UMEÅ UNIVERSITET

Effects of noise on memory performance in adults

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Bachelor thesis
Bachelor thesis in Psychology, 15 hp
Autom term 2018
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Abstrakt

Tidigare studier har visat att buller kan ha negativa effekter på vår kognitiva prestation. Dessa effekter på minnet har dock undersökts i mindre skala. Denna studie hade för avsikt att undersöka effekten av buller på arbetsminnet såväl som prospektiva minnet hos den vuxna populationen. En experimentgrupp bestående av frivilliga universitet studenter frågades att delta från Umeå Universitets Campus i denna studie (*N*=30*, M* =24.26 år gamla). En reversed digit span test och en event-based prospective memory test användes för att mäta arbetsminne och prospektiva minnet under tyst och buller tillstånd. Resultaten visade att deltagarna hade en signifikant sämre prestanda på arbetsminnestestet i buller tillstånd jämfört med tyst tillstånd men inte på prospektiva testet.

Nyckelord: arbetsminne, prospektivt minne, buller

Abstract

Previous studies have shown negative effects of noise on cognitive performance. However, these effects on memory have been less examined. This study was set out to investigate the effect of noise on working memory as well as prospective memory in an adult population. One experiment group comprised of university students approached at the Umeå University Campus volunteered for this study (*N*=30, *M*=24.26 years of age). A reversed digit span memory test and an event-based prospective memory test were used to measure working memory and prospective memory under silent and noise condition. Results showed that participants had significantly poorer performance on working memory task in noise condition compared to silent condition but not for the prospective memory task.

Keywords: working memory, prospective memory, noise

Noise can be best described as a sound that is, unwanted, annoying, with a fluctuating loudness and intensity level that can disturb ones hearing (Elert, 2016). In today's modern world, humans consume a huge load of various noises in their environmental or occupational settings. Much of these unwanted noises get filtered out by our brains and remains rather unnoticeable. But some of these noises cannot be habituated unconsciously depending on our personal differences (Basner, Müller, & Elmenhorst, 2011). Once, a noise reaches a certain level of intensity, it can no longer remain unattended and begins to affect the task we might be involved in or simply just cause annoyance for us. If the exposure to noise exceeds certain levels and become chronic, it could lead to some serious health effects such as hearing loss or cognitive impairments (Stansfeld, Haines, & Brown, 2000). Noise from road traffic, rails, building sites etc. are the types of environmental noise which are common in our daily lives. Earlier studies have shown that these types of noise can have a wide range of non-auditory health effects such as annoyance, impairment of cognitive performance in children, sleep disturbance and cardiovascular disease (Miedema & Oudshoorn, 2001; Muzet, 2007; van Kempen & Babisch, 2012; Sørensen et al., 2012; Stansfeld & Matheson, 2003). In our modern cities, we see a decrease of the quiet places and more people are exposed to levels of noise that go beyond the recommendations levels from World Health Organisation (Basner et al., 2014). Furthermore, Noise exposure has also been related to some psychiatric conditions such as depression, paranoia, and anxiety (Yoshida et al., 1997; Bocquier et al., 2014; Hardoy et al., 2005). Noise not only can influence our inner cognitive functions like attention, arousal and task strategy but also our social behaviors such paying attention to social cues, our communications with others and can also contribute to a higher risk of getting angry in others actions (Passchier-Vermeer & Passchier, 2000; Stansfeld & Matheson, 2003).

There are some central concepts that must be clearly defined for the context of this study. Working memory: " Working memory refers to the system or systems that are assumed to be necessary in order to keep things in mind while performing complex tasks such as reasoning, comprehension and learning " (Baddeley, 2010, p. 1). Prospective memory: " refers to the memory required to carry out planned actions at the appropriate time, such as meeting a friend for lunch or taking a medication " (Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997, p. 314). An event-based prospective memory is a form of prospective memory that requires execution of an action cued by an event eg. ask your brother if he wants to join us for dinner when you see him (Schmitter-Edgecombe & Wright, 2004). Decibel (dB): a unit used to measure the intensity of a sound or the power level of an electrical signal by comparing it with a given level on a logarithmic scale ("decibel | Definition of decibel in English by Oxford Dictionaries," n.d.).

