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Does Auditory Stimulation Interfere With Visual Task Performance:

Effects of music and noise on a visual oddball task.

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Preface

What a journey this has been. A major thanks to all who have been involved one way or another. Some of those people deserve some special attention: mom and dad, thank you for listening to me ranting over and over again in this process even though you had no idea what I was talking about. My promotor, prof. dr. Durk Talsma for helping me in bringing this to a good end. My internship promotor, prof. dr. Beatrijs Moerkerke, Bieke, whom I have had the pleasure to work with for 6 months and who taught me a great deal about conducting research and writing papers. Rebecca Willems, for being a rock in this whole whirlwind of a master's program. Jelena Saliën, someone I can reach out to after months of not speaking and she still is prepared to do the craziest things for me (such as completing my experiment). Steven Geysen and Robbe Sevenhant for teaching me to play chess, a very welcome distraction in these times. My dog, Sem, he was always there for a cuddle and some playing when I was reaching my breaking point. All my other friends and family, for participating in this experiment, for listening to me going on and on and on about what all went wrong with this thesis. And my fellow students, many of whom I did not know, but they still were willing to give some of their precious time to the completing of my experiment.

Werchter, June 2021

Maya Vervoort

Corona Statement

As with a lot of fellow students, the current pandemic affected the realization of this thesis. Data acquisition was initially planned to be done on first year psychology students from Ghent University. Due to the living arrangements of the main researcher, it was decided to change this to online data collection. A lot of programming and version issues with Psychopy and the necessary packages forced the researcher to only include fellow students with experience in Psychopy. These were both first and second master students in Experimental Psychology who volunteered to help out and sometimes even got their family involved. This pandemic showed how supporting we all are of each other when times are rough, I never dared to dream of the amount of response I got after posting in our Facebook groups. In the end, 60 participants were planned to do the experiment. But as I said before, this entire experiment was cursed. 21 participants had to drop out because either their computers could not handle the code, or they had updated their operating systems which caused Psychopy to fail when opening. Again, even with their already so busy schedules all 60 of them did everything they could to get my experiment working. A massive thank you is in order for all these people, half of whom I barely even know.

Abstract

Can listening to music improve performance on cognitively demanding tasks or does it impair performance? The present study aimed to investigate whether there was a discrepancy between listening to noise and listening to music in performance on the oddball task. The debate in the literature concerning these effects of auditory distractors still has not been solved and this study wants to contribute to find a possible solution in this debate. In the music and noise conditions, there was a dual task included to make sure participants did not tune out the auditory distractors. The music selection consisted of songs that were found to be most popular among the initial target population through an online survey. Multiple genres were included, such as pop, rock, and rap. Performance was measured as an overall percentage of correct hits and correct rejections. The goal of this research was to determine whether participants performed better when music was playing, compared to noise and silence, and whether we could observe an interaction effect with the timing of the task blocks in the experiment. Finally, we sought to investigate whether there was a discrepancy between listening to noise and listening to music in performance on the oddball task.

Keywords: attention, distraction, dual-task, music, noise, oddball, sound

Table of References

Does Auditory Stimulation Interfere with Visual Task Performance?

In everyday life, people are constantly performing tasks while being confronted with auditory distractions in their environment. One such example of auditory stimulation, which people frequently subject themselves to, is listening to music. Currently, many people listen to music while performing a host of everyday activities. For example, the majority of students report studying with music playing, surgeons listen to music whilst performing surgeries, people are listening to the radio while driving (Calderwood et al., 2014; Dalton & Behm, 2007; Dibben & Williamson, 2007; George et al., 2011; Haake, 2011; Landay & Harms, 2019; Lonsdale & North, 2011; Mitta et al., 2019; Muslimah & Apriani, 2020; Patton et al., 1983). Much research in this area has gained attention in the media, as it warns for possible safety issues that listening to music may cause in traffic (Horrey et al., 2017; Pêcher et al., 2009). The scientific literature is currently divided with respect to the conclusion whether listening to sounds (e.g., music or noise) while doing a cognitive task (e.g., driving, studying) improves or impairs performance (Kou et al., 2018; Landay & Harms, 2019; Ünal et al., 2012; van der Zwaag et al., 2012). The current research aimed to add to the existing literature by going back to basic cognitive performance tasks and seeing what effects auditory distractions could have on performance. Additionally, the current research attempted to distinguish between the effects of music and the effects of noise versus working in silence.

Theories of Attention

One of the reasons why music may impact our cognitive task performance is that music might capture our attention and direct it away from the main task at hand. In everyday life, we are overwhelmed with an abundance of sensory stimuli: we listen to the radio, we hear sirens of ambulances, we notice cars driving by. Even with this all going on around us, we are still able to hold conversations, read a book, study, drive a bike through town, or make a phone call. How is this all possible? Our brain adapted itself in two ways to overcome to this overload of stimulation and limited the amount of capacity we have to direct our attention towards something. The first adaptation is that our brain simply tunes out what seems irrelevant for whatever task we are performing. Think of this: you are working from home and your children are watching television in the same room. Chances are that you will try not to pay attention to the show your children are watching. A second adaptation our brain made is top-down control: depending on what is relevant for our current behavior (e.g., writing a report, reading an e-mail), our brain selects which irrelevant stimuli become tuned out. A third and final adaptation is known as integration. In this context, integration refers to the fact that information from all sensory modalities that are necessary for performing certain behavior (e.g., writing a proper answer to an e-mail) becomes integrated to do this behavior as good as possible (e.g., check your data, make sure the addressees are correct, write a consistent message) (Duncan, 1998). These three adaptations are also the foundations of the Integrated Competition Hypothesis proposed by Desimone and Duncan (1995) and can also be derived from the Perceptual Load Hypothesis which was developed by Lavie and coworkers (2004).

Caveat on Brain Localization

Before discussing theories of attentional selection, it is important to point out the following: we cannot state where (visual) attention is located inside the brain. Attention results from the integration of activity in a multitude of different regions of the brain. Which region contributes what to which aspect of attention is a question that we are unable to answer completely with full certainty. Of more importance is to study the differences in performance and activation certain stimuli can evoke so we can start to understand the underlying mechanisms which are involved in selective attention (Frith, 2001).

Early Versus Late Selection

Contrary to localizing attentional processes in the brain, the theoretical mechanisms underlying these attentional processes have been extensively documented. In the past, two main approaches dominated the field: first of all, theories of early attentional selection suggested that attention can influence early perceptual processes: according to this view, irrelevant stimuli are filtered out by selective attention (Treisman, 1969). The second dominant view was that of late attentional selection, which proposed that attention only influences processes that occur the after processing of irrelevant stimuli. This means that those irrelevant stimuli (i.e., distractors) will not be encoded into memory, and will not be taken into account when the brain is selecting the appropriate responses to a target stimulus (Duncan, 1980). Applied to auditory distraction, this would imply that in theories of early attentional selection, it is proposed that the sounds simply will not be processed. Whereas in theories of late attentional selection, we expect music to not be encoded into our memory, but it will be processed.

From this early dissociation in the literature, researchers attempted to combine these two views into one comprehensive framework of selective attention. We will discuss two of those proposed integrative frameworks that have been dominating the field for over two decades. These are the Integrated Competition Hypothesis by Desimone and Duncan (1995), followed by the Perceptual Load Hypothesis from Lavie and colleagues (2004).

Integrated Competition Hypothesis

The first framework to be discussed is the *Integrated Competition Hypothesis* (Desimone & Duncan, 1995). Based on the first evolutionary adaptation of our brain, the limitations of attentional capacity, Desimone and Duncan (1995) constructed their first principle of competition: all stimuli in our surroundings are continuously fighting for a place in our limited attentional field (Duncan, 1998). The second principle of biased competition is based on the adaptation of top-down control. Our brain can be primed to direct its attention to certain elements in our environment which are of importance in the successful completion of our task at hand. Finally, based on the integration, Duncan applies this to the previously mentioned competition: once a certain element wins the competition in one sensory field (e.g., you hear a loud explosion), all other sensory fields are also directed to this one element (e.g., you will see what causes the crash, you will smell fire, you will feel the blast).

Perceptual Load Hypothesis

As an alternative framework to solve this dissociation in the literature concerning early versus late attentional selection, Lavie (1995) proposed the *Perceptual Load Hypothesis*: the distractor stimuli will only be processed when the relevant stimuli do not exhaust attentional capacity. In this case irrelevant stimuli become able to behave as distractors (Lavie, 1995).

