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What can you do with a bottle and a hanger? Students with high cognitive flexibility give more ideas in the presence of ambient noise

Precious Mones[a,b], Jessica Massonnié[a,c,*]

[a] Department of Psychology and Human Development, Institute of Education, University College London, United Kingdom
[b] The Discovery School, Kent, United Kingdom
[c] University of Portsmouth, Portsmouth, United Kingdom

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ABSTRACT

Creativity has become a favourable skill to develop in higher education due to its value in society. Ambient noise during creative performance has traditionally been regarded as an environmental stressor and distractor, but recent findings suggest a positive impact of ambient noise on creative performance. It is still unclear what drives these inconsistent findings and whether individual differences between students explain the differential impact of noise on their performance. This study investigated the impact of ambient noise on divergent thinking performance in undergraduates during the COVID-19 pandemic, when common learning spaces were restricted and people were instructed to work from home. It also explored how cognitive flexibility (e.g., the ability to switch between different tasks and explore different strategies to problems) interacted with the impact of noise. Forty-two undergraduates completed an adult computer-based version of the Dimensional Change Card Sort task (DCCS) (a measure of cognitive flexibility) in silence, and the Alternative Uses Task (a measure of divergent thinking) in silence and in ambient noise displayed through headphones. On average, participants gave more ideas in the presence of ambient noise than in silence, but these ideas were not more original. Furthermore, the impact of noise interacted with cognitive flexibility. Participants who were more efficient at the DCCS (suggesting better cognitive flexibility) gave more ideas in noise. These findings can help to inform educational institutes and students on the influence the physical environment might have on divergent thinking.

1. Introduction

1.1. *Creativity: the overall picture*

Creativity is traditionally defined as the generation of novel and useful products or ideas (Amabile et al., 1996). In recent years, a dynamic view of creativity as a multifaceted construct has been preferred, which combines a developmental and a systemic framework (Glăveanu & Kaufman, 2020). The developmental framework includes the 4 C's (Kaufman & Beghetto, 2009), which concerns the

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* Corresponding author at: School of Education and Sociology, Faculty of Humanities & Social Sciences, University of Portsmouth, St George's Building, 141 High Street, Portsmouth PO1 2HY, United Kingdom.

E-mail address: jessica.massonnie@port.ac.uk (J. Massonnié).

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trajectory of creativity by acknowledging everybody's potential to be creative, and by emphasising the classroom and learning processes that later leads to creative expression. More specifically, creativity is categorised into four levels: mini-c (subjective creativity, e.g., an individual completing their first ever painting), little-c (creativity used in daily activities, e.g., creating a new dinner recipe), Pro-c (professional-level, e.g., published author) and Big-C (eminent creativity, e.g., great artists). The 5 A's (actor, action, artefact, audience and affordances) (Glăveanu, 2013) is a systemic framework that recognises the individual's personal attributes in relation to their sociocultural environment. Embodied cognition is an important concept within this framework and suggests that our cognition, emotions and behaviours are affected by both internal (i.e., brain, body) and external (i.e., environment, noise) processes. Therefore, in the context of creativity, how people interact with others and objects over time will lead to the generation of new and useful artefacts (Glăveanu, 2013).

1.2. Mechanisms underlying creativity

To understand the impact of environmental factors on creativity, it is important to introduce the main mechanisms through which individuals can come up with creative ideas. These include convergent and divergent thinking.

Convergent thinking orients to the most logical and accurate answer (Cropley, 2006). In Mednick and Mednick's (1971) Remote Associates Test (RAT), students are presented with three cue words and must provide a fourth word that relates to each of the cues. For example, a related word to the cues 'age', 'mile' and 'sand' is 'stone'. Individuals who access both common and uncommon solutions to a problem can identify the correct solution and are therefore deemed to be more creative (Lee, Huggins & Therriault, 2014). The RAT has been criticised for measuring sensitivity to language, rather than creativity (Worthen & Clark, 1971). Additionally, correct answers only include those that are in line with the expected associations predetermined by the researchers (Toplyn & Maguire, 1991). Convergent thinking tests have generally been criticised for being rooted in intelligence (Waddington, 2018) which limits the ability to think outside of the box.

By contrast, divergent thinking involves generating alternative ideas that differ from standard responses. In the commonly used Alternative Uses Task (AUT; Guilford, 1967), participants come up with as many different uses for two common objects. Creative performance is measured by two main dimensions: fluency (i.e., how many ideas are produced) and originality (i.e., how novel and useful ideas are) (Dumas & Dunbar, 2014). The scoring of originality has been debated in the literature. For example, not all authors include usefulness as a criterion when scoring the originality of ideas. However, considering usefulness when scoring for creative performance on the AUT has a purpose for distinguishing between 'random responses' and those 'generated with a purpose in mind' (Alhashim et al., 2020). Furthermore, originality can be scored using 'objective methods' or 'subjective methods'. 'Objective methods' involve listing all the ideas given in a sample of participants and attributing a higher score for ideas that are less frequent, based on a predefined threshold - e.g., ideas given by less than 10% of the population are given a score of 1, and ideas given by less than 5% of the population a score of 2. 'Subjective methods' involve asking external raters (who are either specialised or not specialised in the domain of interest) to rate the originality of answers. The subjective approach of scoring divergent thinking tests has been criticised on the ground that the raters' own perspectives and knowledge on a domain can pervade their originality score (Runco, 2008). It is therefore important to ask multiple raters to score ideas while checking their agreements in order to ensure reliability (Amabile, 1983; Silvia et al., 2008). Furthermore, scoring the entire poll of answers given by an individual is important because the first handful of ideas tend to be common and less original (Kudrowitz & Dippo, 2013).

