϕ_2) providing alternating sequences of syllables. By convention, the sequence that starts first and that may contain a repetition always comes from ϕ_1 . Panel A: condition Rotated-listener in experience 1. Panel B: condition Rotated-sound in experience 1.

64 $=0^\circ$ to $\alpha=90^\circ$ at random. In this condition, the sounds 92
 65 are always played by the same couple of loudspeakers
 66 and the listener turns around at random. As such, the
 67 listener knows *a priori* where to listen and spatial at- 93
 68 tention is potentially enhanced. A visual mark is added 94
 69 to help to clearly identified the loudspeaker located at 95
 70 $\phi_1=0^\circ$ (Figure 1, panel A). 96

71 By observing the effect of α in the rotated-listener con-102
 72 ditions, we should observed the potential effect of head103
 73 orientation for sequential segregation of speech items [4].104
 74 According to [4], depending of the spectrum of the speech105
 75 signal, the best angular difference α of the head from106
 76 zero azimuth could be different than $\phi = \phi_1 + \frac{\phi_2 - \phi_1}{2}$ to107
 77 better segregate speech coming from one fixed angle ϕ_1 108
 78 from speech coming from an other fixed angle ϕ_2 (see109
 79 Fig 1, panel A). Simulations are provided in the next110
 80 section as an attempt to predict the best position. As111
 81 the acoustical cues reaching the ears would be the same112
 82 (in an anechoic room), by comparing the two conditions113
 83 (rotated-sound versus rotated-listener) we should be able114
 84 to evidence any effect of spatial attention for sequential115
 85 segregation of speech items [5]. In fact, a larger effect of116
 86 segregation in the rotated-listener condition than in the117
 87 rotated-sound condition would be in favor of an effect of118
 88 spatial attention on stream segregation (i.e. the ability119
 89 to focus on a particular fixed spatial position to segre-120
 90 gate sounds, independently of acoustical cues related to121
 91 position). 122

III. SIMULATIONS

Previous studies [4, 6] used binaural simulations to pre-
 dict the effect of head movements on Speech Reception
 Threshold (SRT) with a concurrent speech masker. To
 do so, the authors estimated the Speech to Noise Ratio
 (SNR) for different angular positions of the speech and
 masker. The most favorable SNR would then predict the
 better SRT. In the current experiment, the question is
 slightly different as the two concurrent speeches are not
 simultaneous. Computing a SNR is then inoperative.
 However, doing simulations, could still enable to do, *a*
posteriori, some correlation of the results with the best
 angle α that would provide the largest spectral or tem-
 poral differences between ears. Some simulations have
 been performed using the average speech signal used in
 this experiment convolved with HRTFs (i.e. virtual en-
 vironment) to mimic the experimental configuration and
 the relative positions of sounds sources and rotated lis-
 tener. Figure 2 shows the estimated differences in one
 ear for source A and B coming from 0° and 15° when
 the listener is rotated from 0° to 90° (condition ro-
 tated-listener, Figure 1, panel A). Figure 2 evidences that the
 largest spectral difference in one ear between source A
 and B occurs when the listener is facing 7.5° . In other
 words, when the listener is at equal angular distance of
 both sources. Based on the assumption that monaural
 spectral cues are critical for streaming [1–3], this angular
 position should then provide the largest streaming effect.

Figure 3 show the difference between ILDs (panel B)
 and difference between ITDs (panel D) for two sound
 sources (0° and 15°) and a rotated listener moving from

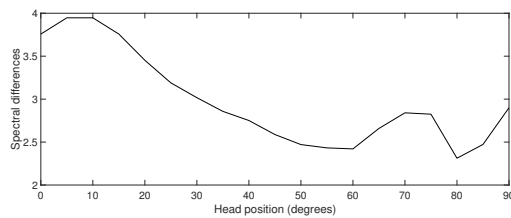


FIG. 2. Sum of the two monaural spectral differences (in right and left ears) between sources at 0° and 15° when the listener is rotated from 0° to 90° .