Historically in working memory studies using noise as an experimental condition, participants have shown poorer performance in various types of noise conditions. Perhaps one of the leading researchers on the effect of noise in this field is Staffan Hygge professor at the Gävle University in Sweden. In one study Hygge, Evans and Bullinger (2002) have shown possible negative effects of noise exposure on working memory performance in a non-adult group. In their design, they compared the aircraft noise from new-airport /old-airport site to two control groups where they were no noise presented. To test the working memory, strings of consonants were presented one per second over headphones. Randomly, the sequence was stopped, and the children were asked to write down as many consonants as they could remember Their results showed that participants had a tendency to have more correct responses in a no-noise condition compared with the noise condition measured by reading tests. Further, there is evidence from meta-analytic reviews on the effects of noise on human performance in general which showed that even exposure to a normal intensity of noise (45-60 dB) during a short period of time (5-30 minutes) could have negative effects on one cognitive performance including working memory (Szalma and Hancock, 2011).

Further, one could ask that if there is a possibility that different types of working memory tasks could result in positive or even non-effect at all in noise condition. One study by Wright, Peters, Ettinger, Kuipers, and Kumari (2016) used a so-called Letter number task where participants were asked to read a sequence of numbers and letters and then recall the numbers in ascending order and the letters in alphabetical order to measure the working memory performance in adults. They used building-site noise (Leq =60 dB) to test their participants and found that they had a significantly higher rate of incorrect answers in noise condition compared to the non-noise condition (quiet room, Leq=30 dB). Noise has also been shown to have negative effects on not only healthy individuals but also those who suffer from complex psychiatric disorders like Schizophrenia. Some symptoms for this disorder involves alterations in information processing in brain functions such attention which can have some direct effects on working memory and thereby distorted in the presences of noise (Rene & Richard, 2013; Rutten, Kenis & van Os, 2010).

The most commonly studied groups regarding the effects of noise on cognitive performance are children where researcher often investigate them in their school environments in conditions which typically involves a quite versus noise condition (Szalma & Hancock, 2011). One of the largest studies on this subject is by Stansfeld et al., (2005). In their study, they examined the outcomes of external noise exposure from road traffic and aircraft on children's cognitive and health. A total of 2844 from Netherland, UK, and Spain participated in this big study. Surprisingly, considering a large number of earlier studies, their results did not detect any significant correlation between aircraft noise and working memory, prospective memory, and sustained attention. Here, as the author mention in their discussion, it is important that their results were not conducted in a laboratory environment and therefore laboratory experiments could show other contrary results. Moving on to the studies about the noise exposure on adults, a literature search on this subject showed that the majority of the studies in the adult population does not include studies on working and prospective memory which strongly motivated the need of this present study in hope to fill this knowledge gap; most of the studies that were found included the measurements of executive functions, immediate recall, personality, attention, noise sensitivity, and vigilance (see Wright, Peters, Ettinger, Kuipers, & Kumari, 2014 for meta-analytic review). Pursuant to these results, there is therefore very few earlier studies that have exclusively examined the effects of noise on working memory together with prospective memory in adult groups. Furthermore, those studies used different types of working memory span test than one used in this study namely reversed digit span test which addresses the need for an investigation that could contribute to our current knowledge on the effects of noise on working memory.

