Background white noise and speech facilitate visual working memory

Sizhu Han[1, †], Ruizhen Zhu[1, †], Yixuan Ku[1,2,3,*]

[1] School of Psychology and Cognitive Science, East China Normal University, Shanghai, China

[2] Guangdong Provincial Key Laboratory of Social Cognitive Neuroscience and Mental Health, Department of Psychology, Sun Yat-sen University, Guangzhou, China

[3] Peng Cheng Laboratory, Shenzhen, China

† co-first authors.

* correspondence should be addressed to: Yixuan Ku, Department of Psychology, Sun Yat-sen University, Guangzhou, China. E-mail: kuyixuan@mail.sysu.edu.cn

Acknowledgement

This work was supported by the National Social Science Foundation of China (17ZDA323), the Shanghai Committee of Science and Technology (19ZR1416700), and the Hundred Top Talents Program from Sun Yat-sen University.

Abstract

Phonological loop and visuospatial sketchpad have been proposed as two independent systems in working memory (WM). Previous studies suggest that background speech but not white noise declines performance of verbal WM. However, whether the background sounds influence visual WM remains unclear. In the present study, participants performed an orientation reproduction task while we played background speech or white noise. Electrodermal activity (EDA) and Electromyography (EMG) were recorded simultaneously. Results indicated that both background speech and white noise significantly improved visual WM performance, and such behavioral enhancement was significantly correlated with changes in physiological signals linked with arousal or emotion expression. Taken together, our results suggest that the phonological loop and visuospatial sketchpad is not fully independent and background speech and white noise facilitate visual WM through physiological changes in arousal and emotion expression.

Keywords: background white noise, background speech, visual working memory, arousal, retro-cues

Introduction

Working with background sounds is a preferred mode for many individuals. Numerous studies suggest that background sound such as music can influence cognitive performance (e.g. Rauscher, Shaw, & Ky, 1993).

As a core cognitive function, working memory (WM) is the ability to store and manipulate sensory information that is no longer accessible in the environment (Baddeley, 1996). It is widely accepted that WM contains two “slave” systems, one is the phonological loop, which processes and stores verbal WM information (Baddeley & Hitch, 1974). Previous studies indicated that background speech declined performance of verbal WM (Salamé & Baddeley, 1987), while background white noise did not change verbal WM performance (Salamé & Baddeley, 1987, 1989). In light of this, the phonological loop was proposed to include a speech detector, which interacted with unattended background speech but not with white noise (Salamé & Baddeley, 1989).

The other “slave” system is known as the visuospatial sketchpad, which processes and stores visuospatial WM information. It should be noted that although phonological and visuospatial storages were proposed to be independent (Baddeley & Hitch, 1974), there existed similar attention-based refreshing for both phonological (Oberauer, 2019) and visuospatial (Souza, Czoschke, & Lange, 2019) WM. Moreover, others offered a cross-modal interaction model with both shared central part and distinct peripheral part of verbal and non-verbal WM (Cowan, Saults, & Blume, 2014). These findings indicated that background sound that changed verbal WM performance (Salamé & Baddeley, 1987, 1989) may influence visual WM as well.

To examine this issue, we compared the impacts of background speech (deteriorating verbal WM) vs. background white noise (no effect on verbal WM) on visual WM, using a reproduction task to measure the precision of visual WM, which is more sensitive than traditional measurement with change detection tasks (Ma, Husain, & Bays, 2014). In addition, we used electrodermal activity (EDA) and electromyography (EMG) to track the arousal and emotion expression changes (Thompson, Mackenzie, Leuthold, & Filik, 2016) caused by the background speech or white noise, compared to the background quiet condition. Such design helps in disentangling the physiological mechanisms of background sound effects on visual WM.

Apart from the potential changes in the level of arousal caused by background sounds, visual WM can also be refreshed by active attentional effects, which is usually manipulated by a spatial retro-cue during the retention interval (Berryhill, Richmond, Shay, & Olson, 2012; Griffin & Nobre, 2003; Landman, Spekreijse, & Lamme, 2003; Makovski, 2012; Matsukura, Luck, & Vecera, 2007; Matsukura & Vecera, 2011; Pertzov, Bays, Joseph, & Husain, 2013; Williams & Woodman, 2012). In the present study, we apply two typical forms of spatial retro-cues, endogenous (i.e., central cuing) and exogenous (i.e., peripheral cuing), in different background sound conditions to differentiate the orienting/execution vs. arousal components of attention (Posner & Petersen, 1990).

In sum, we used a reproduction visual WM task under one out of three background sound conditions (speech, white noise, quiet) to investigate whether background sound could influence visual WM. And then if there exists a sound effect, what are the underlying psychological and physiological mechanisms?