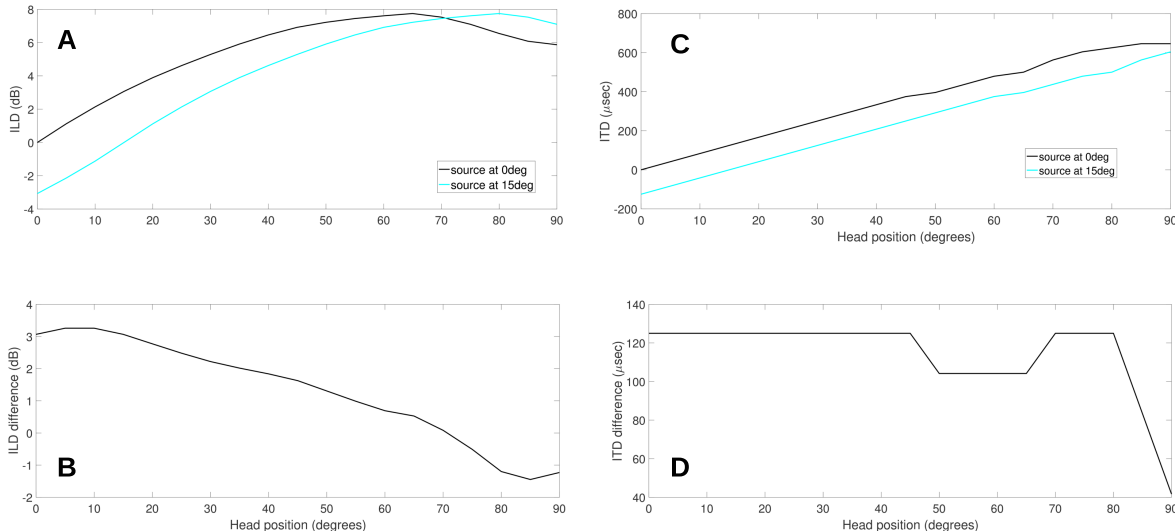


FIG. 3. Panels A and B show the simulated ILD and the difference between these ILDs for two sound sources (0° and 15°) and a rotated listener moving from 0° to 90° . Panels C and D show the simulated ITD and difference between these ITDs in the same configuration.

123 0° to 90° . As for monaural spectral differences, the differ-140
 124 ences between ILD values is maximum when the listener
 125 is facing 7.5° . The differences between ITD is very low
 126 and about constant for sources only distant of 15° . 141

127 Overall, for non simultaneous sounds located at 0°
 128 and 15° , based on the simulations, both the spectral,142
 129 monaural cues and the difference between ILD predict,143
 130 the largest segregation at 7.5° . It is unclear how ITD,144
 131 could also influence segregation 145

132 IV. PRE-EXPERIMENT

133 This pre-experiment is dedicated to estimate the per-148
 134 formance levels at 0° , 15° and 30° separations (subject
 135 always facing 0°) and to check for any effect of segrega-149
 136 tion when using real sound sources in a real room and any150
 137 saturation effect at 15° . In fact, if the performances are151
 138 too low or too high with a 15° difference between sources,152
 139 no room of improvement would remains to evidence any153

effect of spatial attention and/or head orientation.

A. Subjects

145 Five young normal hearing and native female English
 146 speakers from 18 to 31 (mean age 22,8) participated to
 147 this preliminary experiment. One was research assistant
 in the lab and the others were students from the depart-
 ment and received credits for their participation to this
 rather short experiment.

B. Experimental setup and listening Room

The listening room was the same used for previous
 studies [7, 8]. It consists of 24 loudspeakers (Boston
 Acoustics 100X, Peabody, MA) connected to a computer
 through three sound-cards (Audiofire 12), three ampli-
 fiers (AudioSource AMP 1200) and 24 passive attenua-