Both convergent and divergent thinking are equally important for creativity (Gibson, Folley & Park, 2009): divergent thinking is necessary for idea generation, and convergent thinking evaluates ideas into the most rational, appropriate and useful ones. It should be kept in mind however, that creativity is not solely based on convergent and divergent thinking styles, and there are multiple thought processes and skills involved (Dietrich, 2015). Nonetheless, it has been argued that overt convergence encourages a grading culture that systematically penalises students for being 'wrong' (Robinson, 2011). It is therefore important to shift the traditional pedagogical practises in universities away from convergent thinking and to develop and improve divergent thinking (Ledwidge, 2014).

1.3. Creativity in education

Education is a fundamental area where creativity is utilised and valued as an essential skill that will help individuals to prepare for, and innovatively adapt to, an ever-changing social and economic environment (Tan, 2015). Within the Early Years Foundation Stage framework in the United Kingdom, creativity is a core Early Learning Goal because it fosters problem-solving and encourages children to think in different ways (Department for Education, 2017). The Welsh National Curriculum launched in 2019 also encourages the development of children's creativity (Welsh Government, 2019) and most recently, the Durham Commission has developed a vision to promote creativity through the early years to post-16 education in England (James et al., 2019). However, embedding creativity within learning and assessment objectives in UK higher education (HE) seems to have been overlooked, and is rarely explicitly encouraged (Hosseini, 2011; Jackson, 2014). These issues might stem from traditional pedagogical practices (Torrance & Goff, 1990), such as memory-based methods that focus on solving predictable problems, which can decrease motivation in undergraduates (Hosseini, 2011). Interviews with HE students in Sweden revealed that they felt a restriction to their creativity because they were not encouraged to be open-minded in their approach to research for their dissertations (Brodin, 2016). Dissertations are a common feature in the final year of undergraduate study (Feather, Anchor & Cowton, 2014). Similarly, HE students in Brazil perceived a low incentive to creativity, reasons including professor's criticisms to new perspectives, restriction to autonomy and rigidity to course structure (de Alencar & de Oliveira, 2016). Therefore, graduates might not be equipped with the creative skills they require in the workplace (McWilliam, 2007). Fortunately, recent initiatives, such as the National Improvement Framework and Improvement Plan 2020 in Scotland (The Scottish Government, 2019) consider nurturing creativity across different disciplines within UK universities (Winks, Green & Dyer, 2020). The Education and Training 2020 Framework (European Commission, 2020) also wishes to ensure the dissemination of creativity to all levels of education within the European Union, which might give other areas of the UK the incentive to consider creativity within educational frameworks. Higher education can therefore act as a primary producer of creative talents and skills that will feed into the workplace (Universities United Kingdom, 2010). A useful framework developed by Battelle for Kids (2019), which considers a wide range of multidisciplinary teams (e.g., teachers, education experts, business leaders), highlights that creativity is one of the skills that students need to succeed in the 21st century (also see the Emerging Issues Report by Joynes, Rossignoli and Fenyiwa Amonoo-Kuofi (2019) and United Nations Educational, Scientific, & Cultural Organisation, 2022, which recognise the global significance of creativity and divergent thinking to education, the workplace and the wider society).

University students are independent in their learning and study in different environments, such as cafés, libraries, and their homes. With the need to encourage student creativity, there is also a need to explore the influence of their physical learning environment on their creative outcomes. Social and educational contexts play an important role on the creative performance of young adults (18–30 years), particularly on divergent thinking (Restrepo, Arias-Castro & López-Fernández, 2019). Contradictory findings exist regarding some aspects of the physical environment, such as noise. Noise is generally considered to be a distraction - auditory stressors and distractions have been found to have a negative impact on creativity (Hillier, Alexander & Beversdorf, 2006; Threadgold, Marsh, McLatchie & Ball, 2019). However, ambient noise can be beneficial for undergraduate students' ability to generate creative ideas (Mehta, Zhu & Cheema, 2012). More studies need to be done to confirm such findings. A better understanding of whether certain levels of noise encourage, or hinder creativity will be useful for informing educational institutes on the impact the physical environment might have on the creative performance of their students, particularly divergent thinking.

1.4. *The impact of noise on creativity*

Noise is characterised as an unwanted, unattended (Erickson & Newman, 2017) and disruptive (Buchari & Matondang, 2017) sound that often distracts people from performing cognitive and communication tasks (Braat-Eggen, van Heijst, Hornikx & Kohlrausch, 2017; Szalma & Hancock, 2011). Ambient noise is a naturally occurring background noise that can be heard in everyday life (e.g., furniture being moved, roadside traffic, overheard conversations) (Blunnie, 2014). When considering the ambient noise perceived by undergraduates while studying, this might include noise from coffee shops, classrooms and the home. University students consider ambient noise in the learning environment as an environmental stressor (Onchang & Hawker, 2018; Servilha & Delatti, 2014), which has been shown to negatively impact speech perception, cognitive performance and emotional state (Sarsenbayeva, van Berkel, Velloso, Kostakos & Goncalves, 2018). In a meta-analysis of 191 studies (Szalma & Hancock, 2011), noise negatively affected performance in perceptual, cognitive and psychomotor tasks in adults aged 18–57. However, this was dependent on the type of noise and type of task. For example, noise containing speech caused greater interference and distraction on perceptual, cognitive and communication tasks, compared to non-speech and music conditions. A review of the literature (Wright, Peters, Ettinger, Kuipers & Kumari, 2014) has also found that noise stress had a negative effect on attention, working memory and recall in healthy adults.

