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Research Article

The Spatial Release of Cognitive Load in Cocktail Party Is Determined by the Relative Levels of the Talkers

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ABSTRACT

In a multi-talker situation, spatial separation between talkers reduces cognitive processing load: this is the "spatial release of cognitive load". The present study investigated the role played by the relative levels of the talkers on this spatial release of cognitive load. During the experiment, participants had to report the speech emitted by a target talker in the presence of a concurrent masker talker. The spatial separation (0° and 120° angular distance in azimuth) and the relative levels of the talkers (adverse, intermediate, and favorable target-to-masker ratio) were manipulated. The cognitive load was assessed with a prefrontal functional near-infrared spectroscopy. Data from 14 young normal-hearing listeners revealed that the target-to-masker ratio had a direct impact on the spatial release of cognitive load. Spatial separation significantly reduced the prefrontal activity only for the intermediate target-to-masker ratio and had no effect on prefrontal activity for the favorable and the adverse target-to-masker ratios. Therefore, the relative levels of the talkers might be a key point to determine the spatial release of cognitive load and more specifically the prefrontal activity induced by spatial cues in multi-talker situations.

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INTRODUCTION

In a multi-talker situation, the auditory system uses a variety of cues to attribute among stream of speeches one to a unique target talker, among the other masker(s) talker(s). Previous studies (reviewed in Bronkhorst, 2015) have found that two cues are particularly important: the voice frequency characteristics and the spatial separation between talkers. The most favorable voice characteristic condition is reached when the target and the masker have different genders. Likewise, higher intelligibility can be attained when the target and the masker are spatially separate. It seems that large spatial separation led to greater improvement in speech reception threshold 50 (SRT_{50}, level differences between the target and the masker to obtain 50 % intelligibility) than did gender differences (Zekveld et al. 2014b).

Hence, one important question is to know whether this improvement of speech intelligibility due to spatial separation is achieved at the expense of a cognitive cost. Indeed, probably due to cognitive decline, older listeners seemed to be less able to take advantage of spatial separation between talkers (Glyde et al. 2011). Similarly, working memory span size seems to limit the ability to use spatial cues in hearing impaired listeners (Neher et al. 2009). Nevertheless, those results are questioned when audiometric sensitivity is considered (Füllgrabe et al. 2014). In normal hearing listeners, there is no consistent result about the relationship between cognitive resources and the use of spatial cues (Zekveld et al. 2014b).

Recently, the relationship between cognitive resources and spatial release from masking was addressed by measuring the cognitive load in multi-talker situations. Zekveld and colleagues (Zekveld et al. 2014b) assessed the cognitive load of listeners by pupil dilation while measuring the SRT_{50}. The authors found that the spatial separation between talkers improved performance but had no effect on the cognitive load, whereas gender differences between talkers improved performance and reduced cognitive load. However, the null effect of spatial separation on cognitive load was questioned by Xia et al. (2015). In this latter study, listeners had to perform the speech task while performing a secondary task (visual tracking), the score of which was used as an indicator of the cognitive load. Unlike Zekveld and colleagues, Xia and colleagues found that spatial separation yielded lower cognitive load than gender differences.

Interestingly, those two recent studies differ in the relative levels of the target and masker talkers (Target-to-Masker Ratio, TMR). Xia and colleagues presented the target and the maskers at the same level (approximately 0 dB TMR). Zekveld and colleagues used a louder masker level (approximately −8 dB TMR) in order to decrease the intelligibility score (SRT_{50}) down to 50 % with spatial separation. Such experimental differences can explain the contradictory results between these two studies, as the impact of TMR on speech intelligibility has been shown in many previous studies (Brungart 2001; Eddins and Liu 2012; Bronkhorst 2015). The speech intelligibility generally decreases as the TMR decreases, i.e., when the masker gets louder. There was an 8-dB TMR difference between the Zekveld and colleagues and the Xia and colleagues' study. In a given experiment, an 8-dB TMR decrease could greatly reduce the performance (for instance see Eddins and Liu, 2012). In addition, we could also expect an impact of this large TMR difference on the cognitive load.

Moreover, for adverse TMR, a different pattern could emerge: because of the large level difference between the target and the masker, the listeners could specifically attend to the softest voice (Brungart 2001). Therefore, various TMRs can produce different effects on speech intelligibility. This suggests complex interactions between the TMR and the spatial separation which could explain a part of the inconsistency in the cognitive load results of the two previous studies.