Furthermore, Lavie and coworkers (2004) introduced two different mechanisms that keep this balance of attentional capacity in order. The first mechanism, the *perceptual selection mechanism*, comes into action when perceptual load is high and irrelevant stimuli need to be ignored so the demanding task can be succeeded successfully. The second mechanism, the *cognitive control mechanism*, becomes necessary when the perceptual load is low since we then need to actively control ourselves not to process the distractor stimuli (Lavie et al., 2004). This second mechanism is of importance in dual tasks, which rely on multiple sensory modalities such as in the current research. In these circumstances, Lavie and coworkers expected diminished performance in high perceptual load conditions combined with distractors: “Whereas increasing perceptual load is expected to reduce distractor interference, increasing cognitive control load is expected to increase distractor interference” (Lavie et al., 2004, p. 399).

Investigating Attention

All of these frameworks and the knowledge the field has gathered originates from performing investigations on human participants in a number of well-defined tasks. One of the most well-known tasks is the oddball task. We will discuss the workings of the oddball task, and its advantages that are of importance for the current research.

Oddball Task

One of the paradigms developed to study these attentional processes is the oddball paradigm. The rationale behind this paradigm is to present participants with a continuous flow of stimuli (either auditory, visual, olfactory, tactile, or gustatory). In a small percentage of trials, a stimulus is presented that is (slightly) different from the stimuli in the main flow. Participants are instructed to indicate when they perceive this deviant stimulus, also known as the oddball, or target. In visual paradigms, stimuli can be letters, shapes, or even images.

The oddball paradigm can be unimodal (i.e., focusing on one modality), but it is also possible to study multiple modalities in an oddball investigation. This is one option how researchers can investigate the competition between multiple sensory fields in directing attention. Also known as dual tasks, these paradigms are applied to investigate possible differences in the processing of multiple sensory modalities.

Auditory Distraction

Since we focus on auditory distraction on (visual) attention, it is necessary to discuss a number of distinctions that have been made in the literature concerning the mechanisms of auditory distraction. The first distinction the literature makes is how an auditory stimulus distracts you from the task at hand. There are two possible mechanisms, as proposed by Hughes (2014). The first mechanism, *interference-by-process*, is relevant to situations where the auditory distractor is interrupting the ability to perform a task. Whereas with *attentional capture*, the second mechanism, this auditory distractor is unrelated to the task at hand and is merely pulling your attention from what you are doing (Hughes, 2014). Next, within the mechanism of *attentional capture* there are two classes that can be identified. Attentional capture can be either *specific* or *aspecific,* the difference between these two lies in the properties of the distractor. With *specific* attentional capture, something inherent to the auditory stimulus captures your attention (e.g., hearing someone call your name in a room full of people). When nothing about the auditory distractor itself draws attention, but instead it is more about the context in which you hear it, we name this *aspecific* attentional capture (Hughes, 2014). Those same authors suggested that effects of attentional capture on cognitive task performance can be attenuated with increasing the task demands that do not require auditory processing. The current research focused on aspecific attentional capture and whether this form of capture affects visual task performance.

Another aspect of auditory stimuli that can influence whether they operate as distractors is the volume of these sounds. Research on cognitive performance comparing conditions with auditory distraction at multiple sound levels found a significant decrease in performance (increased reaction times and decreased accuracy) in the condition where the sound level was perceived as uncomfortably loud, but not when this sound level was comfortable or in the silence condition (Dolegui, 2013; LaPointe et al., 2007).

Finally, personal differences in habituation rate influence the susceptibility of individuals to auditory distraction. Habituation rate is suggested to increase with increasing working memory capacity. Thus, cognitive control has its own role to play in certain types of auditory distraction. We have to remain aware of this, as some participants might habituate faster to the music or noise than others, influencing our results. Overall, all participants show some level of habituation (Sörqvist et al., 2012).

Visual Attention and Auditory Distraction

In the literature, the most-researched combination of modalities to study in dual tasks is visual attention with auditory distraction. Research has found important distinctions that have to be made when investigating this type of effects. We will discuss the following: the age category of the participant pool, their personality, whether the music was instrumental only or also vocal, how repetitive the visual task was and clinical populations (e.g., attention deficit hyperactivity disorder).

First, it seems that younger children are less able to monitor themselves when auditory distractions are present. Studies regarding visual attention with increasing perceptual load have found auditory distractors to reduce performance significantly more in young children compared to adults (Robinson et al., 2018). This effect was not only visible in accuracy, but also on the reaction times and this was worse in conditions with higher attentional loads (Robinson et al., 2018).

Second, the personality of participants appears to be relevant. Here, we find evidence for an important distinction: introverts tend to perform worse on cognitively demanding tasks than extraverts when auditory distraction (e.g., music) is present (Davies et al., 1969; Furnham & Bradley, 1997). Introverts perform better on a multitude of tasks (e.g., Stroop tasks, recall tasks, Raven's Progressive Matrices) when they can do this in silence, whereas extraverts' performance increases when music is playing (Cassidy & Macdonald, 2007; Dobbs et al., 2011; Furnham & Allass, 1999; Furnham & Bradley, 1997). Presumably, this is related to baseline levels of arousal that depend on personality types, as proposed by Eysenck (1967). Introverts are expected to experience higher baseline levels of arousal, causing them to quickly reach their maximum. In contrast, extraverts are believed to have lower baseline levels of arousal, which implies they need more stimulation to reach the optimal level (Schellenberg & Weiss, 2013). Contrary to dominant findings in Western samples, a minority of studies report no effects of personality on performance when this was done with Chinese participants instead of an American or British population (Kou et al., 2017). The reasoning of the authors for this failure to replicate was the habituation of their participant pool to background noise.

The effect of different genres of music has also been investigated and results suggest that the either positive or negative effects of background music on cognitively demanding tasks depend on whether the music contained vocals, or only instruments. It seemed that performance with instrumental music playing was slightly less worse than with vocal music, however this was not the consistent across all tasks (Crawford & Strapp, 1994).

Another aspect that points towards the effects of arousal, is that background music is found to be of major advantage in more boring, repetitive tasks that do not require a lot of effort.

Clinical Populations

Following these indications of possible effects caused by differing levels of arousal in participant pools, it could be interesting to see what effects auditory distraction could have on visual task performance in clinical populations with attention disorders such as attention deficit hyperactivity disorder (ADHD). Investigations in child populations with compared to without ADHD have found beneficial effects on memory performance when playing white noise in the background (Söderlund et al., 2007).

Studies of Dual Tasking

As considered previously, the interaction between visual attention and auditory distraction has been widely investigated. This is not only because of its straightforwardness, but primarily because of its implications on our everyday life. As we discussed, people listen to music while performing an abundance of cognitively demanding tasks in their everyday life. This raises questions whether people can in fact still perform at the same level as they would without the distractions of music. Dibben and Williamson (2007) made an interesting statement: "Listening to music while driving, like other dual tasks (…), may add to a driver's attentional load" (Dibben & Williamson, 2007). As we pointed out with the Integrated Competition Hypothesis and the Perceptual Load Hypothesis, our attentional capacity is limited. What evidence can we find in the literature for everyday dual tasking with music and its effects on the performance in the main task? What follows is evidence for the importance of research regarding visual attention with auditory distraction in a variety of situations in everyday life. We discuss evidence from multiple fields (surgeons, driving a car, studying, and working in an office) where people tend to listen to music while performing a cognitively demanding task and what possible implications this could have on a day-to-day basis.

Some of the first important research regarding musical distraction and its effects on cognitive performance originates from the early 1990s. This is when research on dual tasking with music playing in the background was starting to gain a lot of attention with the development and rising popularity of portable music players, radios, and commercialization of CDs. Researchers became interested in the effects that music could have on cognitive performance with music playing in the background versus without music. One important, but controversial, finding was the so-called "Mozart Effect" (Rauscher et al., 1994). Initial research compared a condition where participants first had to listen to Mozart's sonatas to a condition where participants first had to sit in silence before having to perform cognitively demanding tasks. What Rauscher and coworkers found was an increase in performance in de Mozart condition which was then named the "Mozart Effect". Later research showed that this effect does not only appear when the music being played was Mozart, but also with other composers and even other genres of music (Schellenberg & Weiss, 2013).

Surgeons and Music

A first daily life situation in which music is frequently present is inside the operating room. Self-reporting surveys have shown that the majority of surgeons and nurses tend to play music in the operating room while performing surgery (George et al., 2011; Mitta et al., 2019). Research also shows beneficial effects of playing music on the stress level of surgeons in operating rooms with surgeons feeling more at ease and able to better think through their actions when music is playing (George et al., 2011; Lies & Zhang, 2015). Together with this, playing music in the operating theatre has benefits for the patient as well as this seems to diminish stress levels in patients before being anesthetized (George et al., 2011; Li & Dong, 2012). However, evidence for the physiological effects (e.g., heart rate, blood pressure, respiration rate) of music on stress reduction remains inconsistent but points into the direction of small improvements (Nilsson, 2008; Pittman & Kridli, 2011).