However, opposing findings suggested that certain levels of noise are beneficial for creativity. For instance, Toplyn and Maguire (1991) used a variety of verbal and visual divergent thinking tasks to measure undergraduates' creativity. They investigated whether three levels of noise (60 dB (dB), 80 dB and 100 dB) would hinder the creative performance of students. The measurement of creativity included fluency (total number of responses) and originality (how many responses were unique across the sample). Overall, noise did not decrease creative performance. Individual differences were noted. The impact of noise on originality depended on whether participants had an overall creativity level that was low or high. The originality scores of the students considered as highly creative increased from 0.36 in the 60 dB condition to 0.89 in the 80 dB condition. When the noise increased from 80 dB to 100 dB, the mean originality score for high scorers decreased to 0.32. This was not the same for students classified as low in terms of creative scores. Their performance did not vary between noise conditions. The researchers suggest that moderate levels of noise increased arousal, which enhanced creativity for those who were highly creative to start with. This is important, as arousal impacts an individual's vigilance and alertness (Carter, de Lecea & Adamantidis, 2013) and moderate levels of arousal leads to enhanced focus and attention on various tasks, including those testing convergent and divergent task performance (Seo, Bartunek, & Barrett, 2009). Toplyn and Maguire (1991) do not provide a clear rationale for choosing these levels of noise, nor what constitutes low, moderate or high noise. This study has further been criticised for using white noise (artificial noise involving all audible frequencies from the sound spectrum), failing to depict a realistic environment for which undergraduates would normally learn and study in. For these reasons, efforts to implement more naturally occurring types of ambient noise have been made.

Mehta et al. (2012) used noise commonly heard in everyday life (e.g., a mix of coffee shop, restaurant and roadside traffic noise) and found that moderate ambient noise enhanced originality across five different tasks that measured convergent and divergent thinking (including the RAT and the AUT). Participants assigned to the moderate noise condition (70 dB) gave more original ideas, compared to those assigned to the high (85 dB) and low (50 dB) noise conditions, regardless of whether they were highly creative to begin with or not. This disputes Toplyn and Maguire's (1991) findings. Furthermore, arousal, which was measured by heart rate and blood pressure, was not the preferred explanatory mechanism for the impact of noise on creativity since arousal levels tended to normalise and not persist over the course of the experiment.

Instead, Mehta et al. (2012) findings were explained by processing disfluency. Processing disfluency is a metacognitive experience of difficulty associated with completing a mental task. If the task is perceived as easy or fluent, one often uses heuristics and intuitions to process information. In contrast, if the task is perceived as difficult or disfluent, one is more likely to engage in effortful and analytical processing (Alter, Oppenheimer, Epley & Eyre, 2007; Kühl & Eitel, 2016). In Mehta et al. (2012) study, processing disfluency was measured by asking participants how distracting they found the room ambience, how well they were able to concentrate and how comfortable they found the experimental room. In relation to their findings, moderate noise, in comparison to low noise, stimulated disfluency on the tasks, meaning that more effort was required as a result of the noise's moderate distraction. In turn, this encouraged the participants to look at the bigger picture, and was facilitated by abstract thinking, which aided their ability to analyse situations, problem solve and change perspectives rather than concentrating on one idea. High noise reduced the time spent on task, which negatively impacted creativity scores.

In support of Mehta et al.'s interpretation, defocused attention (the ability to consider several ideas at the same time) (Kaufman, Kornilov, Bristol, Tan & Grigorenko, 2010) and mind-wandering (Baird et al., 2012) have both been found to improve creativity. Baird et al. (2012) found that taking a break from undemanding tasks, compared to breaks from demanding tasks and no breaks led to greater mind-wandering, which improved originality on the AUT after repeated exposure to the problem. To further support the benefits of distraction on divergent thinking, it has been found that when distracting information is relevant to creativity, it can help to boost performance (Carpenter, Chae & Yoon, 2020). These findings help us to understand why cognitive fixation, which in this context means that an individual spends too much time concentrating on one idea, has been deemed to be a barrier to creativity (Chrysikou & Weisberg, 2005). The positive effects of distraction on creativity suggest that switching between different tasks or ideas would be beneficial for creativity, which leads us to consider the role of cognitive flexibility on creativity.

1.5. *Cognitive flexibility and creativity*

Cognitive flexibility involves mentally switching between different tasks or concepts, adapting behaviours to change, and exploring different strategies to problems (Diamond, 2013). Cognitive flexibility and creativity likely share similar cognitive processes (Khalil, Godde & Karim, 2019) because they are both involved with adjusting to new demands, changing perspectives, problem solving and producing novel and useful ideas.

The dual pathway to creativity model (Nijstad, De Dreu, Rietzschel & Baas, 2010) proposes that cognitive flexibility is one of the functions through which creativity might be achieved. The flexibility pathway involves the ability to "achieve creative insights, problem-solve, use broad and inclusive cognitive categories, use flexible switching, and use remote (rather than close) associations" (p. 43). This links back to abstract thinking (Mehta et al., 2012), defocused attention (Kaufman et al., 2010) and mind-wandering (Baird et al., 2012) as individuals should not rely on fixed strategies to solve problems and generate ideas.

The ability to shift attention from one task to another contributes to divergent and convergent thinking and reduces the barrier of cognitive fixation (Lu, Akinola & Mason, 2017). This suggests that reduced fixation (e.g., interruptions, breaks, and distractions) – the opposite of cognitive fixation, is beneficial for individuals' creativity because it helps to temporarily set a task aside. Most people predicted that switching between tasks would be the least effective for creativity, which suggests that what people might think will work, is the opposite of what seems to work (Lu et al., 2017).

Along with the flexibility pathway, it is worth mentioning the persistence pathway to creativity. This pathway suggests that when focusing on a particular idea or task, creative ideas and solutions are enhanced because the individual's full attention is on the task and on exploring the problem's space, thus blocking out distracting and irrelevant thoughts. So far, it is still unclear whether cognitive flexibility modulates the impact of environmental factors such as noise distractions on participants' performance. For example, students with high cognitive flexibility might benefit more from switching between their task and noise, whereas participants with low cognitive flexibility might be too overwhelmed by noise to benefit from distraction.