The current work aims to investigate the role played by the TMR in the spatial release of cognitive load in a classic cocktail-party paradigm. The cognitive load was assessed by the activity of the prefrontal cortex recorded with a functional near-infrared spectroscopy (fNIRS) device. fNIRS is a brain imaging device that takes advantage of the optical properties of the human tissues that are transparent to near infrared light. Interestingly enough, oxygenated (HbO2) and deoxygenated (HHb) hemoglobin are two chromophores that absorb near-infrared light at two different wavelengths and their changes in concentration are associated with cortical activity (Ayaz et al. 2012). Using the modified Beer-Lambert Law (Villringer and Obrig 2002), relative and local concentrations of Hb02 and HHb can be estimated from the near-infrared light transmittance of the brain measured by placing a light emitter and a light sensor around the area of interest. This affordable, field deployable, and easy-to-use technique (Ayaz et al. 2013; McKendrick et al. 2015) has been used to measure hemodynamics in response to stimuli (Strait and Scheutz 2014) in a variety of experimental paradigms such as speech processing-related task (Dieler et al. 2012). fNIRS has gained momentum to investigate cognitive load (Bunce et al. 2011; Gagnon et al. 2012; Ayaz et al. 2012; Durantin et al. 2015; Gateau et al. 2015; Mandrick et al. 2016) as it gives a more direct insight on the cortical activity than do other psychophysiological techniques (Durantin et al. 2014).

MATERIALS AND METHODS

Participants

Fourteen young (8 men and 6 women; mean age, 21.9 ± 2.1 years) normal-hearing listeners took part in the present study. All had audiometric thresholds below 20 dB HL for all octave frequencies from 125 to 8 kHz evaluated using AudioConsole software and Silento Supermax headphone. All listeners were undergraduate engineer students at Institut Supérieur de l'Aéronautique et de l'Espace (ISAE), and all have perfect understanding of English number and color words. This study was approved by the Institutional Review Board, IRB00003888. Written informed consent was obtained.

Multi-Talker Task

The performance in a multi-talker situation was assessed by using the coordinate response measures (CRM) corpus (Bolia et al. 2000). In that corpus, all sentences had the same pattern: "Ready *call sign* go to *color number* Now." The call signs could be the following words: *Baron*, *Charlie*, *Ringo*, *Eagle*, *Arrow*, *Hopper*, *Tiger*, *Laker*. The colors can be *red*, *blue*, *green*, and *white*, and the numbers *one* to *eight*. Only male voices (four talkers) were used for the target and the masker.

Experimental conditions varied according to two factors: the TMR and the spatial separation between the target and the masker. Three TMRs were used (−12, −4, and +4 dB). We chose 8-dB steps to get strong contrasts between the levels of the TMR factor: adverse (−12 dB), intermediate (−4 dB), and favorable (+4 dB) TMR. The spatial locations of the talkers were manipulated by filtering voice signals with head related transfer functions (HRTFs). Two conditions were tested: in the separate talker condition, the target talker was presented at 60 degrees right and the masker at 60 degrees left; in the collocated condition, the two talkers were presented straight ahead (0 degree).

The experiment consisted in six homogenous blocks. Each block was the combination of one TMR and one spatial separation: TMR-12 collocated, TMR-12 separate, TMR-4 collocated, TMR-4 separate, TMR + 4 collocated, TMR + 4 separate. The block order was randomized for each participant using a Latin square design. Each block contained 32 trials, i.e., 32 repetitions for each experimental condition. In each trial, two sentences were simultaneously presented: one by the target (call sign Baron) and the other one by the masker (all the seven others call signs except Baron). The listener had to report the color and the number of the sentence corresponding to the target call sign. The color and number in each sentence was chosen randomly. In a given sentence, the color and number of the masker talker were different from the color and number of the target talker. Each block lasted approximately 5 min. Before data acquisition, all listeners performed two short training blocks of 16 trials at 0 dB TMR. Half of the listeners began the training with the spatially separate talkers and the other half with the collocated talkers. The experiment lasted approximately 40 min.

Stimuli were generated using custom software written in Mathworks Matlab®. The audio files (.wav) were transmitted from the computer (Dell Optiflex 990) to a digital signal processor (RX8; Tucker Davis Technologies) to be filtered in real time with HRTFs measured with an artificial head (Neuman KU-100). The signal was amplified through a headphone buffer (HB7, TDT) and presented using headphones (Beyer Dynamics DT770) at an overall level around 70 dB SPL (rms power) at both ears. The combined signal (target speech and masker speech) was roved over a 6-dB range (from 67 dB SPL to 73 dB SPL, in 1-dB step).