One aspect of music that affected the pleasantness and its beneficiary effects was the volume at which it is being played inside the operating theatre (El Boghdady & Ewalds-Kvist, 2020; George et al., 2011). Obviously, music that is playing too loud influences the ease of communication inside the operating room which in turn can increase stress levels and tension. This is the reason why the World Health Organization (WHO) put forward guidelines for this as well (Berglund et al., 1995). Another feature of music that has shown effects on both performance and stress levels in surgeries, is whether the surgeon liked the music that was being played or not (Ahmad, 2017; Miskovic et al., 2008).

Driving and Music

Second, when we think of anecdotal indications such as turning off the car radio when we are reversing into a small alley with twists and turns, or when we attempt to parallel park, we all once wondered why we do this. An expression such as "I can see better when the music is turned off" is something that we must all have experienced when driving somewhere unfamiliar in the dark (let alone park in reverse there). Research shows that only a minority of people drive their cars without the radio turned on (Dalton & Behm, 2007; Dibben & Williamson, 2007). But is this safe? Evidence shows two main sources through which listening to music influences driving performance. On the one hand, music works as a distractor. Something most people have forgotten by now, is how they learned to drive. It takes a lot of focus to successfully shift from first to second gear, to remain aware of the cars in front of you and possible pedestrians or bikers. It is very likely that when you first learned how to drive, the radio was turned off to help you focus (and we still do this in tricky situations). Secondly, the type of music you listen to influences your mood, which then influences your driving style. Imagine you are driving down the freeway, and you hear your favorite uplifting song of all time: you will start singing along and before you know it, you are over speeding. Or think of the opposite: a sad, slow song is playing, how big are the odds that you will slow down?

This means that, in the case of driving, music has the potential to impair your ability to travel safely. Be it by distracting the driver from their surroundings, or by influencing their mood which potentially leads to more hazardous behavior.

Students and Music

A third circumstance in which music plays an important role, is doing schoolwork. In the early eighties a large proportion of students already listened to music whilst studying or making homework and this has not changed according to more recent research (Calderwood et al., 2014; Lonsdale & North, 2011; Muslimah & Apriani, 2020; Patton et al., 1983). The main reasons why students do this are reported to be: (1) to help concentrating, (2) to reduce stress and anxiety, and (3) to prevent sleepiness (i.e., increase arousal) (Dolegui, 2013; Lonsdale & North, 2011; Muslimah & Apriani, 2020). Research investigating instrumental music in different tempos and in versus out of tune found no influence on verbal learning (Jäncke & Sandmann, 2010).

In the Office

Finally, the fourth setting where music appears is in the workplace. As a means to counteract fatigue, stress, and risks of burn-out, corporations have started investigating whether playing music in the workplace could have beneficial effects on their employees (Haake, 2011). Results indicate employees listen to music for two main reasons: (1) to regulate their mood and (2) to relax (Haake, 2011). Most employers and employees believe this in turn increases productivity and improves quality of the work performed. However, recent reviews suggest that the literature remains divided whether music has positive, negative, or no effects on performance on the job (Landay & Harms, 2019).

Research Question

This all combines to the current research question: Does listening to music ameliorate er deteriorate performance? This has been researched in a number of different contexts, as mentioned above. However, the discussion remains. What most research has in common regarding the effects of auditory distraction, is that this might have been investigated in real-world environments too soon. We first need to investigate the basics to form well-defined hypotheses and research questions, which we could then apply to more ecologically valid experiments. This is what happens in most research but seems to be a little forgotten when discussing the current topic. Research on cognitive performance in the presence of auditory distraction might need to take a step back and first think about the most basic cognitive processing. This is what the current investigation aimed to do. This experiment measured cognitive performance during an oddball task. Mainly, we asked the question whether there exists a distinguishable effect of listening to music versus listening to noise while performing. The oddball task in the conditions with either music or noise will be treated as dual tasks since participants will have to focus on both the sounds being played and they have to do the oddball task at the same time. This is a major advantage of the oddball task, especially for future research, as oddball tasks can be set up in two sensory domains at the same time. Unimodal oddball tasks can easily be combined with, say, auditory distraction, even when this auditory distraction is of no importance for the completion of the task at hand.

Dual tasks are known to be cognitively challenging, stressing, and fatiguing. The conclusions of this research could possibly be extended to other demanding activities people perform in their everyday life with music. These activities include studying, reading a book, driving a car, doing household chores and many more. As was mentioned before, research has shown that a majority of people complete these tasks while listening to music and the current study might indicate that this is either making people perform worse, or better depending on the conditions and our results.

Main Hypotheses

Our research paradigm consisted of three main conditions: silence, noise, music. Participants had to perform a visual oddball task with these conditions randomly assigned to the experimental blocks. We measured the overall percentage of correct go and no-go trials, and the mean reaction time of the correct hits as measures for cognitive performance.

Following from the Perceptual Load Hypothesis and the Integrated Competition Hypothesis, we expected a decrease in accuracy in both the music and noise condition compared to the silence condition. Since these hypotheses expected a decrease in performance with increasing cognitive load combined with auditory distractors. Due to the necessity of cognitive control to ignore these distractors, the most decrease in performance was expected in the condition where the most effort was necessary to tune out these distractors. More specifically, we expected the highest accuracy in the silence condition, followed by the noise condition, and the lowest accuracy in the music condition.

Second, following the same expectations we derived from the theories discussed above, we predicted a similar trend in reaction times with the fastest reaction times in the silence condition, slightly slower in the noise condition and finally the slowest reaction times in the music condition.

Method

Online Survey

Before the actual experiment, an online survey had been sent out into Facebook groups such as First Bachelor Psychology students at Ghent University. This was done to find out which songs the students in the same age category as the initial target group were familiar with. 122 people (103 female, 19 male) completed this online questionnaire (Mage = 22.24). 129 songs and tunes were included that were categorized in 7 genres for ease of the researcher (Pop, 80s and 90s, rap, childhood, classical, tv and games). For each song, participants were asked to indicate how well they knew the music they were hearing on a 7-point Likert Scale. From each initial genre, the songs that had an average Likert value of over 5 were selected manually. Since blocks in the experiment were supposed to last approximately 3 minutes, all songs that were under this duration were discarded. This left the researchers with 31 songs, see Appendix A for an overview of the songs that were eventually included into the main experiment.

Main Experiment

Participants

Data from 39 participants (12 male, 27 female) was collected (M_{age} = 26.76, SD = 10.50). Most were either first or second master students participating in the Theoretical and Experimental Psychology track from Ghent University. They were recruited through private Facebook groups. A small number of participants were family or friends from either the researcher or from other participants. Data from 4 participants (3 female, 1 male) had to be left out, as they reported realizing at the end of one block that they realized they did not respond to the correct stimulus.

Materials

The experiment was designed through PsychoPy Experiment Coder version 3.2.4 (Peirce et al., 2019). The monitor on which participants completed the experiment varied, as participants performed this on their own computer. Versions of PsychoPy more recent than version 3.2.4 were not compatible with the designed code due to the *pygame* software package used to play the audio.

Thirty-one songs and three noise files were included from which four songs and four noise files were randomly selected per participant (repeats were made possible for the noise files). These songs lasted at least three minutes and were stored in *.wav* format for compatibility with PsychoPy.

Procedure

Participants were recruited through posts on the Facebook pages *First Master of Theoretical and Experimental Psychology* and *Second Master of Theoretical and Experimental Psychology*. Those who responded were contacted through private messages and were sent a short explanation of the purpose and set-up of the experiment, a link to a OneDrive folder, and a personal participant number.

Inside this OneDrive folder participants could find a *Read Me* file with explicit instructions concerning the experiment, how they were supposed to save everything and what data was expected to be sent back to the researchers. Next, an empty informed consent and answer form were provided, which participants had to fill in and send along with the data. Finally, a .py file, which contained the script that had to be ran and a subfolder containing all audio files was also to be found inside the OneDrive folder.

Participants were free to complete the experiment whenever they found the time to do so. They were instructed to use headphones and to find an empty and quiet room to limit the amount of distraction.