Methods

Participants

Twenty-seven healthy participants (18 - 23 years old) were recruited from East China Normal University (ECNU). Participants had normal or corrected-to-normal vision and each received ¥ 80 for their participation. The experimental protocol was approved by human research ethics committee at

ECNU, and all participants provided written informed consent prior to the experiment.

Apparatus and stimuli

We programmed the experiment using Psychtoolbox implemented in MATLAB R2014b. Visual stimulus was presented on the screen with a resolution of 1024 * 768 pixels and 60Hz refresh rate.

We selected background white noise from the website: http://vdisk. weibo.com/s/d2wl3MjefQaw4, and speech noise from “30 Minutes News - 20180410”. The length of these materials was edited using Adobe Audition software and restricted to 20 minutes**.** In addition, we set the volume of background speech and white noise to a fixed value beforehand, as previous research found it per se could modulate visual WM (Helps, Bamford, Sonuga-Barke, & Söderlund, 2014; Söderlund, Marklund, & Lacerda, 2009). To do so, we firstly used the keywords "white noise", "speech noise", "working memory" and "irrelevant speech effect" to search for relevant publications. Six out of 86 pieces of literature (see Table 1 for details) were finally selected for further analysis based on the following criteria: (1) including both quiet and noise conditions; (2) using VWM task in the experiment; (3) reporting the dB value of noise materials; (4) subjects were healthy adults.

Table 1

The volume of noise and corresponding performance in literatures.

Reference	Volume(dB)	BQ	BW Raw	BW Revised	BS Raw	BS Revised
1	47.5	2.91	4.23	0.452	--	--
2	55	0.17	0.81	3.765	--	--
3	57.5	0.28	--	--	0.17	-3.214
4	70	28.2	29.6	0.050	29.9	0.060
5	78	40	31	-0.225	37.5	-0.063
6	85	37.3	--	--	36.8	-0.013

	90	37.3	39.3	0.054	--	--

Note. References from number 1 to 6 are in turn: Daud & Sudirman (2017a), Borella et al. (2017), Sörqvist (2010), Van Gerven, Meijer, Vermeeren, Vuurman, & Jolles (2007), SöDerlund & SikströM (2012) and Baker & Holding (1993). BQ = Background Quiet, BW = Background White Noise, BS = Background Speech Noise, the same below.

Data from each study was then transformed into the normalized value with the formula as below:

$$\text{TS (Noise)}_{revised} = \frac{\text{TS (Noise)}_{raw} - \text{TS (Quiet)}_{raw}}{\text{TS (Quiet)}_{raw}}$$

TS denotes the task score. The data after transformation (i.e., Noise revised) is shown in Table 1 and Figure 1. To maximize the reverse effects by background white noise and speech, we fixed the volume at 55dB in our experiment, measured by a decibel meter (Model AWA 5636).

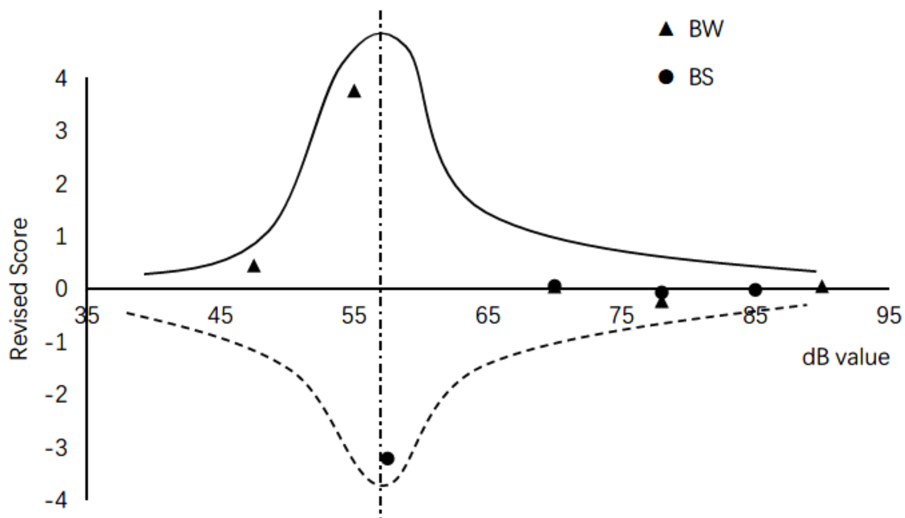

Fig. 1. A normalized distribution of task scores as a function of volume.

Experimental procedure

During the experiment, participants were seated 63 cm away from the screen with their head fixed on the chin rest.