Behavioral responses were recorded using a homemade response box with three button rows (the first row was dedicated to the colors, the second row to the numbers one to four, and the third row to the numbers five to eight). The response box was linked to the real-time processor and the responses were recorded with the custom software.

fNIRS Measurements

In the current study, during each session, hemodynamics of the prefrontal cortex was recorded with the functional near-infrared spectrometer fNIR100 (Biopac®) equipped with 16 prefrontal optodes (Fig. 1). Each optode recorded hemodynamics at a frequency of 2 Hz in terms of light level variations in comparison to a 10-s baseline. The baseline was acquired at the beginning of the recording and consisted of a 20-sample recording at rest. The data was then referenced to the averaged baseline value. fNIRSoftPro® was used for preprocessing and to calculate changes in oxygenated hemoglobin (HbO2) and deoxygenated hemoglobin (HHb) concentrations with the modified Beer-Lambert Law (Delpy et al. 1988). Statistical differences between condition-related HbO2 and HHb would ensure cortical-related activations whereas coevolution of both chromophores would stand for a blood volume effect. Concentration measurements were band pass filtered (0.012 Hz to 0.33 Hz) with a finite impulse response linear filter (order of 20) to remove signal noise components (thermoregulation, vasomotion, respiration, heart pulse) and slow signal drift (Roche-Labarbe et al. 2008). HbO2 and HHb concentrations were then normalized using a signal detrending and an offset subtraction, and mean concentrations for each experimental condition (TMR × spatial separation) were calculated.

Due to artifacts induced by frontal sinus, the data from optodes 8 and 10 were excluded from the analyses.

Statistical Analysis

For each block and each listener, the CRM scores and the fNIRS measures were recorded. The CRM score corresponded to the percent of trials where the number and the color were both correctly reported. Before statistical analysis, the CRM scores were transformed from percent correct to rationalized arcsine unit (RAU, Studebaker, 1985) to control for ceiling effect. The effect of spatial separation and TMR on speech intelligibility were assessed using a repeated measures analysis of variance (ANOVA) with spatial separation (collocated vs. separate) and TMR (−12 dB vs. −4 dB vs. +4 dB) as factors. The same analysis was performed to analyze the prefrontal activity with optodes (14 optodes) as a supplementary factor. In case of violation of sphericity, a Greenhouse-Geisser correction was applied. The relationship between speech intelligibility and prefrontal activity according to the combinations of

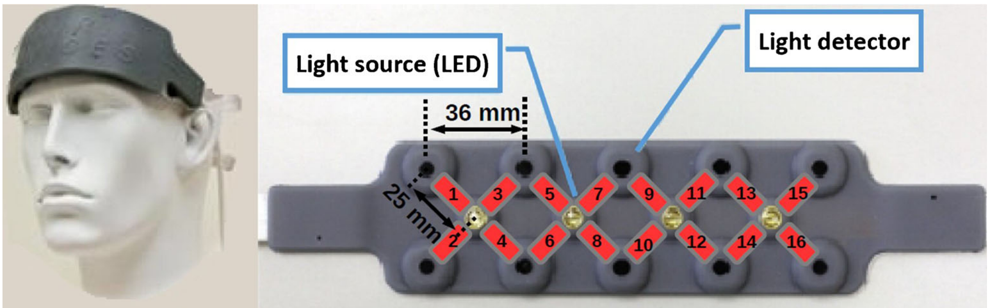

FIG. 1. fNIRS device optode location**.** The device is composed of four light sources and ten light detectors. The association of one light source and one light detector composes the optodes. The disposition of the sources and detectors leads to 16 optodes over the prefrontal cortex. The emitter-detector distance is 25 mm. The original image comes from the fNIRSOFT® manual and has been slightly modified.

the spatial separation and TMR factors was explored using a linear mixed-effect model. All analyses were performed using the software R and the packages "ez" for repeated measures ANOVA and "lmerTest" for linear mixed-effect model. Pairwise post hoc comparisons were carried out with the Tukey's honestly significant difference (HSD) with a P value threshold of 0.05. No P value was reported for F ratio below 1 (within-sample variability greater than between-sample variability).