1.6. *How cognitive flexibility might help individuals to deal with noise*

Undergraduates (Carriere, Seli & Smilek, 2013) and primary school children (Massonnié, Frasseto, Mareschal & Kirkham, 2020) who reported having lower cognitive flexibility skills also reported being more distracted in noisy environments. Mehta et al. (2012)

suggested that the feeling of being distracted (i.e., processing disfluency) explained the positive impact of noise on originality measures. It is unclear whether all students might benefit from noise when performing a creative task, or whether individual differences in cognitive flexibility interact with the impact of noise. In other words, do students need to have a certain level of cognitive flexibility to alternate between the distraction and their task? We are not aware of any studies investigating the impact of noise on creativity along with a behavioural measure of cognitive flexibility.

2. Goals of the study

This study aimed to investigate: (1) the impact of ambient noise on creativity, specifically divergent thinking and (2) the role of cognitive flexibility in the ability to perform a divergent thinking task in the presence of ambient noise.

Research Question 1. Will undergraduates have a better performance at a divergent thinking task in the presence of moderate ambient noise compared to silence?

In line with Mehta et al. (2012), it was expected that divergent thinking performance would be better in the presence of moderate levels of ambient noise.

A high noise condition was not explored in this study, which focused on moderate levels of noise. This is because moderate levels of noise have previously been shown to be most beneficial for creativity.

Research Question 2. Does the impact of ambient noise on divergent thinking depend on participants' level of cognitive flexibility? It was expected that individuals with higher levels of cognitive flexibility would benefit more from the presence of ambient noise, compared to those with lower levels of cognitive flexibility.

The COVID-19 pandemic restricted the use of common learning spaces and students were required to work from home. These conditions accelerated the use of technologies, which is important to consider when measuring divergent thinking (Glăveanu, Ness & de Saint Laurent, 2020). This study therefore used an online platform to test Research Questions 1 and 2 in a naturalistic environment - when students worked from home.

3. Methods

3.1. Design

A mixed experimental design was used. The dependent variable was divergent thinking (two variables were extracted per participant: fluency and originality). The independent variables were noise condition (ambient noise vs. silence, within-subject) and cognitive flexibility (measured with a continuous score).

3.2. Participants

Undergraduates were contacted through social media (LinkedIn and Instagram) and were encouraged to forward the link to their peers. Due to the nature of the tasks, individuals who could not distinguish between red and blue, as well as those who were hearing impaired were instructed not to take part. The sample therefore included participants with normal-corrected vision and normal hearing. There were 51 participants (21 males, 29 females and 1 who ticked 'prefer not to say'), whose ages ranged between 18 and 23 (*M* = 20.80, *SD* = 1.15). This study was granted ethical approval by the University Ethics Committee. Participants' informed consent was ensured before the start of the experiment (see Appendix A).

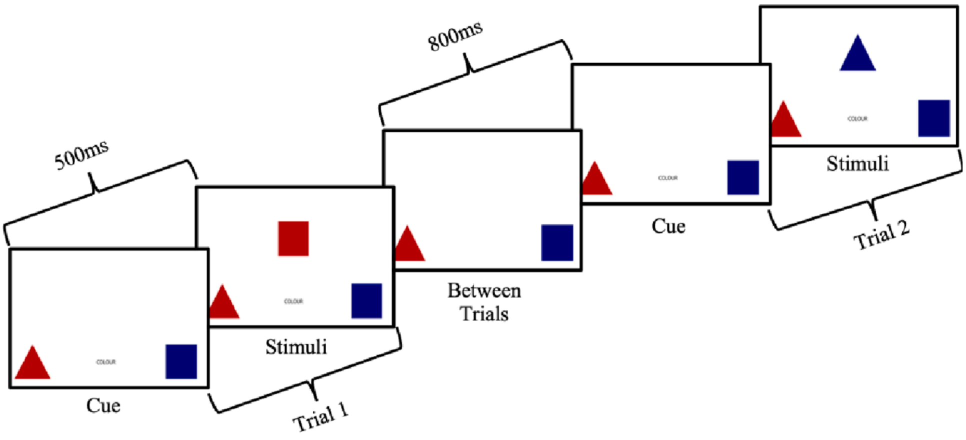

Fig. 1. Schematic representation of the DCCS task.

3.3. Procedure

A link was sent via email to access the experiment on a desktop/laptop. Participants read an information sheet before deciding to take part. To confirm their consent, participants ticked four boxes stating that: (1) they had read and understood the information sheet and had the opportunity to ask questions, (2) they consented to take part in the study, (3) they understood their participation was voluntary and that they had the right to withdraw at any time without giving a reason, and (4) they understood that the study had been reviewed and approved by the Ethics Committee. The information sheet and consent page are provided in Appendix A. Participants then completed a demographics sheet regarding their age, sex and field of study. The first task was a computer-based adult version of the Dimensional Change Card Sort (DCCS) (Diamond & Kirkham, 2005) used to measure cognitive flexibility. The second task was the AUT, a measure of divergent thinking, for which participants took part in a silent condition and in a condition with ambient noise (approx. 65 dB), and were instructed to wear their headphones throughout. Upon completion, participants were asked to (1) describe their noise environment during the silent task, (2) report whether they found the noise distracting, and (3) provide a reason for yes or no. Finally, participants were fully debriefed on the aims and purpose of the study and were reminded of their confidentiality, anonymity and rights to withdraw. They were given the option to request a copy of the overall findings by emailing the researcher. This email address was provided on the debrief sheet. The overall length of participation was approximately 15 - 20 minutes.