As shown in Fig. 2, each trial started with a central fixation dot for 500ms, followed by memory items for another 500ms. The display consisted of two Gabor patches (radius 5°, contrast 100%, spatial frequency 2 cycles/degree) differed by at least 10°. After a short delay (2,000ms), a Gabor with a randomly chosen orientation showed up at one of the two locations where memory items were presented before. Participants were requested to adjust its orientation to match the one that was early encoded at the same location. A trial ended with a click of the left button. The inter-trial-interval was 1,000ms. In two thirds of trials, either an endogenous (i.e., a central arrow) or an exogenous retro-cue (i.e., a peripheral circle) was presented for 100ms at 1000ms after memory items offset. In the remaining trials, the central fixation dot remained on screen during the whole delay period, without any changes to it (i.e. no cue).

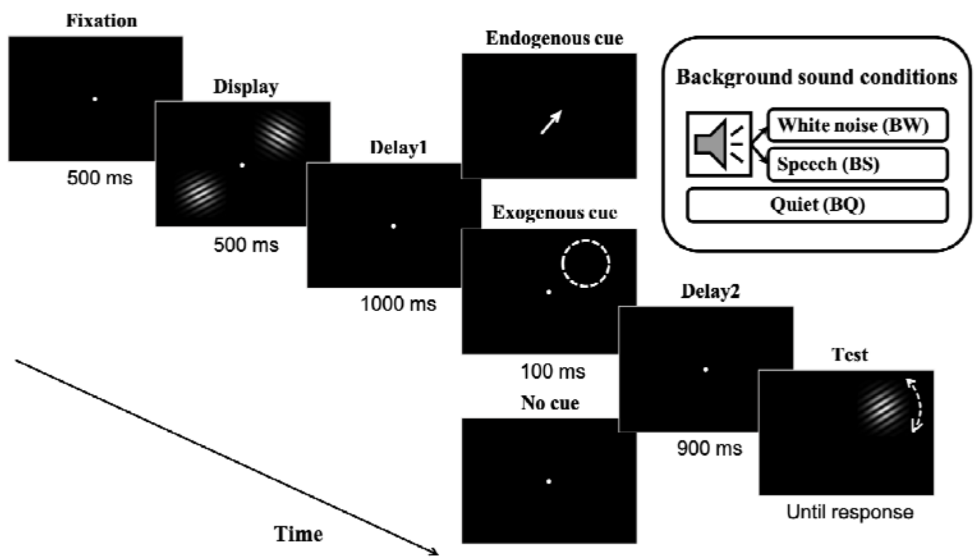

Fig. 2. Trial sequence. After a fixation dot, two Gabor patches were presented followed by an initial delay period. Next, one of three cues (a central arrow indicates the endogenous cue, a dashed circle at the periphery indicates the exogenous cue, a fixation point indicates the no cue) flashed and followed by a second delay period. After the second delay period, a probed Gabor appeared and subjects had to rotate the orientation of the Gabor to match the one in their memory at the same location by using the mouse.

To get familiar with the task, participants were instructed to practice 20 trials. The experiment contained 9 blocks with 72 trials each. Three cue types were randomly intermixed within each block. The auditory condition alternated in every 3 blocks, whose sequence was counterbalanced across participants.

Electrophysiological data collection.

We used MP150 multi-conducting physiological recorder (America, BIOPAC company) to collect electrophysiological signals. Specifically, EMG signals were measured through an EMG100C amplifier with 2 shielded LEAD11A0S wires, 1 non-shielded LEAD100A wire and 3 BIOPAC disposable electrodes. EDA signals were measured through a skin electric sensor (TSD203). These signals were recorded with AcqKnowledge 5.0 software and then exported for further analysis.

Data analysis

Behavioral analysis. We calculated Raw SD as the circular standard deviation of response errors (-90° ~ 90°), which was adjusted with CircStat2012a toolbox (Berens, 2009). Two sources of response errors, the guess rate and SD (1/precision), were respectively estimated from the Standard Mixture Model (Zhang & Luck, 2008) using the MemToolbox toolbox (Suchow, Brady, Fougnie, & Alvarez, 2013). The guess rate represents the probability of forgetting a target item. SD indicates how precise the mnemonic item is. Three subjects were excluded due to poor behavioral performance (guess rate>chance level/0.5).

Electrophysiological analysis. EMG and EDA reflect the electrical impulses of muscle fibers and the skin conductance, respectively. A lower value of EMG or a higher value of EDA suggest a larger level of arousal (Thompson et al., 2016). Data from 4 participants was additionally excluded due to abnormal values (>2 standard deviations) or missing data (2 subjects), leaving data from 20 subjects were included into analysis.