Dual Task

Participants had to perform 12 blocks of a visual oddball task with a duration of 3 minutes per block. In four blocks, participants listened to music, in another four blocks they heard noise with bird sounds inserted (white noise, pink noise, or brown noise), and in another four blocks they had no audio input. The order of these blocks was randomized. The task was to press space when participants saw an X or an O on the screen depending on the instructions given at the beginning of each block. The visual stimuli consisted only of Xs and Os and they were presented rapidly following each other.

Thus, a total of 12 blocks consisted of the following (in fully randomized order): two blocks with music where participants had to respond to the Xs, two blocks with music where they had to respond to the Os, two blocks with noise where participants had to respond to Xs, two blocks where participants heard noise and had to respond to the Os, two blocks with no audio where participants had to respond to the Xs, and two blocks with no audio where participants had to respond to the Os. After each block, participants got an opportunity to take a break and they had to press a key to continue to the next block.

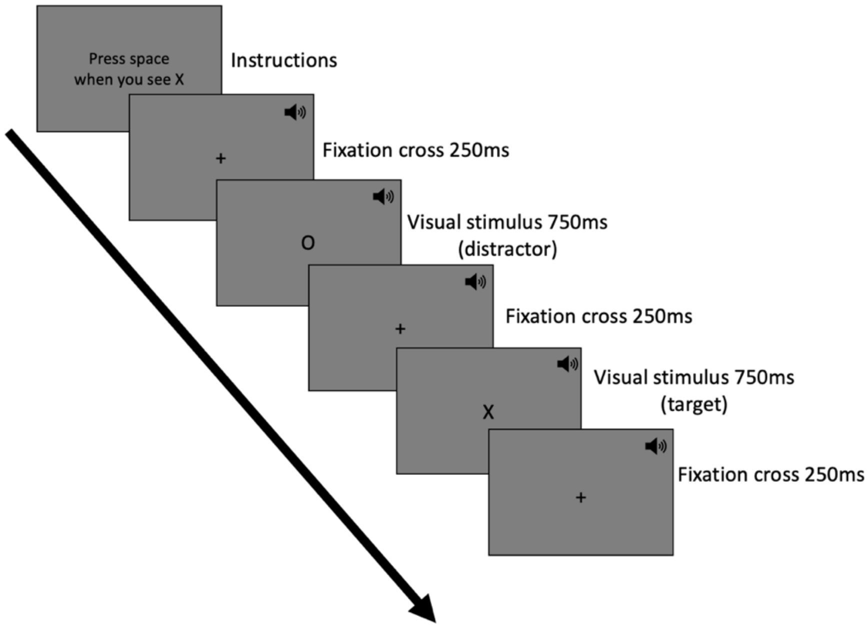
To ensure the sounds could interfere with the performance and were not tuned out, participants were instructed before the experiment that they would receive questions about the auditory stimuli they heard after each block ("*You will perform an attention task and you will also hear sounds or music, try to focus on this as well because you will get some questions after this block about these sounds or music. Do not forget that your main focus should be on the attention task.*"). In blocks where participants heard a song, they had to write down the name of the song and the artist. If they did not know this, they were instructed to write down on a scale of 1 to 7 how well they recognized the song (1 meaning "*I have never heard this before*", 7 meaning "*I can (almost) entirely sing along with this song*").

Each block began with an instruction to which stimulus participants were supposed to respond. The block started only when they pressed space, if the block was a sound condition, sounds would start playing after space was pressed. Then the flow would start with a fixation cross for 250ms, after which the first stimulus appeared for 750ms or until participants pressed space. This lasted for 144 trials (approximately three minutes) (Figure 1 and Appendix B). At the end of the sound blocks, participants were asked to answer the question that was shown on screen onto a questionnaire. This screen remained until participants pressed space. Then they got the instructions to which letter they had to respond for the next block, which started when they pressed space again.

Participants did not receive any feedback about their performance rate, neither during nor after the experiment, unless they were curious and directly asked the experimenter.

Figure 1

Experimental Paradigm



Note. One example of a possible block with auditory distraction (either music or noise), with the target stimulus set as X. See Appendix B for the other possible experimental flows depending on the conditions.

We measured reaction time as an indicator of difficulty of the auditory condition (music, silence, noise) and we compared this between those three conditions.

For the music condition, the experiment randomly picked four songs to play from a list of 31 (i.e., one song per block). The same was done in the noise condition where the options were White Noise, Brown Noise, or Pink Noise (all with bird sounds added to them).

Raw Data Storage

Data of interest per participant was stored in a .csv formatted Excel file containing information for each trial separately. We stored the block number, the stimulus (X or O), whether the correct response was to hit spacebar or ignore (1 or 0), how the participant responded (1 for hitting spacebar or 0 for ignoring), the accuracy (1 for correct, 0 for incorrect), the stimulus participants had to respond to (X or O), the reaction time when participants hit spacebar, the name of the audio file that was played (in the noise and music conditions) or silence (in the silent condition), the sound condition (music, noise, or silence), the participant number, the age of the participant, their gender and finally, their handedness.

Data Preprocessing

Data was preprocessed and analyzed in RStudio version 1.4.1103 on a Macbook Pro 2018 running on macOS Big Sur 11.2.3. For each participant, we calculated the following which was all stored in four master .xlsx files which were utilized for the main analyses. First, overall accuracy was measured as the percentage of correct go and no-go trials (i.e., one value per participant). Mean reaction time (RT) was measured on trials that were correct hits (i.e., one value per participant). We also calculated the absolute number of false hits and false misses. Second, we calculated accuracy and mean reaction time on correct hits in the same manner per condition ("Silence", "Noise", "Music") (i.e., three values for accuracy and three values for reaction time per participant). And we counted the number of false positives and false negatives per condition. Third, we were interested in comparing the sound conditions together to the silence condition. To be able to do this, we calculated the mean accuracy for the noise and music conditions together per participant as well as their mean reaction time for correct hits (i.e., two values per participant for each variable of interest). Fourth, it was also interesting to compare accuracies and reaction times depending on when in the experiment ("Early" for the first four blocks, "Middle" for the middle four blocks, "Late" for the final four blocks) the blocks were situated. Finally, we calculated both means and standard deviations for accuracy and reaction time per block per participant so we could also control for the interaction between timing of a block and the sound condition in our analyses (i.e., twelve values per participant for each variable of interest).

Data Analyses

Analyses were performed in RStudio version 1.4.1103 on a Macbook Pro 2018 running on macOS Big Sur 11.2.3. The R packages carData (Fox et al., 2018), car (version 3.0-10; J. Fox, Weisberg, Price, Adler, et al., 2020), and effects (version 4.2-0; J. Fox, Weisberg, Price, Friendly, et al., 2020) were used for analyses and visualization of the data.

Nominal variables concerning condition and time section were adjusted to sum coding for the purpose of testing. For condition, the “Silence” condition was set as reference level. For time section, the reference level was “Early”.

Two main dependent variables of interest were explored through general linear models (GLMs) and analysis of variance (ANOVA): possible effects on mean accuracy and possible effects on mean reaction time. For these analyses, we worked with average values per participant which were then put into the GLMs of interest. All were investigated with one-way ANOVA and α set at 0.05.

We investigated predictors of Accuracy with two different output files (in the global master file, and in the file per condition per time section). Predictors of interest were Age, Condition, Reaction Time, and Time Section and their possible interactions.

Predictors of interest for Reaction Time were Age, Accuracy, Condition, Time Section, and their possible interactions. This was again calculated based once on the master output file and once on the file split per condition per time section.

For additional investigation, we ran some basic analyses to investigate whether the number of false positives could be explained by reaction time or condition from the data included in the master file.

Results

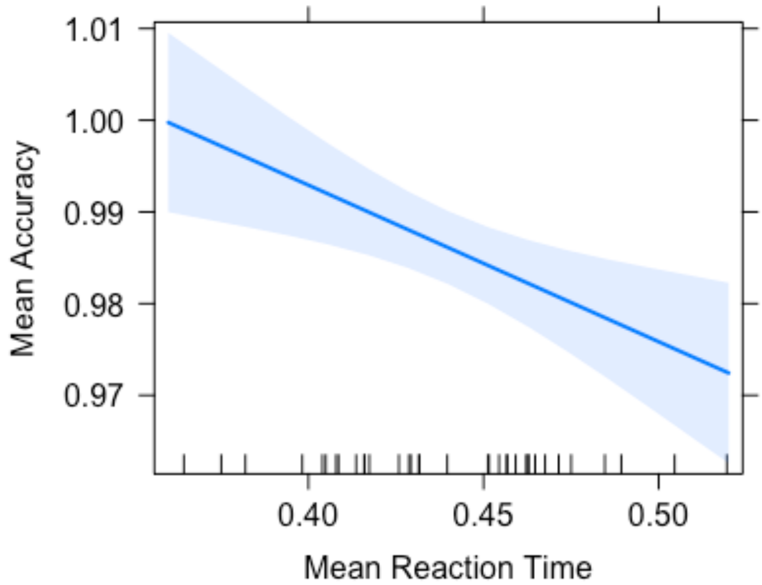
Dual Task

Calculated Across Conditions

The overall mean accuracy was 98.61% (SD = 1.29) measured as the percentage of correct go and no-go trials across all trials, the mean reaction time on the correct hits was 0.4396 seconds (SD = 0.036). The estimated correlation between these accuracy and reaction time was -0.4750. Linear regression showed a significant effect of reaction time on accuracy ($F(1,33) = 9.617$, $p = 0.0039$, $b_1 = -0.171$) (Figure 2).