3.4. Materials/Measures

The experiment was created using The Gorilla Experiment Builder (gorilla.sc). Gorilla efficiently runs reaction-time-sensitive behavioural experiments (Anwyl-Irvine, Dalmaijer, Hodges & Evershed, 2020a, 2020b; Massonnié, Rogers, Mareschal & Kirkham, 2019), and has been successfully used to display auditory narratives (Richardson et al., 2020), and to measure speech perception (Tierney, Patel, Jasmin & Breen, 2021).

3.4.1. Cognitive flexibility

The DCCS task (Diamond & Kirkham, 2005) measured cognitive flexibility. Participants sorted a picture according to its shape or colour as quickly as possible. All participants completed the task in silence (no noise stimulus). The first screen displayed two model images on the bottom left (red triangle) and right (blue square) hand-side of the screen, with the cue word ‘colour’ or ‘shape’ in between them to tell participants what dimension they would be sorting by. After 500 milliseconds (ms), either a blue triangle or a red square stimulus appeared above the cue word. Participants pressed the ‘A’ key for ‘red’/’triangle’ and the ‘L’ key for ‘blue’/’square’. Once ‘A’ or ‘L’ was pressed, the stimulus and cue word disappeared, and the model pictures remained on the screen. After 800 ms, the next cue word and stimulus appeared (see Fig. 1 for a schematic representation of the task).

Four practice trials (2 colour trials, 2 shape trials) ensured that participants understood the instructions. The main task included 80 trials grouped into 7 blocks (10 colour, 10 shape, 10 colour, 20 mixed, 10 shape, 10 colour and 10 shape), as in Diamond and Kirkham (2005). The sorting dimensions in the mixed trial were pseudo-randomly intermixed (e.g. no more than 2 of the same dimensions in a row). The average completion time was 4 minutes. Response times (RTs) were recorded for when the participant pressed the “A” or “L” key.

According to previous research, participants are slower in the mixed block trials where they are cued to regularly switch from shape to colour, as opposed to the repeated trials where they sort based on only shape or colour. This increase in response time is deemed to reflect the need to switch from one dimension to another (Diamond & Kirkham, 2005).

The DCCS measure for cognitive flexibility is reliable and valid across different ages (Diamond & Kirkham, 2005; Zelazo, 2006). Amongst adult populations, it has a test-retest reliability of $r = 0.58$, an intra-class correlation coefficient of 0.81, and a good convergent validity with a Flanker task ($r = 0.71$) and a Stroop Colour-Word test ($r = 0.55$) (Zelazo et al., 2014).

The computer version has been commonly used with adult populations, showing reliability and sensitivity to individual differences (Von Suchodoletz, Slot & Shroff, 2017).

3.4.2. Divergent thinking

Two versions of the AUT were used to measure divergent thinking in silence and in ambient noise. Instructions appeared on the screen before the tasks began. For Version A, the instructions read: ‘You will be asked to produce as many different uses as you can think of for a bottle. For example, bottles are commonly used for storing liquids. You will have 3 minutes to answer.’ For Version B, the instructions read: ‘You will be asked to produce as many different uses as you can think of for a hanger. For example, hangers are commonly used for hanging up clothes. You will have 3 minutes to answer’. In the ambient noise condition, participants were instructed to put on their headphones/earphones at approximately 60% of volume capacity. In the silent condition, participants were instructed to perform the task in silence and to put their headphones/earphones on with no noise being displayed. To control for order effects, the noise conditions (noise first or silence first) and items in noise (hanger or bottle) were counterbalanced across participants.

The tasks were not accompanied by an image to eliminate cognitive fixation, in which participants might conform to the image and generate ideas based on them. A one-minute countdown appeared on the screen to remind the participants of how much time was left at the end of the task.

The fluency (total number of responses, excluding the example) and originality of responses were measured. Originality was measured by asking four external raters to score each answer based on its combined uniqueness, usefulness and inventiveness on a scale from 1 (not at all creative) to 5 (highly creative). Using Cronbach's alpha (Cronbach, 1951), interrater reliability was calculated on 100% of the study sample and was achieved for both objects (αbottle $= 0.76$, αhanger $= 0.84$). The originality scores of each participant were calculated by averaging the originality scores of all their answers for each task. Such scores derived from the AUT have been validated by previous studies against the Big Five personality Inventory, which explains 17.2% of their variance, and against participants' educational background as art majors in college, which increased the explained variance to 22% (Silvia et al., 2008).

3.4.3. AUT noise stimulus

Ambient café noise from YouTube was used. To test for an appropriate headphone audio level, the iPhone "Health" app, under "Hearing" was used. During set up, 60% volume displayed a 65 dB (ambient) noise level for 3 minutes. Participants were therefore instructed to display a 60% volume.

4. Results

4.1. Data screening and outliers

The tasks were initially checked to ensure that the participants completed them properly. In the DCCS, 3 participants obtained less than 50% accuracy (i.e., 31%, 47.5% and 49%), 1 participant experienced loading delay (slow internet connection causing inaccurate RTs) and 1 participant exited the task mid-way through. Data from these participants were removed because it was unlikely that they would give an accurate estimate of their cognitive flexibility.

RTs below 200 ms at the DCCS were excluded because they were too quick to have been a response to the stimuli (Whelan, 2008). The average RT per block on the DCCS was inspected. One outlier, whose mean RT was 2.5 standard deviations (*SD*s) above the mean of the sample for Block 4 (mixed) was removed. RT data at the DCCS are typically positively skewed, and have therefore been transformed using a log transformation (based 10) to reduce skewness (Zelazo et al., 2014). Histograms were plotted to analyse the shape of the distributions and are provided in Appendix B.