A possible theoretical framework that could be applied in order to understand the results from these studies is the well known working memory model developed by Baddeley (2010). This model provides a multicomponent theory of working memory which compose of (1) central executive unit ; regulate all cognitive processes (2) phonological loop ; deals with interpretation of speech and sound (3) Visuospatial Sketchpad ; process the visual and spatial information (4) Episodic Buffer ; which works as a buffer for holding information between working memory and long-term memory. The component that is of interest is the phonological loop that process speech and sound in general. Here, a possible explanation for the poorer performance on working memory tasks could be that, because of the very limited capacity of the phonological component, participants fail to suppress the background noise. Interestingly, a similar effect has also been shown to be true even in the case of irrelevant speech as the background noise (Larsen & Baddeley, 2003). In Baddeley's model, the phonological component is also involved in the process of rehearsing the perceptual information in order to help to remember things. Here, it is possible that the background noise disrupts rehearsing process by disturbing the attention from focusing on the task to the background noise and therefore cause poorer performance in those tasks (Baddeley & Hitch, 1974; Wright, Peters, Ettinger, Kuipers, & Kumari, 2014).

In summary, it seems that the impact of the noise on the working memory together with prospective memory is relatively unknown territory. The absence of such studies settles the central motivation of conducting this present study. The aim of this study was to investigate the effects of noise on the working and prospective memory, more specifically put: is there a significant difference on working and prospective memory performance among adult population in silent compared to noise condition?

Method

Participants

One experimental group comprised of student volunteers approached at Umeå University campus and asked to participate in the study. A total of 30 (16 female) participated. Their ages ranged from 18 to 30 (*M*= 24.26, *SD*= 2.82). All participants reported healthy with no hearing or cognitive impairment. All ethical guidelines followed the WMA Declaration of Helsinki (“WMA - The World Medical Association- Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects”) and General Data Protection Regulation (“Key Changes with the General Data Protection Regulation – EUGDPR,” 2018). All the participants in the study were given a code instead of giving their names on the paper to guarantee their anonymity. Only their age and gender was asked to be written down for the study. All the participants signed a consetentletter that gave them the right to withdraw from the study at any point during the test session without any explanation needed and also ask for removing their data after the study if they so desired.

Material and design

This study used a within-group design examining the effect of noise mainly on working memory together with prospective memory in noise and silence condition. The tasks were run on a laptop using the software WPS (writer, presentation and spreadsheets, Kingsoft Corporation).

Working Memory. A reversed span digit test was used to measure the working memory (WM). The reason for using a digit memory span test for measuring working memory performance was due to its good reliability and validity level. In an article by Conway et al., (2005), authors conclude that, based on the body of research and over hundred studies, memory span tasks have adequate reliability in general and measure what they are supposed to measure. In the same study, authors also examined the validity of the memory span tests across previous studies. Their results showed a considerable construct validity varying across different factors such as experimental setup and the tasks involved. Here numbers were presented in different sequences that varied from 3 to 7 in size in randomized order that inhibited participants to predict the size before they were shown. There were a total of 40 sequences. Each number in each sequence were individually presented in the middle of the screen for 1 second (font: Calibri, 80 pt).

Prospective Memory. A typical type of event-based prospective memory paradigm was used (Einstein & McDaniel, 1990). A total number of 12 event cues were added at the end of randomly selected number sequences. Prospective memory tests have shown inconsistent results in determining construct validity so far. Reason for this inconsistency, according to studies summarized in an article by Salthouse, Berish, & Siedlecki (2004) can be explained by the small samples and its combination with other tasks. Furthermore, the reliability of prospective memory tasks has seldom been reported, thereby making it hard to have any determined claims about it.

Conditions. Altogether, the following two conditions were included: a silence condition and a noise condition. For silence condition, a quiet study room was used with a mean sound pressure level of Leq= 30 dB. Leq is the average level of sound pressure within a certain time period that was measured during the testing sessions by the mobile application Buller Version 2.1.0 for IOS operating systems developed by the Swedish Work Environment Authority. For the noise condition, background noise was played back in the same room as the silence condition with a mean sound pressure level of Leq= 60 dB averaged during the test session using a Bose-Soundlink 2.0 Bluetooth speaker. Reason for using this sound pressure level was mainly based on the Environment noise guidelines for the European Region (World health organization & Regional office for Europa, 2018) in order to prevent any eventual harm for participants and was made to be correctly achieved using the software FL Studio developed by Imagine-Line company. The noise was recorded from a construction site and downloaded from Youtube which is a sharing platform for music and video developed by Google corporation. Here the primary motivation for choosing this kind of noise was the variation of loudness and perceived intensity of this noise, which according to previous studies are the main characteristic of unwantedness and annoyance of noise irrespective of the source of it (Stansfeld & Matheson, 2003). To record the participant's answers, a Numeric Keypad connected to a digital tablet iPad mini 4 designed and developed by Apple company were used.