Statistical analysis. All analysis was performed using the SPSS 22.0 software. For behavioral data, we performed a two-way repeated ANOVA with auditory condition and visual cue type as factors. For physiological data, we performed one-way repeated ANOVA with auditory condition as a factor. Post-hoc *t*-tests were further conducted if significant main effects or interactions were founded (alpha<0.05). Finally, we used Pearson correlation to analyze the correlation between behavioral and physiological data.

Results

Behavioral results

Raw SD. As shown in Fig. 3a, there was no interaction between auditory condition and cue type (F (4, 76) =0.644, p=0.633, η_p^2=0.033). The main effect of auditory condition was significant (F (2, 38) =8.539, p=0.001, η_p^2=0.310). Post hoc t-tests (see Fig. 3b) revealed that the Raw SD was significantly lower in background white noise (t=-3.092, p=0.006) and speech noise (t=-3.547, p=0.002) than in background quiet condition, but no difference was found between background white noise and speech noise condition (p=0.830). The main effect of cue type was also significant (F (2, 38) =16.972, p<0.001, η_p^2=0.472). Post hoc t-tests (see Fig. 3c) revealed that Raw SD was significantly lower in both exogenous (t=-4.547, p<0.001) and endogenous retro-cues (t=-4.417, p<0.001) compared to no cue condition, there was no significant difference between two types of cues (p=0.863).

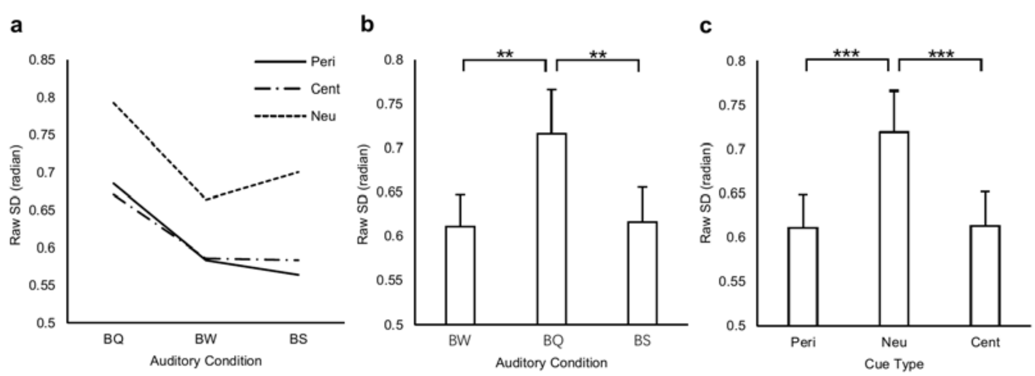

Fig. 3. Raw SD results. (a) mean values for each condition. (b) the main effect of auditory condition. (c) the main effect of cue type. Error bars denotes standard deviation. Peri = exogenous cue, Neu = no cue, Cent = endogenous cue. *p <0.05, **p< 0.01, ***p< 0.001, the same below.

Model fitting results. For the guess rate (see Fig. 4a), the main effect of cue type (F (2, 38) =1.069, p=0.354, η_p^2=0.053; Fig. 4c) and the interaction between auditory condition and cue type (F (4, 76) =0.146, p=0.964, η_p^2=0.008) was not significant. However, there was a significant main effect of auditory condition (F (2, 38) =3.822, p=0.031, η_p^2=0.167). The post hoc t-tests (see Fig. 4b) showed that only background white noise decreased the guess rate compared to background quiet condition (t=-2.602, p=0.018), no other difference was found (ps>0.05).

For SD (see Fig. 4d), the interaction between auditory condition and cue type was not significant (F (4, 76) =0.673, p=0.613, η_p^2=0.034), but the main effect of auditory condition was significant (F (2, 38) =4.299, p=0.021, η_p^2=0.185). Post hoc t-tests (see Fig. 4e) showed that only background speech noise decreased SD compared to background quiet condition (t=-3.753, p=0.001), and no other difference was found (ps>0.05). In addition, the main effect of cue type was also significant (F (2, 38) =15.413, p<0.001, η_p^2=0.448). Post hoc t-tests (see Fig. 4f) showed both exogenous (t=-4.919, p<0.001) and endogenous (t=-4.590, p<0.001) retro-cues decreased SD compared to no cue condition, there was no significant difference between the two cues (p=0.503).