For the AUT, histograms were inspected for fluency and originality scores in silence and in noise. To identify the extreme cases, Z-scores were computed to screen for outliers who were 2.5 *SD*s above or below the mean. Three outliers were identified and removed, corresponding to two fluency scores in the ambient noise condition ($Z = 3.36$ and $Z = 2.80$) and to one originality score in the silence condition ($Z = -3.34$). As shown in Appendix C and Appendix D, removing these outliers did not change the main conclusions of the paper. Distributions that were obtained following the removal of these outliers are plotted in Appendix B. The following analyses are carried out on a sample of 42 participants (17 males, 24 females and 1 who ticked 'prefer not to say'), between the ages of 18 and 23 ($M = 20.79$, $SD = 1.18$). Twenty fields of study were represented with the modes being Business and Psychology (see Appendix E).

4.2. Power analyses

Our main interest was in the within-subject comparison between silence (no noise stimulus) and ambient noise, and the interaction between the effect of ambient noise and cognitive flexibility. The Power analyses were performed a posteriori on GPower 3.1 using the ANOVA repeated measures, within-between interaction function. It specified two groups (participants with 'high' cognitive flexibility being above the median and participants with 'low' cognitive flexibility being below the median) and a correlation between the two repeated measures at 0.5. A sample of 42 participants provides 89% power to detect a medium effect size ($f = 0.25$), and 99% to detect a large effect size ($f = 0.40$) for these effects.

4.3. DCCS

Accuracy (percentage of correct answers) was at 93.62% across all blocks, and at 84.64% for the mixed block. The average RTs for correct answers were obtained for all 7 blocks and are reported in Table 1 and Fig. 2.

A repeated-measures analysis of variance (ANOVA) was run to compare the differences in RTs between the 7 blocks. Mauchly's test of sphericity indicated that the assumption of sphericity had been violated, $\chi2(20) = 51.90$, $p < .001$. Therefore, a Greenhouse-Geisser correction was applied ($\varepsilon = 0.62$). The ANOVA revealed that the mean RTs for the 7 blocks were significantly different, $F(3.51, 144) =$

Table 1
Descriptive statistics for the response times (in ms) at the DCCS task per block.

	M	*SD*
Block 1 Colour	840.41	437.41
Block 2 Shape	918.60	493.25
Block 3 Colour	800.47	359.12
Block 4 Mixed	1105.25	577.76
Block 5 Shape	845.11	356.76
Block 6 Colour	819.42	393.65
Block 7 Shape	848.29	399.62

$n = 42$.

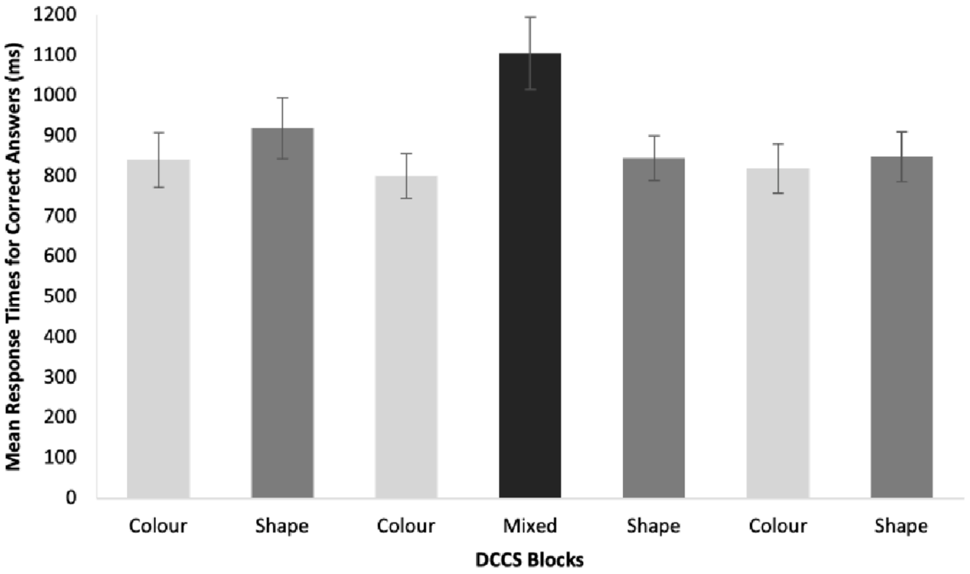

Fig. 2. Bar chart representation of mean response times on the DCCS blocks. Error bars represent the standard error of the mean.

6.01, $p < .001$, ηp2 = 0.13. Bonferroni post-hoc comparisons tests indicated significant differences in RTs between block 1 (colour) and block 4 (mixed) ($p < 0.001$), between block 2 (shape) and block 4 (mixed) ($p = .01$), block 3 (colour) and block 4 (mixed) ($p < .001$), block 5 (shape) and block 4 (mixed) ($p = .02$), block 6 (colour) and block 4 (mixed) ($p = .01$) and block 7 (shape) and block 4 (mixed) ($p = .01$). Therefore, participants took significantly longer to respond in the mixed block, compared to blocks including only colour and shape. This is in line with Diamond and Kirkham's (2005) findings.

4.4. Analyses plan

Two multivariate analyses of covariance (MANCOVA) were computed to test the impact of ambient noise on divergent thinking scores and its potential interaction with cognitive flexibility.

In Model 1, Fluency scores in the two Conditions (Silence vs Noise) were entered as repeated measures variables. Two between-subject factors were included as control variables as they represented counterbalancing procedures: Item in Noise (Bottle or Hanger) and Noise Order (Silence First or Noise First). Cognitive Flexibility was entered as a covariate.[1] We tested the main effect of noise on Fluency (Research Question 1) and its interaction with Cognitive Flexibility (Research Question 2).

In Model 2, Originality scores in the two Conditions (Silence vs Noise) were entered as repeated measures variables. Two between-subject factors were included as control variables as they represented counterbalancing procedures: Item in Noise (Bottle or Hanger) and Noise Order (Silence First or Noise First). Cognitive Flexibility was entered as a covariate[1]. We tested the main effect of ambient

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[1] The results reported for the interaction between noise and cognitive flexibility did not change when cognitive flexibility was entered as a between-subject factor, splitting participants as having 'high' cognitive flexibility (above the median) and 'low' cognitive flexibility (below the median).