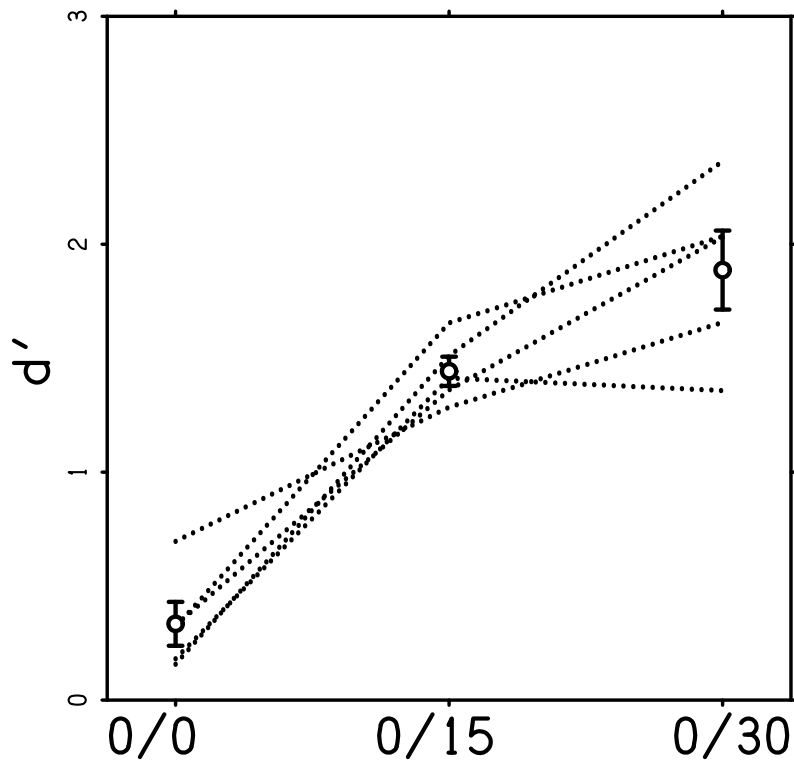


FIG. 4. Individual and averaged performances with couple of sources located at different angular positions (abscissa, ϕ_1/ϕ_2). The bars indicate the standard error within subjects.

154 tors (ATLAS SOUND LP, AT 100-RM) in parallel. The 179
 155 24 loudspeakers are on an azimuth circle 3 meters in di-180
 156 ameter at pinna height. The loudspeakers are located in 181
 157 a $4.6 \times 3.6 \times 3$ meters room lined on all six surfaces with 182
 158 0.1 meter thick acoustic foam resulting in a room with 183
 159 a wideband reverberation time (RT 60) of 102 ms. Lis-184
 160 teners were seated in the middle of the azimuth array 185
 161 and were monitored by an experimenter through a video 186
 162 system. Listeners were asked to face straight and to keep
 163 their heads stationary. They were free to look at any
 164 direction without moving the head. 187

165 C. Methods 188

166 The same experimental material and protocol than [3] 191
 167 have been used. Only voluntary segregation is estimated 192
 168 and the listener is instructed to detect a repetition in 193
 169 the sequence of syllables that starts first and that always 194
 170 comes from the 0° loudspeaker. As such, spatial atten-
 171 tion is maximized. An interleaved sequence of syllables
 172 is played from 0° , 15° , or 30° . All syllables have been 195
 173 equalized in RMS level and are played at about 65 dB
 174 SPL. All three loudspeakers have been calibrated in the 196
 175 room to deliver the same SPL level at head position us-197
 176 ing a class A sound level meter (Larson Davis 800B). The 198
 177 listener is always facing 0° and three conditions of angu-199
 178 lar distance between sources have then been tested (0° , 200

15° , and 30°). Each sound sequence duration is 5 sec-
 onds in average. The three angle conditions are repeated
 three times in a block in random order. Each listener
 is presented with 14 blocks to reach the same number
 of repetitions than in David *et al* [3] and thus compar-
 able performance levels in terms of d' . Overall, for each
 listener, the duration of the experiment is less than 15
 minutes.

D. Results

The results are plotted on figure 4. In average, for these
 listeners, d' is increasing when increasing the angular dis-
 tance between sources from 0° to 30° . The performances
 start around $d'=0.33$ and grow up to $d'=1.89$ for $\Delta=30^\circ$.
 A repeated measure ANOVA applied to the data reveals
 a significant effect of the angular distance [$F(2,8)=41.51$,
 $p<0.001$].