RESULTS

Speech Intelligibility

As shown in previous studies (Brungart 2001; Xia et al. 2015), higher scores of speech intelligibility were provided by favorable TMR ($F_{(1.4,\ 18.18)} = 21.67$, $P = 0.00006$, $\eta^2_G = 0.30$) and separate talkers ($F_{(1,\ 13)} = 133.96$, $P = 0.00000008$, $\eta^2_G = 0.73$). The interaction between TMR and spatial separation [$F_{(1.82,\ 23.64)} = 12.86$, $P = 0.0002$, $\eta^2_G = 0.14$) revealed that the effect of spatial separation was more pronounced for intermediate TMR (Fig. 2, upper panel). Moreover, in the collocated condition, post hoc tests showed that the decrease in TMR from intermediate to adverse did not give lower averaged speech intelligibility but rather increased the scattering of listeners. We thus explored in more details the pattern of results according to the listeners (Fig. 3, upper panel). Half of the listeners (three females, four males) had a U-shape performance, defined as similar performances between the adverse and the favorable TMR despite the 16-dB gap. The other listeners (three females, four males) had a more monotonous decrease in performance following the decrease of TMR in the collocated conditions. The comparison between the performances of the adverse and favorable TMR was performed for each listener with a Chi^2: U-shape performers were defined as listeners who showed no significant difference (i.e., each $P > 0.2$), whereas non U-shape performers were defined as the listeners who showed lower performance with the adverse than with the favorable TMR (each $P < 0.05$) in the collocated conditions.

Prefrontal Activity

A repeated measures ANOVA was conducted on HBO2 changes with TMR, spatial separation, and optode number as within-listener variables. A main effect of spatial separation was observed ($F_{(1,\ 13)} = 7.05$, $P = 0.02$, $\eta^2G = 0.08$) with higher HbO2 concentrations ([HbO2]) for the collocated condition. No significant main effect of TMR [$F_{(2,\ 26)} = 3.10$, $P = 0.06$] nor optode number [$F_{(13,\ 169)} = 0.98$] was found. However, the effect of spatial separation on prefrontal activity varied with the TMR as shown by a significant interaction between the two factors ($F_{(2,\ 26)} = 3.9$, $P = 0.03$, $\eta^2_G = 0.03$). The post hoc tests revealed that spatial separation provided lower prefrontal activity only for the intermediate TMR. No significant difference was observed for the adverse and favorable TMR (Fig. 2, lower panel).

Moreover, no interaction involving the factor optode number (spatial separation × optode number: $F_{(13,\ 69)} = 0.95$; TMR × optode number: $F_{(26,\ 338)} = 1.21$, $P = 0.23$; spatial separation × TMR × optode number: $F_{(26,\ 338)} = 1.38$, $P = 0.10$) was observed.

No effect of spatial separation nor TMR was observed on HHb (spatial separation: $F_{(1,\ 13)} = 0.1$; TMR: $F_{(2,\ 26)} = 0.63$, spatial separation × TMR: $F_{(2,\ 26)} = 0.38$).

Following the speech intelligibility results, we compared the patterns of [HbO2] across the TMR for the groups of U-shape and non-U-shape performers in the collocated condition (Fig. 3, lower panel). We found that the group of U-shape performers showed higher [HbO2] with the adverse and intermediate TMRs than with the favorable TMR in the collocated condition (Kruskal-Wallis test, $Chi^2 = 7.4$; $P = 0.025$). On the contrary, the group of non-U-shape performers showed similar [HbO2] across the TMRs in the collocated condition ($Chi^2 = 0.20$; $P = 0.90$).