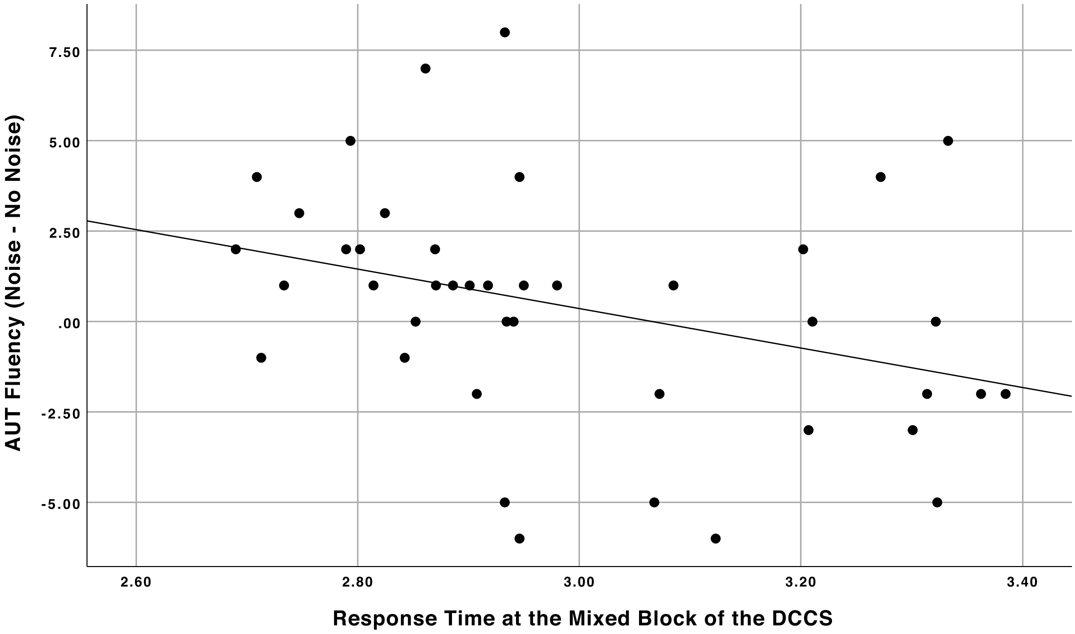


Fig. 3. Scatterplot representation of DCCS response times against AUT fluency scores in noise and in silence.

noise on Originality (Research Question 1) and its interaction with Cognitive Flexibility (Research Question 2).

4.4.1. Model 1

There was a main effect of Conditions on Fluency scores (*F*(1,34) = 6.55, *p* = 0.02, ηp2 = 0.16). On average, participants gave more ideas in Noise (*M*Noise = 5.95, *SD*Noise = 1.97) compared to Silence (*M*Silence = 5.55, *SD*Silence = 2.36).

There was an interaction between the effect of Condition and Cognitive Flexibility (*F*(1,34) = 6.28, *p* = .02, ηp2 = 0.16).

In order to better understand this interaction, we subtracted the fluency score in the silent session from the fluency score in the noisy session. The resulting score gives an estimate of the gain in fluency obtained in the noisy session: if positive, the participants gave more ideas in the presence of ambient noise, if negative, the participants gave more ideas when there was no ambient noise displayed through the headphones. As shown in Fig. 3, the participants who gave more ideas in noise were the ones who were the most efficient at the DCCS mixed block (they took less time to give the correct answer, *r* = - 0.35, *p* = .02).

4.4.2. Model 2

There was no main effect of Condition on Originality Scores (*F*(1,34) = 0.00, *p* = .96, ηp2 = 0.00. There were no differences across the conditions for Noise (*M*Noise = 2.62 , *SD*Noise = 0.43) and Silence (*M*Silence = 2.56 , *SD*silence = 0.43). There was no interaction between Condition and Cognitive Flexibility (*F*(1,34) = 0.01, *p* = .94, ηp2 = 0.00).

5. Discussion

5.1. Did undergraduates have a better performance on divergent thinking tasks in the presence of ambient noise compared to silence?

The first goal of this study was to investigate whether the divergent thinking performance of undergraduates would be better in conditions of ambient noise or in silence. On average, participants gave more ideas on the AUT in the presence of ambient noise, but these ideas were not rated as more original. This stands in contrast to Mehta et al. (2012) findings that moderate levels of ambient noise were associated with better originality, but not better fluency on the AUT. It is worth highlighting the differences in design between the two studies. First, Mehta et al. (2012) asked raters to score only the unique ideas generated by participants, not all their ideas. Second, Mehta et al. (2012) used a between-subject design, placing different participants in each condition. It is possible that the observed differences between noise conditions reflected general differences amongst the participants' creative abilities. To control for this confounding issue, the present study used a within-subject design by testing the same participants in both ambient noise and silence.

5.2. *Did the impact of ambient noise on divergent thinking depend on participants' level of cognitive flexibility?*

The second research question explored the potential interaction between the impact of ambient noise on divergent thinking and cognitive flexibility, with the hypothesis that individuals who display efficient levels of cognitive flexibility would benefit from noise because they have the resources to alternate between processing the task and the noise. Cognitive flexibility interacted with the impact of ambient noise on fluency scores. Individuals who scored more efficiently on the mixed block of the DCCS task gave more ideas in ambient noise.