Figure 2

Overall Association Between Reaction Time and Accuracy



Note. Significant negative correlation between accuracy and reaction time

Calculated per Sound Condition – 3 Conditions

Accuracy. We found no main effect of condition (silence versus noise versus music) on mean accuracy ($F(2,102) = 0.57$, $p = 0.567$). The effect of reaction time on accuracy remained significant ($F(1,103) = 24.57$, $p < 0.0001$) in the same direction ($b_1 = -0.1678$, $r = -0.4389$).

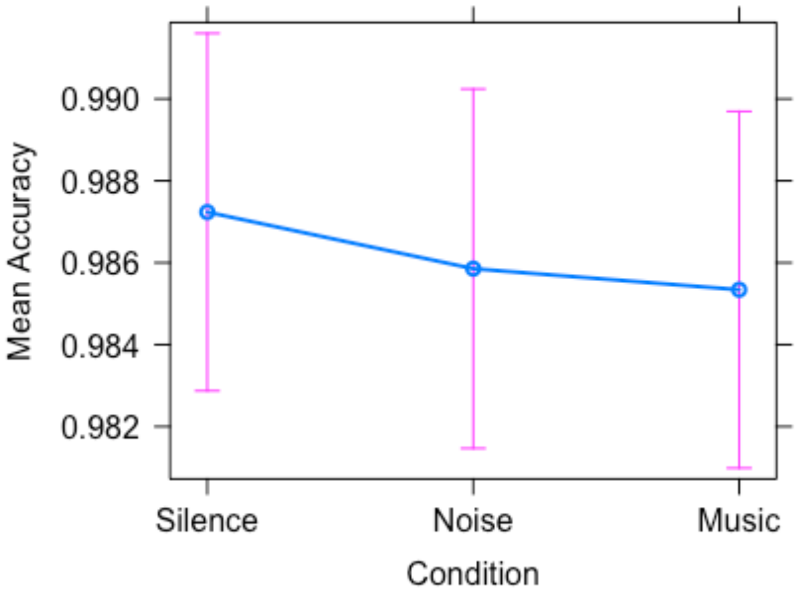
When investigating the effect of condition on accuracy taking into account mean reaction time per condition, one-way ANOVA reported no significance ($F(2,101) = 0.1992$, p

= 0.82) indicating condition was not a predictor of accuracy together with reaction time either. However, we do see some minor evidence for differences between the sound conditions and the silence condition (Figure 3, Table 1).

Reaction Time. We already established the relation between reaction time and accuracy. When we added condition as a predictor to estimate reaction time, taking into account accuracy, we found no significantly added value of condition ($F(2,101) = 0.9494$, $p = 0.39$) in the data only split per condition (Table 1).

Figure 3

Association Between Sound Condition and Accuracy



Note. No significant effect of sound condition on accuracy, however a slight visual trend is visible.

Table 1

Mean Accuracy and Reaction Times per Sound Condition

	Silence	Noise	Music
Accuracy (M%, SD)	98.81% (1.90)	98.45% (1.90)	98.59% (1.75)
RT (M, SD)	0.4332 (0.039)	0.4461 (0.037)	0.4353 (0.046)

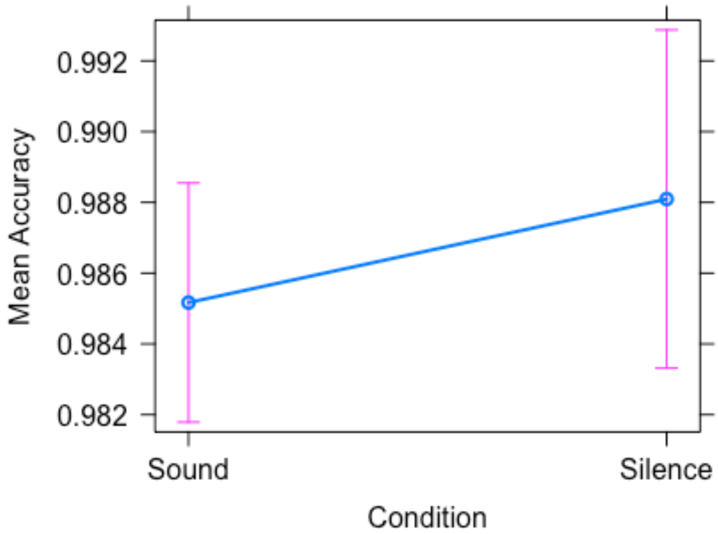
Calculated per Sound Condition – 2 Conditions

Accuracy. When combining the music and noise condition into one "sound" condition, a small trend towards decreased accuracy can be observed in the sound condition compared to silence (Figure 4). However, this remains non-significant (F(1,103) = 0.9833, p = 0.3237). The effect of reaction time on accuracy remained significant (F(1,103) = 24.57, p < 0.0001).

Reaction Time. Condition had neither a main effect on reaction time by itself (F(1,103) = 1.005, p = 0.3185), nor any additive value when the predictor accuracy was taken into account (F(1,102) = 0.3959, p = 0.5306).

Figure 4

Association Between Accuracy and Sound Condition (2 Conditions)



Note. The conditions noise and music are aggregated here into one condition named sound. No significant differences were found, however a slight trend is visible.

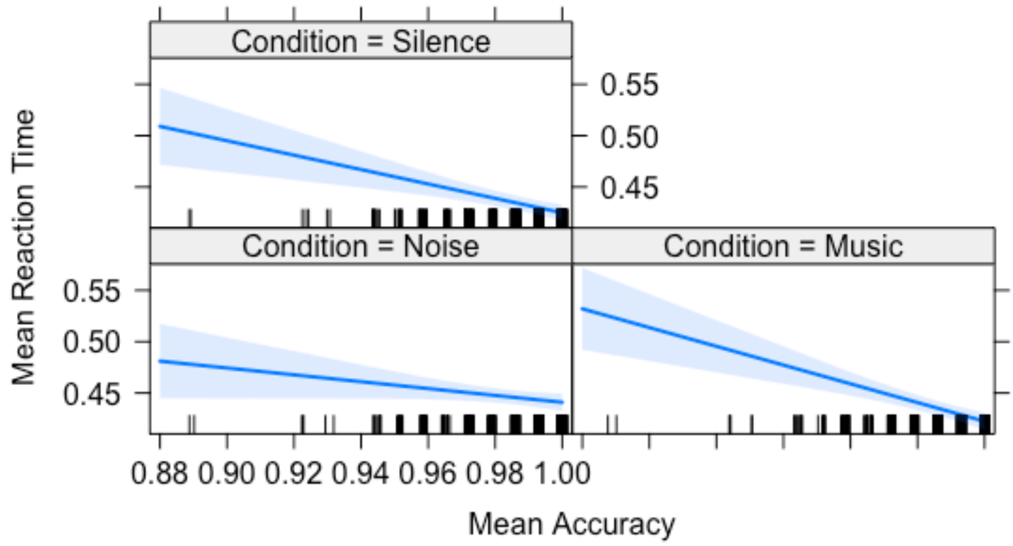
Calculated per Block

Accuracy. In the data split per condition and per time section, the non-significant effect of condition remains (F(2,417) = 1.366, p = 0.26) together with the slight visual trend (Table 2) which we observed before (Figure 3). When combining the music and noise condition into one sound condition, this effect on accuracy remains non-significant (F(1,418) = 2.341, p = 0.1267) as was the case when this was not calculated per block. Furthermore, the significant effect of reaction time ($F(1,418) = 39.82$, $p < 0.001$, $b_1 = -0.1332$, $r = -0.2949$) on accuracy remains. For the average accuracy calculated per time section, per sound condition, see Table C1.