E. Discussion

The results of this preliminary experiment evidence
 that, when using real sound sources (loudspeakers) in a
 real room, segregation still occurs for sound sources sep-
 aration equal or over 15° . In the previous study of David
et al [3], when using virtual reality, the performances

TABLE I. Values of α , ϕ_1 and ϕ_2 in the rotated-listener²²⁵ and the rotated-sound experimental conditions. The last²²⁶ columns provide the apparent positions of LP 1 and LP²²⁷ 2 in right and left ears. By convention, a positive angle²²⁸ value indicates that the sound is on the same side than the ear.²²⁹

	Chair	LP 1	LP 2	Right ear		Left ear	
	α	ϕ_1	ϕ_2	$\phi_1-\alpha$	$\phi_2-\alpha$	$\alpha-\phi_1$	$\alpha-\phi_2$
Rotated listener	0	0	15	0	15	0	-15
	5	0	15	-5	10	5	-10
	7	0	15	-7	8	7	-8
	8	0	15	-8	7	8	-7
	10	0	15	-10	5	10	-5
	15	0	15	-15	0	15	0
	20	0	15	-20	-5	20	5
	30	0	15	-30	-15	30	15
	45	0	15	-45	-30	45	30
	60	0	15	-60	-45	60	45
75	0	15	-75	-60	75	60	
90	0	15	-90	-75	90	75	
Rotated Sound	0	0	-15	0	-15	0	15
	0	15	0	15	0	-15	0
	0	30	15	30	15	-30	-15
	0	45	30	45	30	-45	-30
	0	60	45	60	45	-60	-45
	0	75	60	75	60	-75	-60
	0	90	75	90	75	-90	-75

B. Experimental setup and listening Room

The listening room was the same used for previous studies [7, 8] and for the preliminary experiment (see above for details). Listeners were seated in the middle of the azimuth array and were monitored by a experimenter who always stays in the room. Listeners were asked to face straight and to keep their heads stationary. They were free to look at any direction without moving the head. Listeners were closely monitored to be sure they did not move their heads and they rarely did so. In the rotated-listener condition, the chair was rotated before each sequence presentation using a custom-designed rotating chair moved by a stepper motor with 0.225° micro-step resolution and controlled by Arduino hardware and C++ software.

C. Methods

The same experimental protocol than use in David *et al* (2017) is used. Only voluntary segregation is estimated and the listener is instructed to detect a repetition in the sequence of syllables that starts first (target sequence). The two interleaved sequences are always played from two distinct loudspeakers. The target sequence that starts first and that might contain a repetition is always coming from angle ϕ_1 and the other interleaved sequence is coming from ϕ_2 (Figure 1). The angular distance between these two loudspeakers ($\phi_1-\phi_2$) was hold constant through the whole experiment and equal to 15° in absolute value. All syllables have been equalized in RMS level and are played at about 65 dB SPL. All eight loudspeakers have been calibrated in the room to deliver the same SPL level at head position using a class A sound level meter (Larson Davis 800B). Two conditions of rotation will be introduced and blocked. Each listener is presented with 7 blocks of each condition (14 blocks overall) to reach the same number of repetitions than in David *et al* [3] and in the pre-experiment. In the rotating listener condition (Figure 1, panel A), the sources are fixed and always positioned at 0° and 15° . The listener is rotated with rotation values equal to 0° , 5° , 7° , 8° , 10° , 15° , 20° , 30° , 45° , 60° , 75° or 90° presented in random order 6 times each, in each block. Based on the previous simulations, several angles around 7.5° have been added. In the rotating sound condition (Figure 1, panel B), the listener is fixed and always facing 0° . The loudspeakers are always separated by 15° and the position of loudspeaker 1 (ϕ_1) equals 0° , 15° , 30° , 45° , 60° , 75° or 90° presented in random order 6 times each, in each block. As such, each condition of the rotating-sound block is matched with a condition in the rotating-listener bloc. The only difference between theses conditions is that the ear of presentation is reversed and the listener knows *a priori* in which direction to listen to in the rotated-listener condition. All parameters (α , ϕ_1 and ϕ_2) in all conditions are summarized in Table I. Each sound sequence duration is