Procedure

This study was carried out in a single session at a quiet study room in the building of Behavioral Sciences at Umeå University. The experimental session started with an oral presentation of instructions for each participant. Each participant went through two testing conditions which comprised of a Revered Digit Span Memory as the primary task to measure the working memory capacity and an Action Based Prospective Memory as the secondary task to measure the prospective memory performance. The condition which the participants started the sessions with were assigned randomly (silence or noise). In both two sessions, the Reversed Digit Span Memory task consisted of a total of 40 number sequences (white background) that were presented under each condition. Participants were asked to memorize the numbers in the order which they were presented and then were asked to enter them in reversed order into an empty digital document using a numeric keypad during the response time of 15 seconds that started immediately after a number sequence was fully presented. Each individual number in each sequence was presented one at the time. A grey screen indicated the end of a sequence whereby the response time started. All the sequences and numbers in each of them differed from each other in both conditions so that no number or sequence was repeated twice. The length of the sequences differed randomly from a minimum of 3 and maximum of 7 digits based on the well-known study of Cowan (2010) on our memory storage capacity and its limitations on how many items one can remember after a presented set of items. This design partially differed from the classical design of the digit span tasks (e.g. Blackburn & Benton, 1959) and was modified by removing the performance-adapted list length adjustment component; in the classical design, the length of a number sequence would automatically adjust to subjects answer by either increase, if answer was correctly twice or decrease by one, if the answer was wrong twice (Woods et al., 2011).

Following the completion of the ongoing digit span task, an event-based prospective memory was carried out simultaneously as the secondary task. The reason for this design was based on prior studies on prospective memory (e.g. Einstein & McDaniel, 1990; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997). Generally, prospective responding in everyday life occurs within the context of other ongoing tasks. Here, similar to Tam and Schmitter-Edgecombe (2013) design, a total of 12 green displays were used as the event cues and were added randomly at the end of a number sequence (Schmitter-Edgecombe & Wright, 2004). Next, before the initiation of the digit span test, participants were requested to remember to press the star sign button (*) on the numeric keyboard as soon as a green display were shown on the screen. The two testing sessions in both conditions took approximately 30 minutes; ca.15 minutes in quite and ca.15 minutes in noise condition. The order in which participants opted to respond to either writing down the digits or push the star sign button first was not specified beforehand.

Scoring procedure

To examine the scores from the digit span task, a so-called All-or-nothing unit scoring (ANU) method described by Conway et al., (2005) was used. In this method, for each fully correct recalled number sequence a credit equal to 1 and for each faulty recalled number sequence a credit equal to 0 were given. No credit was given if the answer were partially correct. Next, the mean of all correct answers was calculated by dividing them with the total number of 40 sequences in the test.

To calculate the scores for prospective memory test, a method similar to Kliegel, Martin, McDaniel, and Einstein (2001) were used. Here, each correct response to the prospective memory cue (the green display) gave 1 and each incorrect response gave 0 credits. Next, the total number of correct responses (out of 12) were calculated for each participant to determine the performance score.

Statistical analysis

All statistical analysis was carried out using SPSS for Windows, version 20.0 (SPSS, Inc., Chicago, IL, USA). A paired sample t-test was adopted to examine whether silence and noise conditions had any effect on working memory and prospective memory performance. P-values below 0.05 were considered statistically significant.

Results

Reversed Digit Span Test

Figure 1 shows the mean scores on the revered digit span memory task for both silence and noise experimental condition.