Reaction Time. Condition (i.e., silence versus music versus noise) was found to have a main effect on reaction time ($F(2,417) = 4.057$, $p = 0.018$). When we investigated the additive value of condition to accuracy in the dataset where results were calculated per block per participant, results were significant ($F(2,416) = 3.2308$, $p < 0.05$) in our data. Moving on to investigating the additive value of the interaction between condition and accuracy, we found non-significant results ($F(2,414) = 2.6628$, $p = 0.07$) (Figure 5).

Figure 5

Effect of Accuracy on Reaction Time per Sound Condition (3 Conditions)

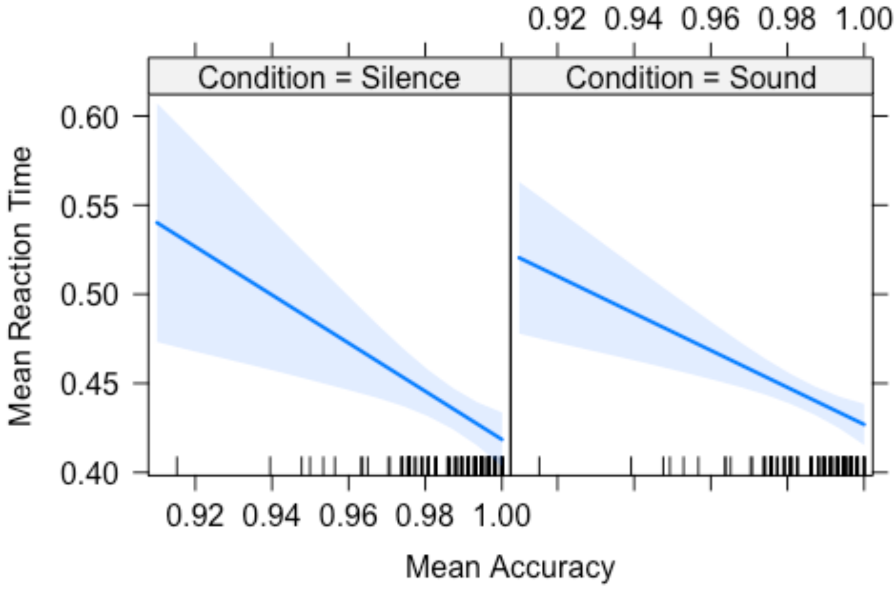


Note. No significant interaction between accuracy and condition on reaction time. Slight indications for a difference between the sound conditions versus silence.

When condition was calculated as "sound" versus "silence", condition was not a significant predictor of reaction time by itself ($F(1,418) = 3.134$, $p = 0.0774$), nor did condition have any additive predictive value when taking into account accuracy ($F(1,417) = 1.9048$, $p = 0.1683$). Adding the interaction between condition and accuracy was also not significant ($F(1,416) = 0.1759$, $p = 0.6751$) (Figure 6).

Figure 6

Effect of Accuracy on Reaction Time per Condition (2 Conditions)

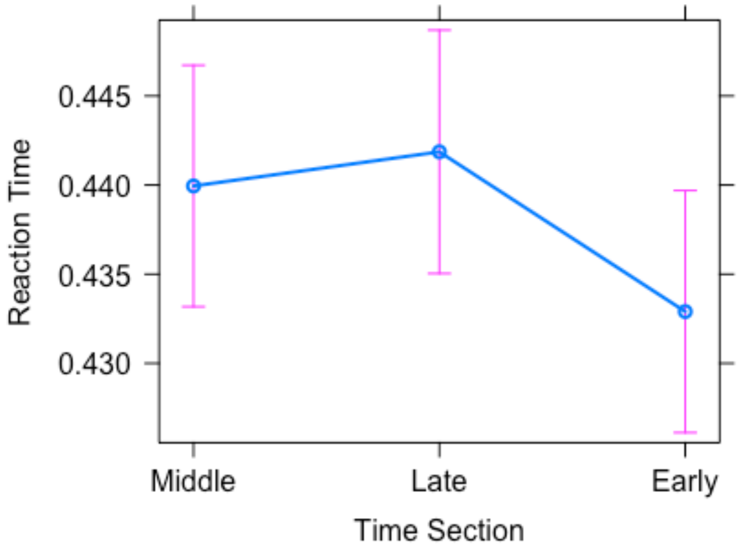


Note. No significant interaction between accuracy and condition on reaction time when the noise and music conditions are added together.

Time section was not a significant predictor for reaction time (F(2,417) = 1.578, p = 0.2076) (Figure 7, Table 2). Time section had no additive effect when accuracy was already established as a predictor for reaction time (F(2,416) = 1.3164, p = 0.2692), nor when condition (music versus noise versus silence) was already established as a significant predictor (F(2,415) = 1.8438, p = 0.1595). For the mean reaction time calculated per time section, per sound condition, see Table C2.

Figure 7

Association Between Reaction Time and Time Section



Note. No significant differences between the time sections concerning reaction time. However, a difference is visible between early and the other two time sections.

Table 2

Mean Accuracy and Reaction Times per Time Section

	Early	Middle	Late
Accuracy (M%, SD)	98.75% (1.66)	98.72% (1.78)	98.38% (2.07)
RT (M, SD)	0.4332 (0.038)	0.4409 (0.043)	0.4406 (0.042)

Additional Analyses

For the false positive rate, we found no effect of reaction time ($F(1,103) = 2.144$, $p = 0.1462$), nor for condition ($F(2,102) = 0.0538$, $p = 0.9477$).

Discussion

In the literature there has been a debate going on for decades now, concerning the question whether auditory distractors could have detrimental effects on cognitively demanding tasks. The current investigation went back to the basics of cognitive performance investigation through the examination of performance on a visual oddball task and how this performance could be influenced by either music or noise playing in the background compared to working in silence. We measured performance in two ways: (1) as the percentage of correct go and no-go trials, and (2) as the mean reaction time on correct hits. These two measures were overall found to negatively correlate (i.e., faster reaction times together with higher accuracy). We found no significant effects of sound condition (i.e., silence versus noise versus music), which was our main research question. To further investigate whether fatigue could play a role, we looked for effects of timing of the experimental blocks (i.e., early, middle, late) on reaction times and accuracy where we again found non-significant results (interactions with condition were also found to be non-significant). When visually inspecting the data, we saw some slight evidence for a small trend confirming our initial hypotheses, however we need to remain cautious as to how we interpret these because of our non-significant findings.

Our main interesting finding was the association between reaction times and accuracies, indicating people who were faster, were also more accurate in their correct hits. This finding has not previously been reported in the literature, to the best of our knowledge. Could this be caused by the long presentation time of the stimuli? Future research should investigate this.

At first sight, one could explain the unexpected absence of differences in accuracies over conditions in terms of the long presentation time of our stimuli. However, following the Perceptual Load Hypothesis (PLH) by Lavie (1995), which stated that performance on cognitive tasks diminishes when the task does not require the full capacity of participants (i.e., allows for distractors to be processed), we cannot conclude that our experimental set-up was simply "too easy" or "too boring" as this would also have had negative effects on task performance (Lavie, 1995). Moreover, when taking into account the *cognitive control mechanism* proposed by Lavie and colleagues (2004), this would mean that the oddball task we investigated was not demanding enough to diminish the ability to actively control for the processing of the auditory distractors (Lavie et al., 2004). Further investigation should include both more and less perceptually demanding tasks to further investigate the perceptual load hypothesis framework. Tasks other than the visual oddball paradigm applied in the current research should also be extensively investigated, with a preference to tasks that are more related to real-world tasks such as driving, studying, or performing surgery. Additionally, the auditory distractors should also be extensively investigated expanding to more real world-like sounds embedded in the auditory distraction conditions (e.g., sounds of cars, conversations, machinery) on top of music and noise.

Nonetheless, these findings of increased accuracy with faster reaction times could be interesting to further investigate, with the longer presentation times the current researchers provided to the participants. Most oddball tasks apply much shorter presentation times as it is believed that this increases cognitive load. What we have shown here, is that even with longer presentation times, cognitive load can be manipulated in other ways (such as auditory distractors). The current research could be an indication for future investigations on oddball tasks, and attention tasks in general, that longer presentation times might also be interesting to further investigate.

Also interesting was the non-significance of time sections, and more importantly, of sound conditions versus silence. Even though in visualizing our data we can see some slight trends towards the expected results of diminished performance (in both slower reaction times and lower accuracy) in the sound conditions compared to the silence condition, these results remained non-significant. The same conclusions of non-significance with a small visual trend can be applied when comparing the early blocks to the late blocks.