start around $d'=1,8$ and grow up to $d'=3$ for $\Delta=30^\circ$. In the current experiment, the performances are lower in average but the size of the effect is roughly similar when increasing Δ from 0° to 30° . This discrepancy can be probably explained by a stimulation with loudspeakers in a real room instead of headphones and a simulated room. Finally, the average performances at 15° equal $d'=1.44$ are higher than those at 0° and lower than those at 30° . This indicate that the performances at 15° are probably not saturated. In the next experiment, at 15° we expect lower performances when reduced spatial attention is available and slightly better performances when moving the listener up to the optimal angular position.

V. EXPERIMENT 1

A. Subjects

10 young normal hearing and native (4 males and 6 females) English speakers from 18 to 32 (mean age 23.3) participated to this experiment. One was research assistant in the lab and the others have signed an informed consent and were paid an hourly wage for their participation. One listener, who did abrupt movements during the test that lead to uncontrolled rotations of the chair has been excluded. The data in the following are then based on 9 listeners.

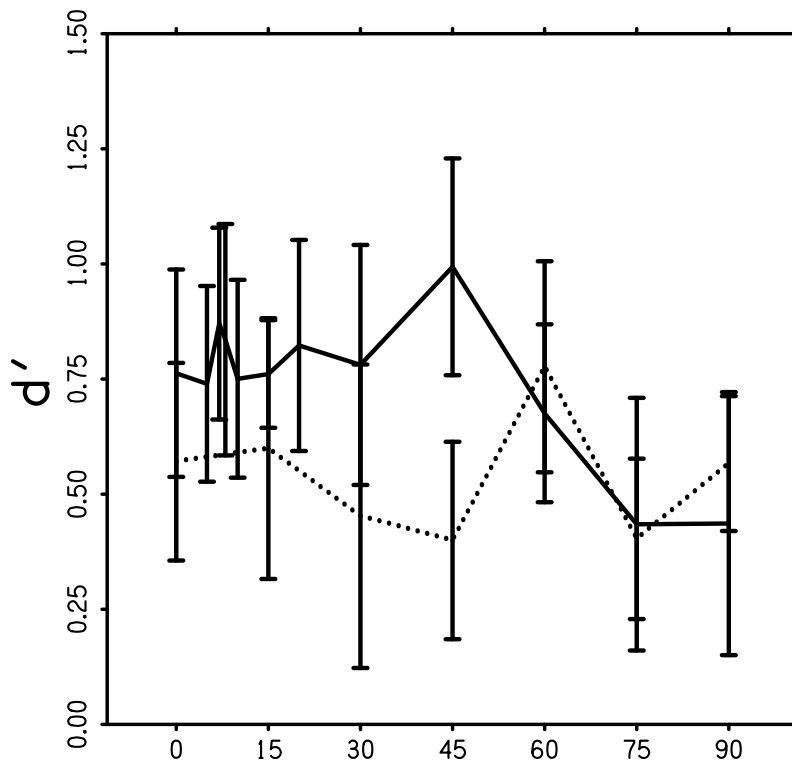


FIG. 5. Averaged performances with a couple of 15° distant sources located at different angular positions (abscissa) related to the head. The bars indicate the standard error within subjects. The results from condition rotated-listener are plotted with a continuous line. The results from condition rotated-sound are plotted with a dotted line.

279 5 seconds in average. Overall, for each listener, the du-303
 280 ration of the experiment is around three hours separated304
 281 in two sessions (8 and 6 blocks respectively to reach 14305
 282 blocks). The loudspeaker at 0° is visually marked with a306
 283 red dot to be easy to spot in the rotated-listener condi-307
 284 tion in order to facilitate the spatial attention. 308