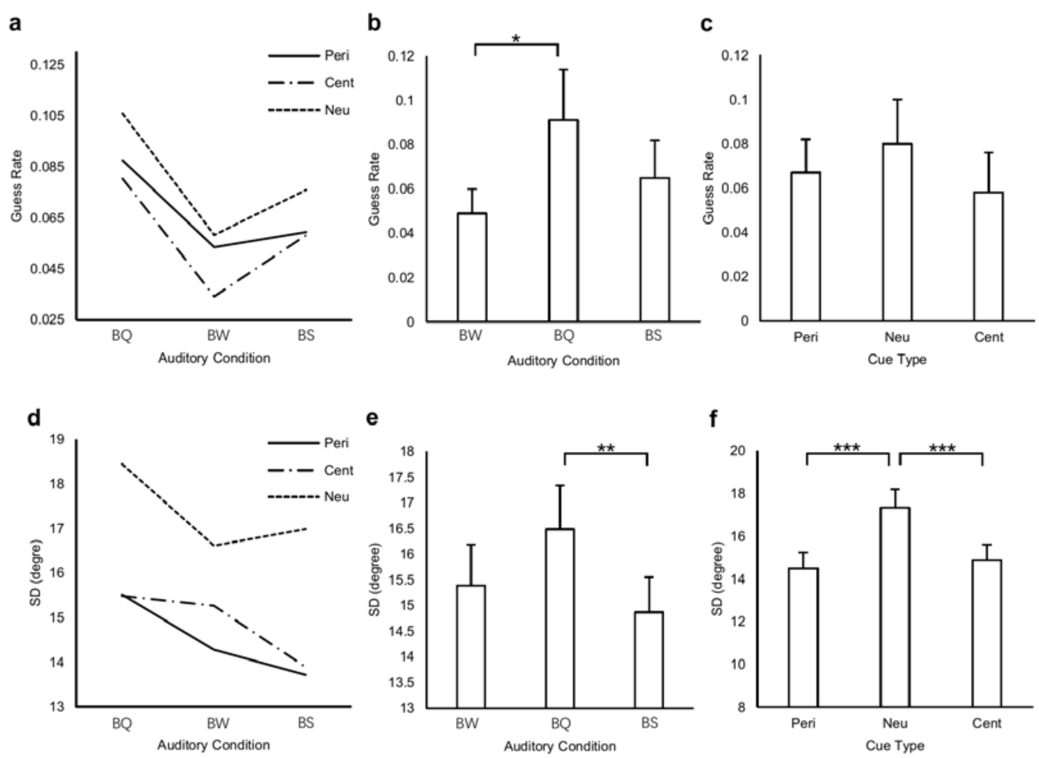

Fig. 4. Model fitting results. (a-c) the averaged guess rate for each condition (a), and for the main effect of auditory condition (b) and of cue type (c). (d-f) the averaged SD for each condition (d) and for the main effect of auditory condition (e) and of cue type (f).

Physiological results

As shown in Fig. 5a, for EMG signals, the main effect of auditory condition was not significant (F (2, 38) =0.448, p=0.642, η_p^2=0.023). The background white noise has the lowest EMG values (M=-3.679, SD=0.292), followed by the background speech noise (M=-3.654, SD=0.288). The background quiet condition has the highest EMG values (M=-3.613, SD=0.318).

As shown in Fig. 5b, for EDA signals, the main effect of auditory condition was not significant either (F (2, 38) =0.183, p=0.834, η_p^2=0.01). The background white noise has the highest EDA values (M=0.002305, SD=0.006236), followed by the background speech noise (M=0.002302 , SD=0.006247). The background quiet condition has the lowest EDA values (M=0.002279 , SD=0.006237).

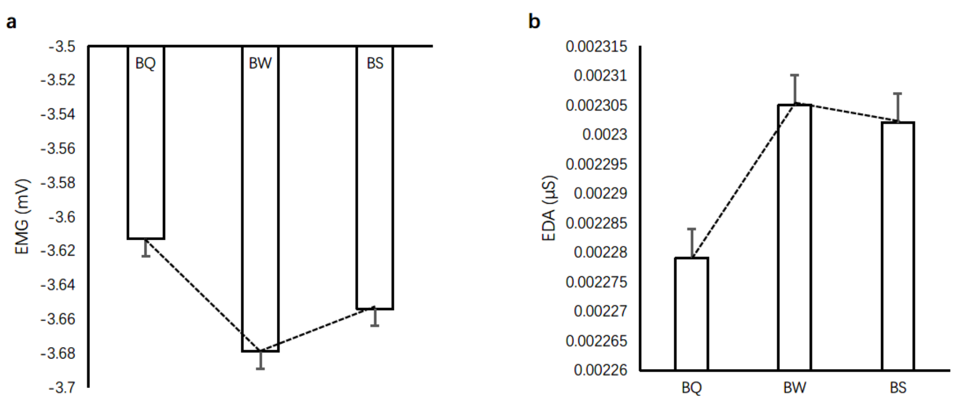

Fig. 5. Electrophysiological results. EMG(a) and EDA (b) values for three auditory conditions, respectively.