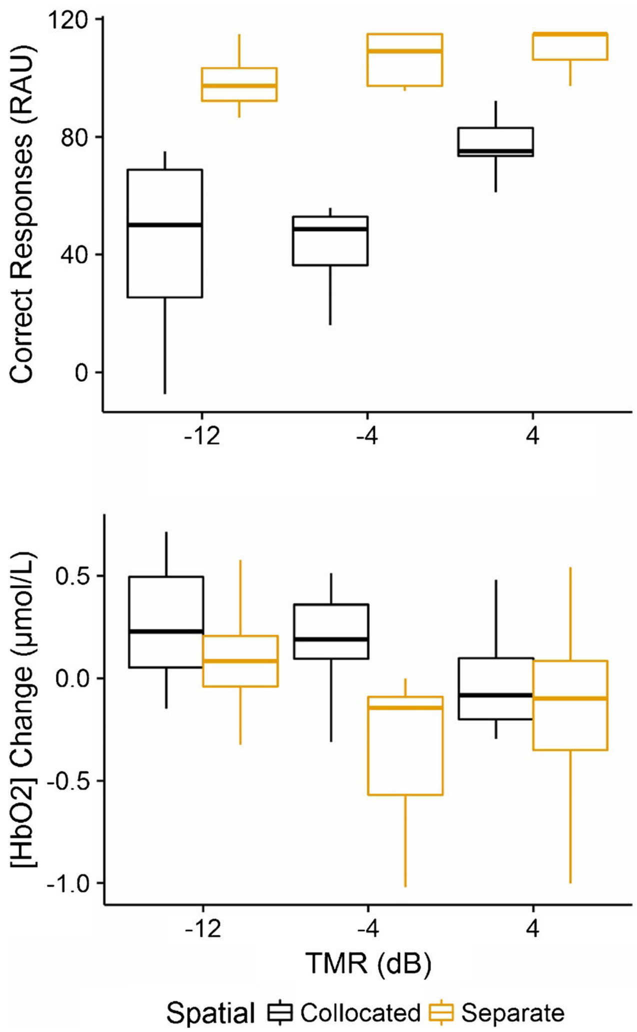

FIG. 2. Correct response scores (*upper panel*) and oxygenation change (*lower panel*) plotted against TMR. For each TMR, the results with collocated talkers are plotted in *black* (*left boxplots*), and the results with separate talkers are plotted in *orange* (*right boxplots*). The *boxplots* show the median (*horizontal bar*) and the interquartile range (*boxes*) and the *whiskers* show the 5–95 percentile interval. The spatial separation of the talkers improved the performance at any TMR. The spatial separation reduced the cognitive load only for intermediate TMR.

Relationship between Speech Intelligibility Performance and Prefrontal Activity

Previous results revealed that the effects of the spatial separation and TMR played a role in both performance level and prefrontal activity. Further analyses were conducted to explore the relationship between performance and prefrontal activity (mean [HbO2]) according to spatial separation and TMR.

Given the absence of voxel number effect, the [HbO2] changes were averaged across the optodes for each listener. Then, a linear mixed-effect model was computed: the dependent variable was the speech intelligibility scores transformed in RAU, and the predictors were the [HbO2] changes, the spatial separation, and the TMR. The listeners were considered as a random effect. The model revealed a significant interaction between the three predictors ($F_{(2, 75.4)} = 4.64$, $P = 0.013$). To decompose that interaction, the correlation between speech intelligibility scores and [HbO2] changes was computed for each combination of the factors spatial separation and TMR.

A significant positive correlation was observed with the adverse TMR in the collocated condition ($r^2(12) = 0.38$, $P = 0.018$) (Fig. 4, upper-left panel). With the adverse TMR, higher performance is related with higher prefrontal activity in the collocated condition. It appeared that U-shape performers exhibited both high performance and high prefrontal activity in that condition.

No correlation was observed in the separate conditions.

DISCUSSION

The motivation of our study was to examine how the relative levels of the talkers influenced the spatial