285 D. Results 311

286 The performances are plotted in Figure 5 function313
 287 of the position of the loudspeaker related to the head.314
 288 In condition rotated-listener, $(\alpha-\phi_1)$ in the left ear is315
 289 used for the abscissa (Table I). In condition rotated-
 290 sound, $(\phi_1-\alpha)$ in the right ear is used for the abscissa
 291 (Table I). As such, the only remaining acoustic differ-316
 292 ence across conditions rotated-listener and rotated-sound
 293 is the ear of presentation which should made the two317
 294 conditions comparable for young normal hearing listen-318
 295 ers. For each listener, as in the preliminary experiment,319
 296 d' computation is based on 42 repetitions in each con-320
 297 dition. The syllable was repeated in about half the321
 298 repetitions so, the hit rate is computed as the num-322
 299 ber of response *repeated* when there was a repeat in323
 300 the sequence and the false alarm rate is computed as324
 301 the number of responses *repeated* when there was no325
 302 repeat in the sequence. A repeated measure ANOVA326

and a Bayesian repeated measure ANOVA has been ap-
 285 plied to the data using the JASP software [9–11]. Nei-
 286 ther the effect of the angular position [$F(6,48)=0,87$,
 287 $p=0,52$, $BF_{01}=10,70$] nor the effect of the rotated con-
 288 dition [$F(1,8)=3,14$, $p=0,11$, $BF_{01}=1.29$] are significant.
 289 The interaction between there two factors is not signifi-
 290 cant either [$F(6,48)=1,44$, $p=0,22$, $BF_{01}=13.54$]. More-
 291 over, based on the simulation, to check for a potential
 292 effect of head position, a dedicated Bayesian repeated
 293 measure ANOVA has been applied to the data in the
 294 rotated-listener condition restricted to angles from 0° to
 295 15° . This analysis reveals not significant effect of head
 296 position [$F(5,40)=0,17$, $p=0,97$, $BF_{01}=12.38$].

E. Discussion

Based on the preliminary experiment, the expected size
 of the effects is small (around 0.5 variation in d'). This
 observation led us to do a large number of repetitions (42
 in each condition) and a reasonable number of listeners
 (10). However, the data plotted in Figure 5 are still very
 noisy, the results are not significant and the Bayesian
 factor, lower than two, does not enable to rule out a po-
 tential effect of the rotated condition. As an attempt
 to reduce the noise in the data, we have introduced a
 training period. To determine the adequate training pe-

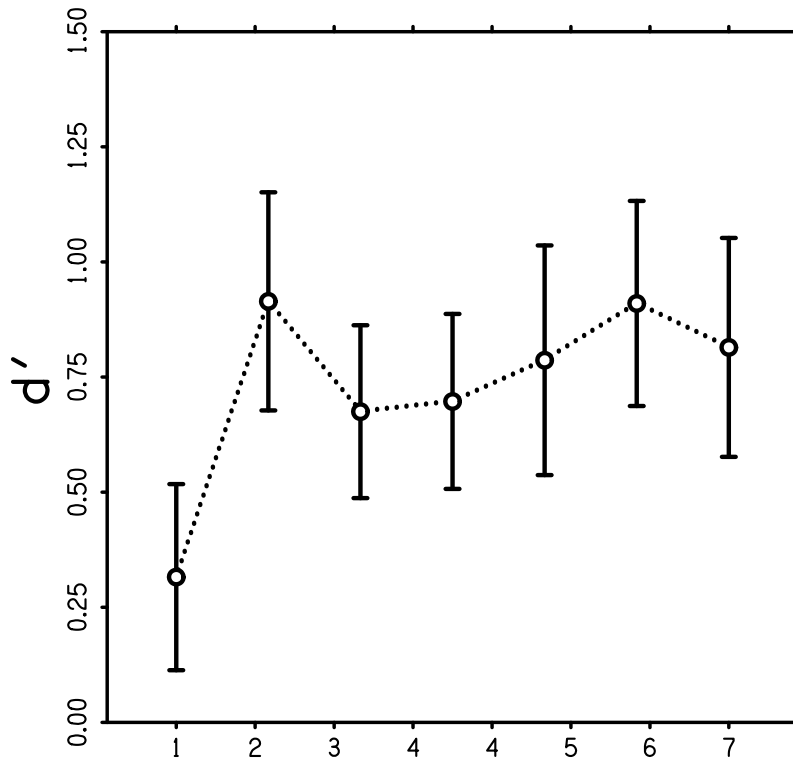


FIG. 6. Averaged performances across all participants and conditions for each block of presentation. The bars indicate the standard error within subjects.