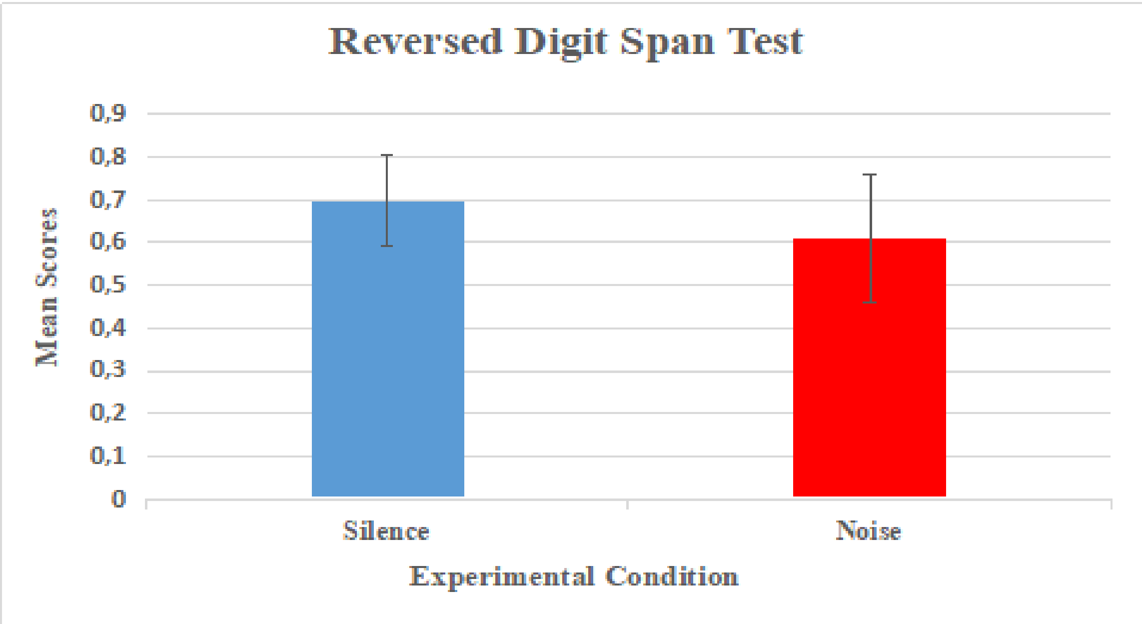

Figure 1. Mean scores on the reversed span digit memory task as a function of the experimental condition..

A paired-samples t-test was conducted to compare mean scores in silence and noise condition. There was a significant difference in the scores for silence (M=0.69, SD=0.10) and noise (M=0.61 , SD=0.14) conditions; $t(29)$=2.811, p =0.009 ($p < 0.05$), Cohen's d =0.65.

Prospective Memory Test

Figure 2 shows the scores on the prospective memory task for both silence and noise experimental condition.