The correlation between the behavioral and physiological results

As shown in Fig. 6, the decrease of guess rate induced by background white noise was significantly correlated with the decrease of EMG values (r=0.443, p=0.05, see Fig. 6a). In addition, the decrease of SD induced by background speech noise was significantly correlated with the increase of EDA values (r=-0.489, p=0.03, see Fig. 6b). These findings altogether suggested that both background white noise and speech noise led to improvement through arousal enhancement (see supplementary Table 1 for more details).

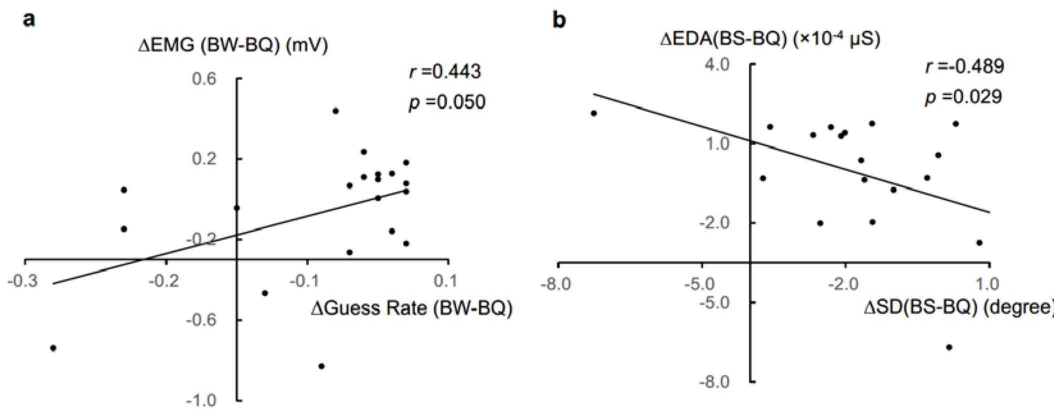

Fig. 6. Correlations between behavioral and physiological results. (a) the correlation between the guess rate of background white noise relative to background quiet condition and their EDA difference. (b) the correlation between the SD of background speech noise relative to background quiet condition and their EMG difference.

Discussion

In contrast to the deficient effect of background speech and null effect of background white noise in verbal WM (Salamé & Baddeley, 1987, 1989), we observed beneficial effects for both background speech and white noise in visual WM. Compared with background quiet condition, background white noise lowered the guess rate while background speech facilitated the precision of visual WM. There are a couple of implications from these results. First, the phonological loop and visuospatial sketchpad may not be fully independent, because if so, the impact of background sound would interact with the phonological loop without effects on visual WM performance.

Second, although both detector and filter mechanisms in verbal WM have been proposed by Salame & Baddeley, they preferred detector theory to account for the results they observed, i.e., background speech deficit and null effect with white noise (Salamé & Baddeley, 1987, 1989). Here in the visual domain, both detector for signal and filter for noise might exist, as we observed that the background speech and white noise influenced different aspects of visual WM. It seems that background white noise biased the filtering mechanism and decrease the guess rate (internal noise); background speech altered the detecting mechanism and increase the precision (signal strength).

Third, how would these interactions be achieved? Through physiological recordings, changes in arousal levels might serve as the mechanism underlying these effects. Although we did not observe significant difference in physiological changes induced by the two kinds of background sound (yet noticing the mean difference), there existed individual differences in behavior that could be accounted by the physiological pattern. The changes in EDA were correlated with the precision difference when background speech was compared with quite; the changes in EMG were correlated with the guess rate difference when background white noise was compared with quiet condition. EDA was suggested to directly measure arousal and EMG was suggested to track the emotional expressions (Thompson et al., 2016). Our results indicate that changes in arousal are linked to signal detection and emotional expressions are related to noise filtering.

It should be noted that our main purpose was to compare different types of background sound, so the sound volume was not varied and set to 55dB. Previous studies have found an inverted "U"-shape between the relationship of task performance and noise volume (Hallam, Price, & Katsarou, 2002), and Yerkes-Dodson Law was used to explain the results. The complexity of noise could also lead to different effects (Baker & Holding, 1993). Moreover, the effects of volume further depended on personality of introverts or extraverts (Furnham & Bradley, 1997). Therefore, future study could extend our settings to investigate the effects caused by different sound volumes to individuals with different personalities.

We did not observe interaction between the types of background sound and types of retro-cues. The former was shown to influence arousal level, while the latter was an active refreshing of WM representations (Griffin & Nobre, 2003; Gunseli, van Moorselaar, Meeter, & Olivers, 2015; Landman et al., 2003; Shimi, Nobre, Astle, & Scerif, 2014; Souza, Rerko, & Oberauer, 2016). These results indicated dissociations between components of arousal and orienting/execution in proposed attention model (Posner & Petersen, 1990).