As was mentioned in the Corona Statement at the beginning of this thesis, we were unable to collect data in a standardized manner. The actual participant pool was somewhat older than the target participants for whom this experiment was set up. Participants were free to complete the experiment whenever they wanted, which caused major differences in the timing of the data acquisition (some participants completed the experiment late at night after an entire day of hard work). This is another possible confounding factor that might have influenced the current results.

Further, the noise condition might have been too much of a distractor, as participants were instructed to count the number of birds they heard embedded in the noise. Participants reported accidentally pushing the space bar when they heard a bird instead of counting the birds, forgetting the main task because of their focus shift to the counting of the birds, and generally focusing more on the bird sounds than the main task of responding to Xs or Os. Even though the instructions clearly indicated the main oddball task was of most importance, these instructions were written and sent to the participants. This caused a risk of participants not reading the instruction document, or inattentively skimming through it without really paying attention to what it said.

An interesting aspect of the literature that the current investigation did not take into account, was the personality of the participants. Previous research has found significant effects of being extravert versus introvert on the influence of the presence of auditory distraction when completing a cognitively demanding task. It seems that extraverts are at an advantage when music is playing in the background, whereas this has detrimental effects on the performance of introverts (Furnham & Bradley, 1997) Future research should thus further investigate these effects considering personality traits of the participants with an experimental setting similar to the current investigation (i.e., longer presentation times). In the literature, we found a multitude of studies pointing to an advantage of music playing for extraverts, but not for introverts (Furnham & Bradley, 1997).

Another interesting element could be to further investigate the plausible differences between different age categories (i.e., children versus adults) as it has been shown that children get more distracted from auditory stimuli regarding visual selective attention compared to adults (Robinson et al., 2018). Again, the longer presentation times of the current experimental set-up could have additive value to the research on this topic.

The investigation of auditory distraction of cognitive performance in everyday life has gained a lot of attention. However, much is left to be discover and a lot of the findings that have been uncovered are still the main topic of debate. The general value of this type of investigation is immense, people nowadays do nearly everything with some type of auditory distraction in their surroundings. Cooking, cleaning, or shopping are some mainstream examples where distraction might not have any terrible effects. But think of driving, performing surgery, bus drivers, vaccinating people, when these individuals become heavily distracted, the consequences are of much more significance. The current investigation found no significant effects of auditory distraction on the performance in a visual oddball task with a limited participant pool. This does not necessarily imply that listening to music has no effect whatsoever on your cognitive performance. The literature is still in debate, and this research is an addition to the discussion. We believe future research should focus on longer presentation times of stimuli, the ability for participants to see the stimuli again and to investigate possible effects these manipulations could have.

Nederlandstalige Samenvatting

Muziek luisteren terwijl we alledaagse dingen doen, iedereen doet dit weleens. We luisteren naar muziek tijdens het studeren, we luisteren naar de radio in de auto, zelfs chirurgen zetten met plezier muziek op in het operatiekwartier. Maar is dit allemaal wel zo veilig? Kunnen mensen nog steeds even goed presteren wanneer ze ondertussen luisteren naar muziek? Het huidige onderzoek ging dit na door een visuele oddball taak te laten uitvoeren in drie verschillende condities: stilte, muziek, ruis. De bedoeling was om zo snel mogelijk te reageren op de doelstimuli (afhankelijk van het experimentblok was dit X of O) terwijl ze in de geluidscondities ofwel het liedje identificeerden dat speelde, ofwel de vogelgeluiden telden die verwerkt zaten in de ruisaudio. We verwachtten zowel in reactietijden als in accuratesse een verschil in de stilte conditie ten opzichte van de ruis- en muziekconditie. Op basis van de Perceptual Load Hypothesis and de Integrated Competition Hypothesis, gingen de onderzoekers ervan uit dat de traagste reactietijden en laagste accuratesse gerapporteerd ging worden in de muziekconditie, gevolgd door de ruisconditie, en in de stilte conditie verwachtten we de hoogste accuraatheid en de snelste reactietijden. We vonden een verband tussen reactietijd en accuratesse: hoe sneller iemand reageert, hoe correcter. We vonden geen significante effecten van tijdsblok (vroeg, midden, laat), noch van conditie, noch van de interacties tussen tijdsblok en conditie. Wat we wel zagen in de data, was een voorzichtige trend richting onze vooropgestelde verwachtingen. Hoe dit komt, is niet volledig zeker. Het kan zijn dat de ruisconditie te veel afleiding bevatte doordat participanten de vogelgeluiden moesten tellen. Hier kan de niet-gestandaardiseerde omgeving van de afnames ook een grote rol in spelen. Wat we wel zien, is dat aandachtstaken misschien iets minder moeten focussen op korte aanbiedingstijden voor de stimuli, zoals wij in het huidige onderzoek hebben gedaan. Uit onderzoek met langere aanbiedingstijden kunnen mogelijks in de toekomst nog veel nieuwe interessante bevindingen volgen.

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Appendix A

Appendix A

Overview of the songs that were included in the oddball experiment

Artist	Title
A-Ha	Take On Me
Alan Walker	Faded
Beyoncé	Single Ladies
Bruno Mars	24K Magic
Carly Rae Jepsen	Call Me Maybe
Culture Club	Karma Chamelion
DNCE	Cake By The Ocean
Dr. Dre, Snoop Dogg, Kurupt, Nate Dogg	The Next Episode
Eiffel 65	Blue
Europe	The Final Countdown
Gary Jules	Mad World
George Michael	Careless Whisper
Icona Pop	I Love It
Idina Menzel	Let It Go
Imagine Dragons	Believer
Jay-Z, Kanye West	Ni**as In Paris

LMFAO	Party Rock Anthem
Lucenzo, Don Omar	Danza Kuduro
Macklemore	Can’t Hold Us
Macklemore, Ryan Lewis, Wanz	Thrift Shop
Maroon 5	Moves Like Jagger
O-Zone	Dragostea Din Tei
One Direction	What Makes You Beautiful
PSY	Gangnam Style
Ray Parker Jr.	Ghostbusters Theme Song
Rihanna	We Found Love
Shakira	Waka Waka
The Beatles	Hey Jude
The Chainsmokers, Halsey	Closer
Vanessa Carlton	A Thousand Miles
Wiz Khalifa, Charlie Puth	See You Again