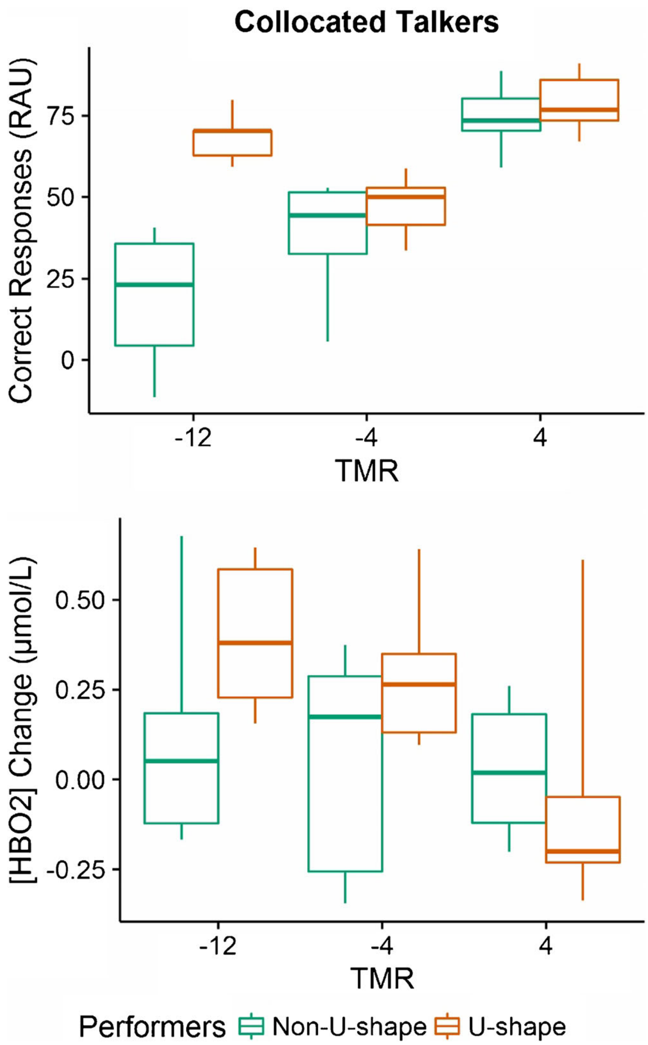

FIG. 3. Correct response scores (*upper panel*) and oxygenation change (*lower panel*) plotted against TMR in the collocated condition. For each TMR, the results of the non U-shape performers are plotted in *green* (*left boxplots*), and the results of the U-shape performers are plotted in *red* (*right boxplots*). The *boxplots* show the median (*horizontal bar*) and the interquartile range (*boxes*) and the *whiskers* show the 5–95 percentile interval. By definition, for the U-shape performers, the intelligibility score was similar for adverse and favorable TMR. For the non-U-shape performers, the intelligibility scores decreased with the TMR. For the U-shape performers, [HbO2] increased with the TMR. For the non-U-shape performers, [HbO2] was similar across the TMRs.

release of the cognitive load in a cocktail party paradigm. The cognitive load was assessed by the [Hb02] changes reflecting prefrontal activity measured by fNIRS. We observed that the cognitive load was reduced by the spatial separation of talkers only for the intermediate TMR. The prefrontal activity did not seem to vary significantly across the optodes as we found no effect of optode number in our analyses. It was consistent with neuroimaging studies, revealing that not a specific area but rather a broad network of cortical areas including several frontal areas are recruited during a multi-talker listening situation (Zekveld et al. 2014a).

Our results at intermediate TMR are consistent with Xia et al. (2015) who found that the spatial separation of different gender talkers presented at the same voice level reduced the cognitive load. However, Xia and colleagues found no spatial release of cognitive load for same-gender talkers. The authors explained this counter-intuitive result by a tradeoff in favor of the secondary task for too difficult listening condition. Our results support this hypothesis: in the absence of any segregating cue (nor spatial nor gender cue), their primary auditory task was too difficult. The absence of spatial release of cognitive load for same-gender talkers in Xia and colleagues could then be due to the dual-task paradigm.

In line with Zekveld and colleagues (Zekveld et al. 2014b), no spatial release of the cognitive load at adverse TMR was found in our study. Zekveld and colleagues compared the cognitive load at two TMRs, one for the separate talkers and one for the collocated

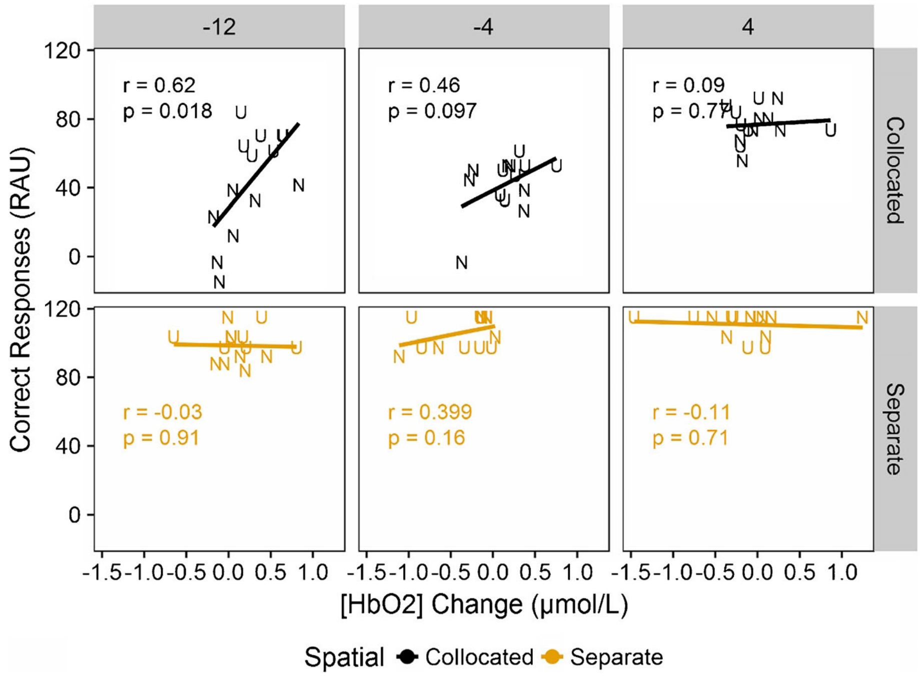

FIG. 4. Intelligibility scores plotted against [HbO2] changes for each combination of TMR and spatial separation conditions. The letter "*U*" indicates the U-shape performers and the letter "*N*" indicates the non-U-shape performers. The Pearson's coefficient of correlation and its degree of significance is indicated in each panel. For collocated talkers, at adverse TMR, the higher the prefrontal activity, the higher the performance was.