riod based on an objective criterion, the training curves across blocks have been estimated and plotted in Figure 6. The training effect is significant [$F(6,48)=3.50$, $p<0.01$] and a post hoc analysis reveals that the performances in block one are lower than in all other blocks. So, based on this training curve, it appears clearly that some training occurs during the first block which has then been ignored in a second analysis plotted on Figure 7. A Bayesian repeated measure ANOVA has been applied to the data after the training occurs (36 last repeats). Still, neither the effect of the angular position [$F(6,48)=1.22$, $p=0.31$, $BF_{01}=8.39$] nor the effect of the rotated condition [$F(1,8)=1.58$, $p=0.24$, $BF_{01}=1.97$] are significant. The interaction between these two factors is not significant either [$F(6,48)=.85$, $p=0.11$, $BF_{01}=15.63$].

For now, the noise prevents us from concluding anything about the data but the Bayesian factor, lower than two, does not enable us to rule out a potential effect of the rotated condition and it seems that the performances in the rotated-listener condition are over those in the rotated-sound condition from 0° to 60° . We should be very cautious but this could reveal an effect of spatial attention in this angular range. Both auditory and visual spatial attention could be involved in the rotated-listener condition. The visual area in human is about 60° . So, this limitation could reduce the effect of visual spatial attention in the rotated-listener condition from 60° to 90° .

Additionally, the Bayesian factor higher than 10 indi-

cate no effect of head position for segregating two sound sources located 15° apart.

To conclude, further data collection are required to better understand the underlying mechanisms involved in this experiment. In order to think further, the individual performances after training are plotted in Figure 8.

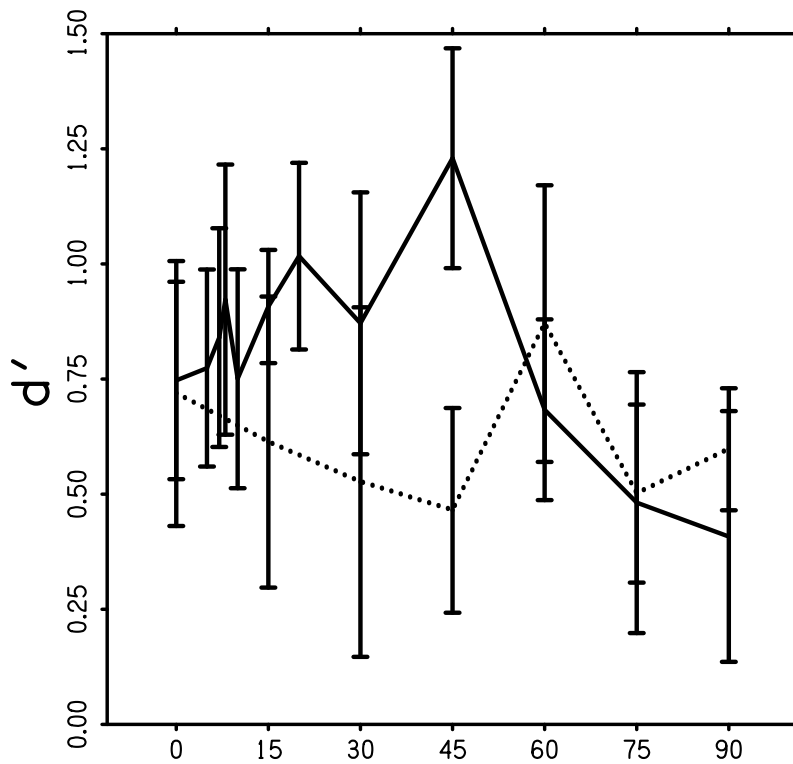


FIG. 7. Averaged performances after training with a couple of 15° distant sources located at different angular positions (abscissa) related to the head. The bars indicate the standard error within subjects. The results from condition rotated-listener are plotted with a continuous line. The results from condition rotated-sound are plotted with a dotted line.