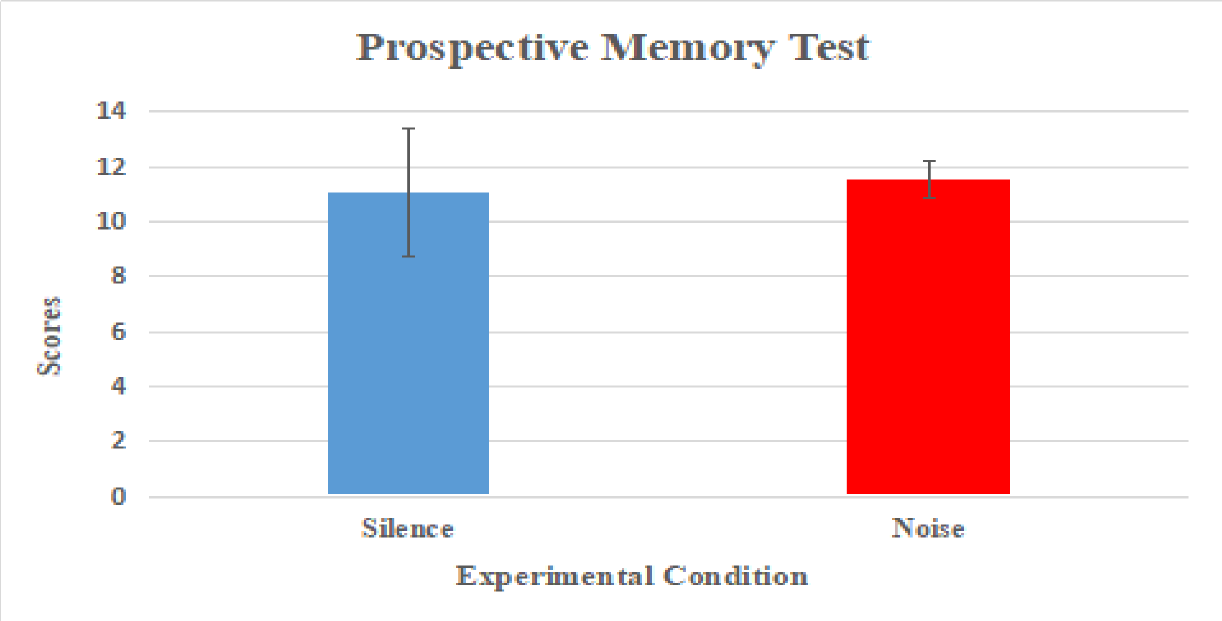

Figure 2. Scores on the prospective memory task as a function of experimental condition.

A paired-samples t-test was conducted to compare the scores in silence and noise condition. The was no significant difference in the scores for silence (M=11.06, SD=2.31) and noise (M=11.56, SD=0.67) conditions; $t(29)$= -1.18, p=0.247, Cohen's d= 0.02.

Discussion

The aim of this study was to investigate whether noise has any effect on working memory as well as prospective memory performance in silence compared with noise condition in adults. The findings suggest that, as the primary task, participants performed less on the working memory task in noise condition compared with the silence condition at a statistically significant level. For the prospective memory task, on the other hand, results suggest that noise had no statistically significant effect on the participant's performance in noise condition compared with silence condition.

It has been shown that the source of the noise is a relatively weak indicator of how well an individual would perform on tasks involving the working memory. This is interesting because as Beaman (2004) argues in his research, it might actually be the characteristic of noise namely its irrelevance and annoyance that are the key factors of its impact on human performance. In comparison, it is conceivable that, if this current study had used some other source of noise it could again get similar results. In his study, Beaman used a so-called memory operation span task to measure working memory. In his design, the irrelevant noise was presented by asking participants to read aloud a word after a mathematical operation were asked to be answered correct or incorrect by clicking on a “yes” or “no” button. He found that the participants in the reading aloud group had a significantly higher rate of incorrect answers to mathematical operations compared to the not read aloud group. In the current study design, in comparison with Beaman design, the noise used also was completely irrelevant to the working memory task itself which can add evidence to the finding in Beaman study. Now, what if participants had a non-limited response time on the working memory task and were presented with an individual noise source that increased in intensity over time. Would this have any different effect on their scores? In a study by Lee and Jeon (2013), researchers examined this question by presenting a word list comprised of 30 words on a screen and then asked the participants to learn these words over 3 minutes. Next, they asked participants to recall as many words as they could in a free recall trial in quiet and noise condition. Similar to this current study they used a construction noise (40-50 dB) to see if it had any effect on the free recall trial and found that increase in noise intensity lead to a decrease in the words correctly recalled. Moreover, other factors like stress evoked by the compilation of the tasks in this study could also explain the results from the working memory test because noise have been shown to act as one of the commonly presented environmental stressors in some previous studies (Szalma and Hancock, 2011).