talkers. The two TMRs were adapted to give the same performance in terms of SRT_{50}. The point is that SRT_{50} was obtained at an adverse TMR with separate talkers whereas it required favorable TMR with collocated talkers. Therefore, Zekveld and colleagues compared the cognitive load between those two combined conditions: adverse TMR/separate talkers vs. favorable TMR/collocated talkers. We also found no difference in our data for those specific conditions. Thus, the studies of Xia and colleagues and Zekveld and colleagues could be conciliated by taking into account the role of TMR in the spatial release of cognitive load. Interestingly, those results are consistent despite the differences in terms of paradigm and measure to assess the cognitive load: Xia and colleagues used a CRM paradigm with a dual task, Zekveld and colleagues an SRT paradigm with pupil dilation, and our study a CRM paradigm with fNIRS.

Our findings also confirm that the level difference between the masker and the target can paradoxically be used as a cue to distinguish the talkers in the adverse TMR condition (Brungart 2001; Ihlefeld and Shinn-Cunningham 2008). Actually, individual analysis disclosed that half of the listeners (U-shape performers) had similar performance in the adverse and the favorable TMRs of the collocated condition, probably because they were able to use the level difference between the target and the masker to segregate them (the condition blocks were randomized across listeners). In other words, with the adverse TMR, i.e., the most difficult condition, the U-shape performers reached similar scores to those achieved with the positive TMR, a much easier condition (16-dB gap in favor of the target). The U-shape performers have probably used the level difference between the two voices to focus on the softest one. Their performance was achieved at a cognitive cost as supported by higher prefrontal activity in the adverse TMR than with the favorable TMR (Fig. 3) in the collocated condition. This increase in prefrontal activity as a function of the TMR may reflect the activation of attentional systems. However, as the attentional systems are not restricted to prefrontal cortex, the measures of other cortical areas (parietal cortex) are required to confirm that hypothesis. The non-U-shape performers showed similar prefrontal activity across the TMRs in the collocated condition which could suggest a lack of attentional engagement (Durantin et al. 2014). More generally, for challenging conditions, the differences in speech intelligibility and prefrontal activity could be related as evidenced by the positive correlation: the higher the prefrontal activity, the higher the speech intelligibility (Fig. 4).

In normal-hearing listeners, our results provide evidence that the measure of prefrontal activity with fNIRS could help undercover the relationship between speech intelligibility, spatial separation, and cognitive load. For instance, spatial separation can dramatically improve speech intelligibility without increasing the cognitive load. In fact, the spatial separation can even decrease the cognitive load for intermediate TMR, as shown by our data. The cognitive resources of listeners can often be limited in everyday life situations, either by age or pathology or when task demands exceed listener's mental capacity—for instance, in multitasking environment. Moreover, those same people can also suffer from low speech intelligibility because of weak or no access to spatial cues, such as hearing-impaired listeners wearing hearing aids (Neher et al. 2009) or the operators of complex systems dealing with multi-channel communications (Brungart et al. 2001). Binaural techniques are therefore a promising way to improve speech intelligibility (Brungart and Simpson 2005) in a cognitively efficient way.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest The authors declare that they have no conflict of interest.

REFERENCES

Ayaz H, Onaral B, Izzetoglu K, et al (2013)Continuous monitoring of brain dynamics with functional near infrared spectroscopy as a tool for neuroergonomic research: empirical examples and a technological development. Front Hum Neurosci 7:871. doi:10.3389/fnhum.2013.00871

Ayaz H, Shewokis PA, Bunce S et al (2012) Optical brain monitoring for operator training and mental workload assessment. NeuroImage 59:36–47. doi:10.1016/j.neuroimage.2011.06.023

Bolia RS, Nelson WT, Ericson MA, Simpson BD (2000) A speech corpus for multitalker communications research. J Acoust Soc Am 107:1065–1066

Bronkhorst AW (2015) The cocktail-party problem revisited: early processing and selection of multi-talker speech. Atten Percept Psychophys 77:1465–1487. doi:10.3758/s13414-015-0882-9

Brungart DS (2001) Informational and energetic masking effects in the perception of two simultaneous talkers. J Acoust Soc Am 109:1101–1109

Brungart DS, Simpson BD (2005)Improving multitalker speech communication with advanced audio displays. In: New directions for improving audio effectiveness. RTO Human Factors and Medicine Panel (HFM-123) Symposium.