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361

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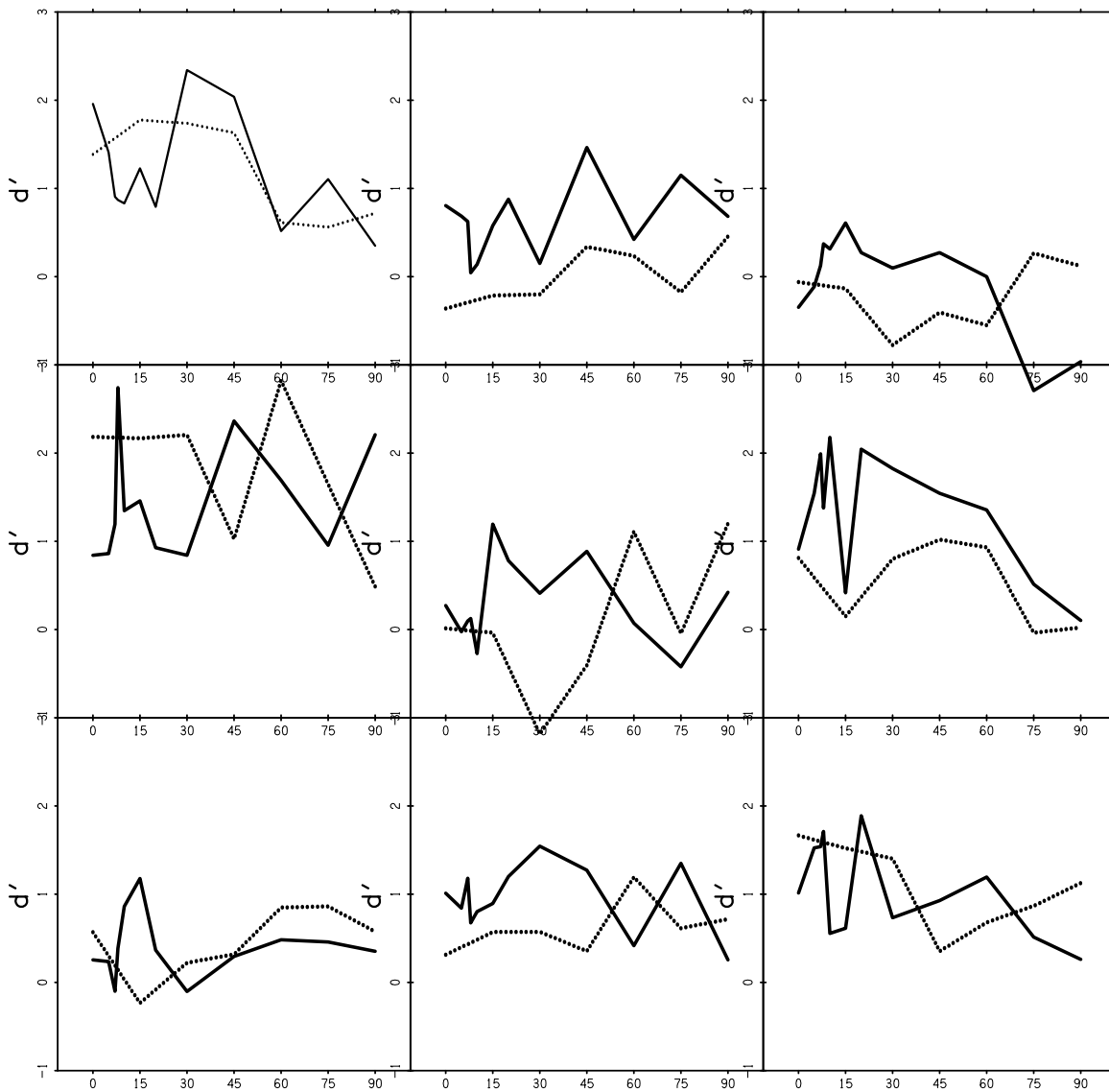


FIG. 8. Individual performances after training with a couple of 15° distant sources located at different angular positions (abscissa) related to the head. The bars indicate the standard error within subjects. The results from condition rotated-listener are plotted with a continuous line. The results from condition rotated-sound are plotted with a dotted line.

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