It is also possible that the prospective memory task also could have some effects on the working memory task because they both were tested at the same time but based on the results from previous studies this effect has not shown to occur when testing these two together (Kvavilashvili & Ellis, 1996; Schmitter-Edgecombe & Wright, 2004; Tam & Schmitter-Edgecombe, 2013). Further, event-based prospective memory tasks are the easiest type of other prospective memory tasks and do not require participants to discontinue much attention from other ongoing tasks (Einstein & McDaniel, 1990).

During the search for finding similarities/differences between prior studies and the current study on the prospective memory, very little were found because in many cases, as discussed earlier, prospective memory tasks most often are carrying out with other ongoing tasks and not as the only object of interest. The closest relatable study that could be found was one by Stansfeld et al., (2005), where authors examined the effects of aircraft noise on event-based prospective memory together with other factors such working memory, recognition and sustained attention in 2844 older children (9-10 years old) across three different countries. Albeit the differences in both design and sample group between this study and the current study, the difference between the sample groups and its effects on the prospective memory has been inconsistent so far. For example in a study by Hudson, Mayhew, and Prabhakar (2011), researchers conclude that individual performance on a prospective test is most likely, affected by attentional demands (e.g. what action to remember to do in a future point of time) and not age differences between. On the contrary in some studies like Park et al. (1997), findings indicate that age could be a foundational factor and conclude that young adults (*M*=19.21) had a significantly better prospective memory than older adults (*M*=69.77). In order to add some more insights about if age may have any effects on the present study results, a meta-analysis by Ihle, Hering, Mahy, Bisiacchi, and Kliegel (2013) showed that in measuring the event-based perspective, there are two different alternatives that a researcher could ask participants to carry out the task; specified an unspecified order. In the specified order participants are instructed to in a particular order when the PM cue appears, " immediately interrupt or stop working on the ongoing task and directly perform the PM action or responding first in terms of the ongoing and afterward in terms of the PM task". In unspecified PM tasks, instructions do not require responding in a particular order when a PM event occurred ". Their results showed that younger adults performed better than older adults and age differences are greater in the specified task order than those of unspecified order. In comparison to this present study, as discussed in the method section, there was no specific order and further, provide a considerable explanation for the high scores on the prospective memory task.

Another possible explanation could be a well known statistical effect called "ceiling effect " that occurs when a high proportion of participants in a study have maximum or near maximum scores on a defined variable (Freemantle, 1999) that make it difficult to detect mean differences within the sample group(s). In this present study, it is highly possible that this effect has occurred for the prospective memory scores which can explain the potential failure to detect possible effects in the results between noise and silence condition.

This study had some advantages: the method of conducting this study hoped to use much aid as possible by using a wide range of previously conducted studies in the same area of interest. The tests used to measure working memory and prospective memory had a good level of validity and reliability and had been used in many peer-reviewed studies. The location where this study took place had good standards with very few external environmental factors that could lead to a significant impact on the results.

In conducting this study there was some limitation: the personal state of mind within participants was not pre-measured before the tests which may have affected the performance on the test (e.g. participant may have been tired, angry, annoyed etc.). The next limitation was the relatively small sample size that was used, the bigger sample size would be more beneficial in favor of generalization of the results. The study used a within-group design, where the same individuals were given the same tests in both conditions. A between-group design, on the other hand, could create higher confidentiality in the results but this had a very little chance to happen due to the limited time available and difficulties in recruiting participants.

In summary, this study showed that noise has a significant impact on working memory but not on the prospective memory performance. Based on the broad evidence from other previous studies and this current study, it is conceivable to conclude that noise could have negative effects on working memory regardless of its source of origin (road traffic, aircraft, construction, ventilation etc) and that, it might be the characteristics of noise that determines its negative impact in general. The future studies should aim to use repeated-measure design with larger sample sizes to be able to generate more accurate results and also examine other domain-specific processes of memory that could also be affected by noise. An interesting future research topic that could arise from this present study is to examine the effects of noise on elderly people's working memory and prospective memory by using a similar design and procedure to provide a deeper understanding in this area of research.

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