Brungart DS, Simpson BD, Ericson MA, Scott KR (2001) Informational and energetic masking effects in the perception of multiple simultaneous talkers. J Acoust Soc Am 110:2527–2538

Bunce SC, Izzetoglu K, Ayaz H, et al. (2011) Implementation of fNIRS for monitoring levels of expertise and mental workload. In: International Conference on Foundations of Augmented Cognition. Springer, pp 13–22

Delpy DT, Cope M, van der Zee P et al (1988) Estimation of optical pathlength through tissue from direct time of flight measurement. Phys Med Biol 33:1433

Dieler AC, Tupak SV, Fallgatter AJ (2012) Functional near-infrared spectroscopy for the assessment of speech related tasks. Brain Lang 121:90–109

Durantin G, Gagnon J-F, Tremblay S, Dehais F (2014) Using near infrared spectroscopy and heart rate variability to detect mental overload. Behav Brain Res 259:16–23. doi:10.1016/j.bbr.2013.10.042

Durantin G, Scannella S, Gateau T et al (2015) Processing functional near infrared spectroscopy signal with a Kalman filter to assess working memory during simulated flight. Front Hum Neurosci 9:707. doi:10.3389/fnhum.2015.00707

Eddins DA, Liu C (2012) Psychometric properties of the coordinate response measure corpus with various types of background interference. J Acoust Soc Am 131:EL177-183. doi:10.1121/1.3678680

Füllgrabe C, Moore BCJ, Stone MA (2014) Age-group differences in speech identification despite matched audiometrically normal hearing: contributions from auditory temporal processing and cognition. Front Aging Neurosci 6:347. doi:10.3389/fnagi.2014.00347

Gagnon J-F, Durantin G, Vachon F, et al (2012)Anticipating human error before it happens: towards a psychophysiological model for online prediction of mental workload. In: Human Factors Ergonomics Society (HFES 2012) Chapter Europe, 10 October 2012 - 12 October 2012 (Toulouse, France).

Gateau T, Durantin G, Lancelot F et al (2015) Real-time state estimation in a flight simulator using fNIRS. PLoS One 10:e0121279. doi:10.1371/journal.pone.0121279

Glyde H, Hickson L, Cameron S, Dillon H (2011) Problems hearing in noise in older adults: a review of spatial processing disorder. Trends Amplif 15:116–126. doi:10.1177/1084713811424885

Ihlefeld A, Shinn-Cunningham B (2008) Spatial release from energetic and informational masking in a selective speech identification task. J Acoust Soc Am 123:4369–4379. doi:10.1121/1.2904826

Mandrick K, Chua Z, Causse M et al (2016) Why a comprehensive understanding of mental workload through the measurement of neurovascular coupling is a key issue for neuroergonomics? Front Hum Neurosci 10:250

McKendrick R, Parasuraman R, Ayaz H (2015) Wearable functional near infrared spectroscopy (fNIRS) and transcranial direct current stimulation (tDCS): expanding vistas for neurocognitive augmentation. Front Syst Neurosci 9:27. doi:10.3389/fnsys.2015.00027

Neher T, Behrens T, Carlile S et al (2009) Benefit from spatial separation of multiple talkers in bilateral hearing-aid users: effects of hearing loss, age, and cognition. Int J Audiol 48:758–774. doi:10.3109/14992020903079332

Roche-Labarbe N, Zaaimi B, Berquin P et al (2008) NIRS-measured oxy- and deoxyhemoglobin changes associated with EEG spike-and-wave discharges in children. Epilepsia 49:1871–1880. doi:10.1111/j.1528-1167.2008.01711.x

Strait M, Scheutz M (2014) What we can and cannot (yet) do with functional near infrared spectroscopy. Front Neurosci. doi:10.3389/fnins.2014.00117

Villringer A, Obrig H (2002) Near infrared spectroscopy and imaging. In: brain mapping: the methods, Elsevier. Science:141–158

Xia J, Nooraei N, Kalluri S, Edwards B (2015) Spatial release of cognitive load measured in a dual-task paradigm in normal-hearing and hearing-impaired listeners. J Acoust Soc Am 137:1888–1898. doi:10.1121/1.4916599

Zekveld AA, Heslenfeld DJ, Johnsrude IS et al (2014a) The eye as a window to the listening brain: neural correlates of pupil size as a measure of cognitive listening load. NeuroImage 101:76–86. doi:10.1016/j.neuroimage.2014.06.069

Zekveld AA, Rudner M, Kramer SE et al (2014b)Cognitive processing load during listening is reduced more by decreasing voice similarity than by increasing spatial separation between target and masker speech. Front Neurosci 8:88. doi:10.3389/fnins.2014.00088