The findings that irrelevant stimuli from the auditory domain could affect WM performance in the visual domain could further prove cross-modal influence (Driver & Noesselt, 2008), and could result from different neural pathways, for example, sensory-to-sensory, sensory-thalamus-sensory, or sensory-associative-areas-sensory. Future studies combing imaging tools could possibly dissect the pathways.

Some studies applied background white noise to enhance cognitive performance in children with attention deficits (for example, ADHD) and proposed a stochastic resonance theory by alter the “signal to noise” ratio through adding different level of background white noise (Helps et al., 2014; Sderlund & Sikstrm, 2012; Söderlund, Sikström, Loftesnes, & Sonuga-Barke, 2010). It would be interesting to further compare between background speech and white noise on visual WM to extend our findings out of normal participants.

In conclusion, background speech and white noise improve visual WM performance. Specifically, background speech increases the precision of visual WM and background white noise lower the guess rate. Both of them increase the signal-to-noise ratio and correlate with changes in physiological measurement linked with arousal and emotional expression. Our results suggest that the phonological loop and visuospatial sketchpad is not fully independent and there exist links between the manipulations in auditory vs. visual domain.

Reference

Baddeley, A. (1996). The fractionation of working memory. *Proceedings of the National Academy of Sciences*, *93*(24), 13468–13472. https://doi.org/10.1073/pnas.93.24.13468

Baddeley, A., & Hitch, G. (1974). Working memory. *The Psychology of Learning and Motivation*, *8*, 47–89.

Baker, M. A., & Holding, D. H. (1993). The effects of noise and speech on cognitive task performance. *Journal of General Psychology*. https://doi.org/10.1080/00221309.1993.9711152

Berens, P. (2009). CircStat□: A MATLAB Toolbox for Circular Statistics. *Journal of Statistical Software*, *31*(10), 34019. https://doi.org/10.18637/jss.v031.i10

Berryhill, M. E., Richmond, L. L., Shay, C. S., & Olson, I. R. (2012). Shifting Attention among Working Memory Representations: Testing Cue Type, Awareness, and Strategic Control. *Quarterly Journal of Experimental Psychology*, *65*(3), 426–438. https://doi.org/10.1080/17470218.2011.604786

Cowan, N., Saults, J. S., & Blume, C. L. (2014). Central and peripheral components of working memory storage. *Journal of Experimental Psychology: General*, *143*(5), 1806–1836. https://doi.org/10.1037/a0036814

Driver, J., & Noesselt, T. (2008). Multisensory Interplay Reveals Crossmodal Influences on 'Sensory-Specific' Brain Regions, Neural Responses, and Judgments. *Neuron*, *57*(1), 11–23. https://doi.org/10.1016/j.neuron.2007.12.013

Furnham, A., & Bradley, A. (1997). Music while you work: the differential distraction of background music on the cognitive test performance of introverts and extraverts. *Applied Cognitive Psychology*, *11*(5), 445–455. https://doi.org/10.1002/(SICI)1099-0720(199710)11:5<445::AID-ACP472>3.0.CO;2-R

Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *Journal of Cognitive Neuroscience*, *15*(8), 1176–1194. https://doi.org/10.1162/089892903322598139

Gunseli, E., van Moorselaar, D., Meeter, M., & Olivers, C. N. L. (2015). The reliability of retro-cues determines the fate of noncued visual working memory representations.

Psychonomic Bulletin & Review, *22*(5), 1334–1341. https://doi.org/10.3758/s13423-014-0796-x

Hallam, S., Price, J., & Katsarou, G. (2002). The Effects of Background Music on Primary School Pupils' Task Performance. *Educational Studies*, *28*(2), 111–122. https://doi.org/10.1080/03055690220124551

Helps, S. K., Bamford, S., Sonuga-Barke, E. J. S., & Söderlund, G. B. W. (2014). Different Effects of Adding White Noise on Cognitive Performance of Sub-, Normal and Super-Attentive School Children. *PLoS ONE*, *9*(11), e112768. https://doi.org/10.1371/journal.pone.0112768

Landman, R., Spekreijse, H., & Lamme, V. A. F. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research*, *43*(2), 149–164. https://doi.org/10.1016/S0042-6989(02)00402-9

Ma, W. J., Husain, M., & Bays, P. M. (2014). Changing concepts of working memory. *Nature Neuroscience*. https://doi.org/10.1038/nn.3655

Makovski, T. (2012). Are multiple visual short-term memory storages necessary to explain the retro-cue effect? *Psychonomic Bulletin & Review*, *19*(3), 470–476. https://doi.org/10.3758/s13423-012-0235-9