Appendix B

Figure B1

Sound Conditions With Target Stimulus O

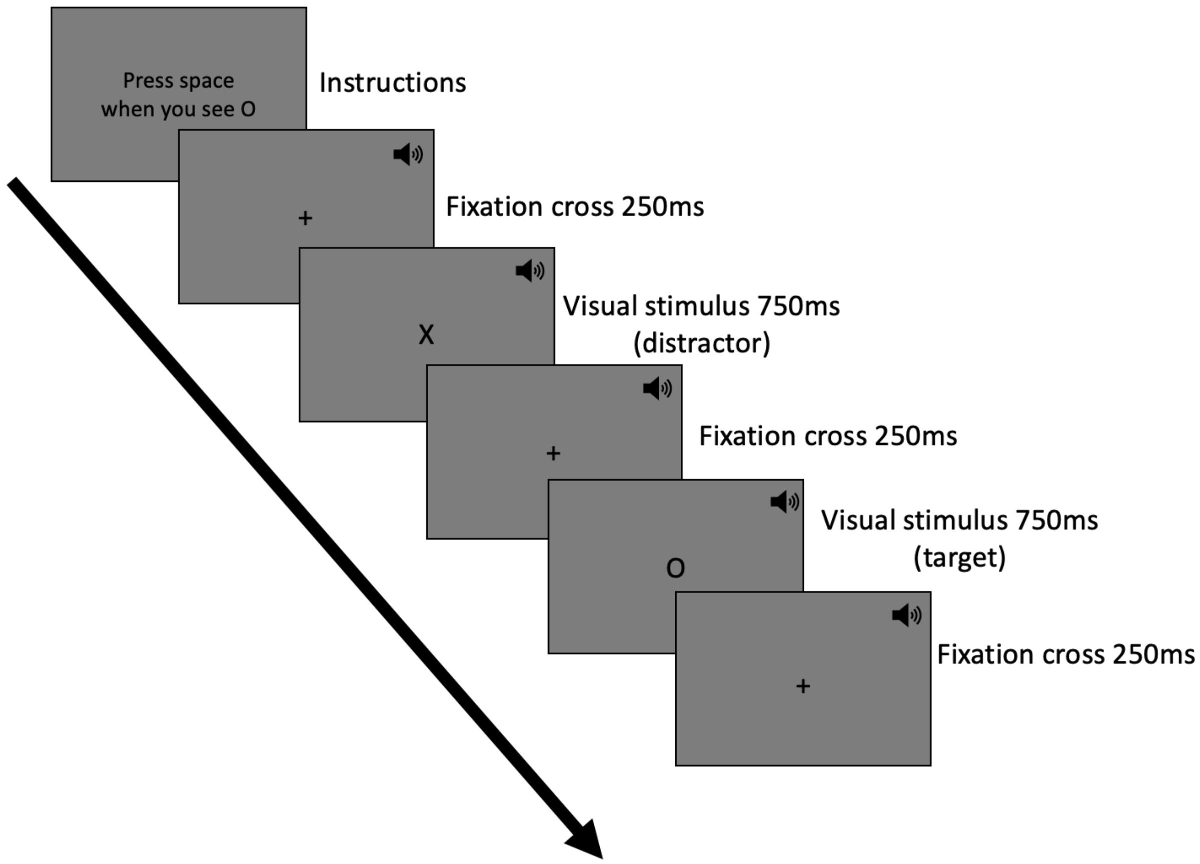


Figure B2

Silence Conditions With Target Stimulus X

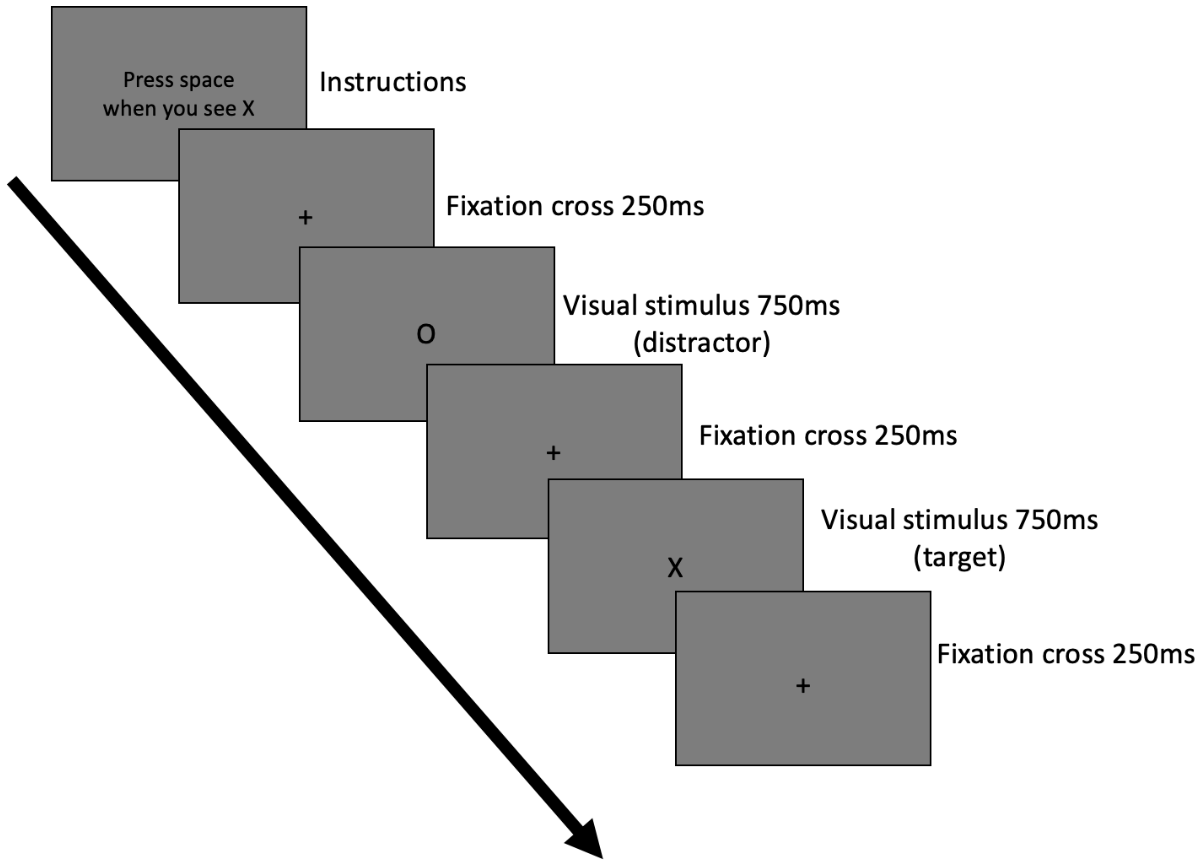
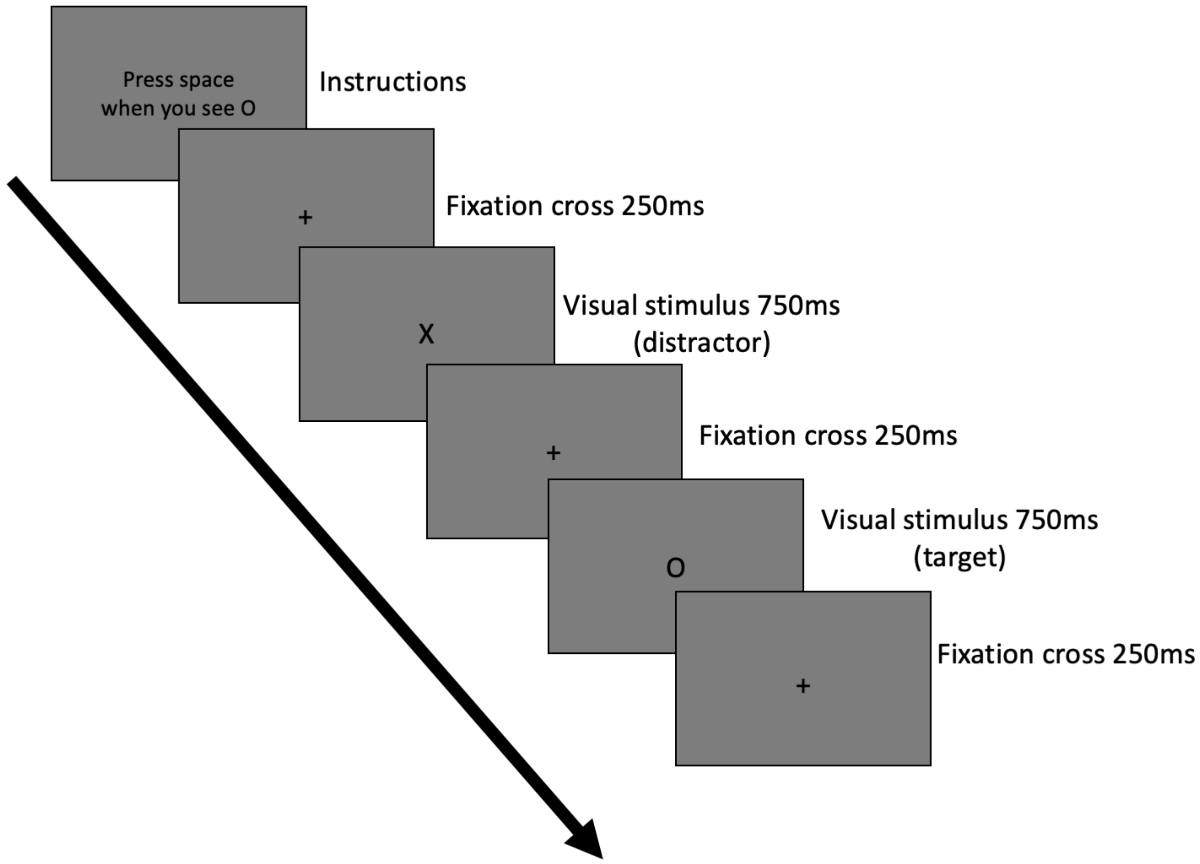


Figure B3

Silence Conditions With Target Stimulus O



Appendix C

Appendix C Tables for Accuracy and Reaction Time Split 3x3

Table C1

Accuracy Split over Condition and Time

		Condition		
		Silence	Noise	Music
Timing	Early	99.23% (1.29)	98.27% (1.91)	98.84% (1.56)
	Middle	98.78% (2.17)	98.64% (1.64)	98.76% (1.58)
	Late	98.60% (1.99)	98.38% (2.25	98.04% (2.06)

Note. Mean percentage (standard deviation of the percentage).

Table C2

Reaction Time Split over Condition and Time

		Condition		
		Silence	Noise	Music
Timing	Early	0.4299 (0.037)	0.4437 (0.036)	0.4267 (0.04)
	Middle	0.435 (0.037)	0.4486 (0.036)	0.4360 (0.054)
	Late	0.4339 (0.042)	0.4454 (0.039)	0.4471 (0.043)

Note. Mean in seconds (standard deviation in seconds).