Matsukura, M., Luck, S. J., & Vecera, S. P. (2007). Attention effects during visual short-term memory maintenance: protection or prioritization? *Perception & Psychophysics*, *69*(8), 1422–1434. https://doi.org/10.3758/BF03192957

Matsukura, M., & Vecera, S. P. (2011). Object-based selection from spatially-invariant representations: Evidence from a feature-report task. *Attention, Perception, and Psychophysics*, *73*(2), 447–457. https://doi.org/10.3758/s13414-010-0039-9

Oberauer, K. (2019). Is Rehearsal an Effective Maintenance Strategy for Working Memory? *Trends in Cognitive Sciences*, *23*(9), 798–809. https://doi.org/10.1016/j.tics.2019.06.002

Pertzov, Y., Bays, P. M., Joseph, S., & Husain, M. (2013). Rapid forgetting prevented by retrospective attention cues. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(5), 1224–1231. https://doi.org/10.1037/a0030947

Posner, M. I., & Petersen, S. E. (1990). The Attention System of the Human Brain. *Annual Review of Neuroscience*, *13*(1), 25–42.

https://doi.org/10.1146/annurev.ne.13.030190.000325

Rauscher, F. H., Shaw, G. L., & Ky, C. N. (1993). Music and spatial task performance. *Nature*, *365*(6447), 611–611. https://doi.org/10.1038/365611a0

Salamé, P., & Baddeley, A. (1987). Noise, unattended speech and short-term memory. *Ergonomics*. https://doi.org/10.1080/00140138708966007

Salamé, P., & Baddeley, A. (1989). Effects of Background Music on Phonological Short-Term Memory. *The Quarterly Journal of Experimental Psychology Section A*, *41*(1), 107–122. https://doi.org/10.1080/14640748908402355

Sderlund, G., & Sikstrm, S. (2012). Distractor or Noise? The Influence of Different Sounds on Cognitive Performance in Inattentive and Attentive Children. In *Current Directions in ADHD and Its Treatment*. https://doi.org/10.5772/29657

Shimi, A., Nobre, A. C., Astle, D., & Scerif, G. (2014). Orienting Attention Within Visual Short-Term Memory: Development and Mechanisms. *Child Development*, *85*(2), 578–592. https://doi.org/10.1111/cdev.12150

Söderlund, G. B., Marklund, E., & Lacerda, F. (2009). Auditory White Noise Enhances Cognitive Performance Under Certain Conditions: Examples from Visuo-Spatial Working Memory and Dichotic Listening Tasks. *Fonetik*.

Söderlund, G. B., Sikström, S., Loftesnes, J. M., & Sonuga-Barke, E. J. (2010). The effects of background white noise on memory performance in inattentive school children. *Behavioral and Brain Functions*, *6*(1), 55. https://doi.org/10.1186/1744-9081-6-55

Souza, A. S., Czoschke, S., & Lange, E. B. (2019). Gaze-based and attention-based rehearsal in spatial working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. https://doi.org/10.1037/xlm0000771

Souza, A. S., Rerko, L., & Oberauer, K. (2016). Getting more from visual working memory: Retro-cues enhance retrieval and protect from visual interference. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(6), 890–910. https://doi.org/10.1037/xhp0000192

Suchow, J. W., Brady, T. F., Fougnie, D., & Alvarez, G. A. (2013). Modeling visual working memory with the MemToolbox. *Journal of Vision*, *13*(10), 9.

Thompson, D., Mackenzie, I. G., Leuthold, H., & Filik, R. (2016). Emotional responses to irony and emoticons in written language: Evidence from EDA and facial EMG. *Psychophysiology*. https://doi.org/10.1111/psyp.12642

Williams, M., & Woodman, G. F. (2012). Directed forgetting and directed remembering in visual working memory. *Journal of Experimental Psychology: Learning Memory and Cognition*, *38*(5), 1206–1220. https://doi.org/10.1037/a0027389

Zhang, W., & Luck, S. J. (2008). Discrete fixed-resolution representations in visual working memory. *Nature*, *453*(7192), 233–235. https://doi.org/10.1038/nature06860

Appendix

Table 1

The correlation between the behavioral and electrophysiological results.

		ΔEMG	**ΔEDA**
BW - BQ	**ΔRaw SD**	0.242	-0.481*
	ΔGuess Rate	0.443*	-0.300
	ΔSD	-0.162	-0.364
BS – BQ	**ΔRaw SD**	0.349	-0.253
	ΔGuess Rate	0.100	0.061
	ΔSD	0.428	-0.489*

Note. ***p**<0.05. BW = Background White Noise, BQ = Background Quiet, BS = Background Speech.