This might be explained by moderate amounts of distraction, which has been found to trigger abstract thinking, which helps individuals to problem solve, change perspectives and analyse situations, rather than focusing on one idea (Kaufman et al., 2010). In the present study, perhaps only those who displayed better cognitive flexibility benefited from the distraction induced by moderate noise as it helped them to defocus their attention and consequently think of different solutions. It is also possible that the ambient noise led to cognitive disinhibition (e.g., flexibility in the way that information is processed based on the situation; Martindale, 1999), leading to better idea generation (Radel, Davranche, Fournier & Dietrich, 2015) for the students with higher cognitive flexibility because they could flexibility focus or defocus their attention to generate ideas in the presence of ambient noise. In contrast, those with lower levels of cognitive flexibility might have difficulties switching. The noise and the task might have been too much information to hold.

It is important to note that flexibility, as measured by the DCCS, only interacted with the impact of ambient noise on fluency scores, not originality scores. Several explanations can be proposed for this phenomenon.

5.3. *Explaining why noise interacted only with fluency, not originality scores*

First, different underlying processes might be involved in different dimensions of divergent thinking, namely fluency and originality. Kharkhurin (2008) identified two groups of creative behaviour. The first included fluency and flexibility, which likely represented idea generation. The second group included originality, which likely represented the ability to extract unique ideas. Fluency and originality are usually correlated, yet have been considered separable aspects of creativity (Dumas & Dunbar, 2014; Forthmann, Bürkner, Szardenings, Benedek & Holling, 2019). Fluency alone is an inadequate measure of divergent thinking as it does not consider the quality of an idea (Acar, Burnett & Cabra, 2017). Originality scores do consider the quality of responses. Benedek, Franz, Heene and Neubauer (2012) found that inhibition (i.e., the ability to suppress irrelevant information) was more related to the fluency and flexibility of idea generation, whereas intelligence was more related to originality. However, fluency, flexibility and originality were all strongly correlated, suggesting the presence of common underlying processes, or of the contamination of fluency scores to other processes (Forthmann, Szardenings & Holling, 2020).

Second, the interaction effect on fluency scores was possibly led by the instructions to come up with 'as many different ideas', leading participants to focus more on fluency than originality. These instructions might have led to a less effortful process where the participants focused on generating as many ideas from memory as they could think of, instead of generating ideas to 'be-creative'. Forthmann et al. (2019) recognised that such differences in instructions cause a variation in the strategies used. For instance, in 'be-fluent' situations, participants focus on giving as many ideas they can think of. In contrast, in 'be-creative' situations, participants focus on generating imaginative ideas, which is a more challenging task. Consequently, the interaction effect based on the 'be-fluent' instructions might reflect speed of processing during interfering conditions - in other words, participants' ability to access many different ideas under distracting conditions.

These two interpretations help to explain that ambient noise only interacted with cognitive flexibility for the measure of fluency, not originality. The ambient noise might not have impacted the evaluative process involved in the originality dimension. These findings open up future avenues of research to explore the impact of ambient noise on different aspects of creative performance.

5.4. *Limitations and future directions*

The study is subject to at least three limitations. First, as an online study, it involved less control over experimental factors, such as participants performing the tasks using headphones and the types of headphones used. For this study, it was important that the noise was displayed at a moderate level of ambient noise (i.e., at approximately 65 dB or 60%), though this could differ between the different operating systems that participants had. Future researchers could instruct the participants to complete the new headphone screening task on Gorilla.sc before the completion of online auditory experiments. This task has been found to efficiently screen out participants who are not using headphones (Milne et al., 2021). Another experimental factor that this study could not control was the various types of computers used. Fortunately, Gorilla.sc has been found to perform well in visual reaction time tests, finding a consistently low variability across different browsers and operating systems (Bridges, Pitiot, MacAskill & Peirce, 2020).

The second limitation is that the 'silent' condition was dependent on the participant's home environment as external noise could not be controlled. This is a common drawback of online studies and should be weighed against the advantage of testing participants in their natural home environment. In our study, the comparison between the conditions with and without ambient noise being played through headphones operated at a within-subject level. Therefore, participants acted as their own control.

Finally, the specific tasks and measurement of cognitive flexibility and divergent thinking are subject to discussion. There are various cognitive flexibility tasks that differ based on how researchers operationalise cognitive flexibility. Therefore, it is difficult to compare findings between studies and agree on the best way to measure cognitive flexibility (Dajani & Uddin, 2015; Ionescu, 2012).

Flexibility as measured by the DCCS reflects the flexible behaviour of following one rule (e.g., sorting by shape), and then following another rule (e.g., sorting by colour). Other measures of cognitive flexibility, such as insight problems or induction tasks, might involve different processes such as linguistic knowledge, or reasoning on taxonomical relations (Ionescu, 2012). The AUT itself, the measure of divergent thinking used in this study, involves a flexible process of generating as many alternative uses for an object as possible. This process of cognitive flexibility might again be partly different to that involved in the DCCS. A replication of the study using a greater diversity of measures of cognitive flexibility would improve the generalisability of the findings. Furthermore, extrapolating participants' performance at creative tasks such as the AUT to real world creativity is still a matter of debate (Baer, 2011). Even when raters are trained, they can still achieve different originality scores for the same idea (Forster & Dunbar, 2009; Sternberg, 2006). Using holistic divergent thinking scores and a greater diversity of measures might allow us to better consider the multidimensionality of divergent thinking (Forthmann et al., 2019).

5.5. Suggestions for future research

Several participants reported being used to working in noisy conditions. This experience might therefore put them in a better position to be able to deal with, or suppress the distractibility of noise, which could have impacted their performance and the results of this present study. Chere and Kirkham (2021) explored the impact of noise on adolescent's executive functions using an online study during the COVID-19 pandemic and found that the participant's home environment significantly correlated with how they perceived noise and their performance on the task. This is an important area of research to explore and the subjective perception of noise is an informative aspect to consider in the future. In addition, undergraduates might not be aware of how their ability to switch (i.e., cognitive flexibility) impacts their ability to produce ideas in noise, so further educating them on this matter is vital.

It is also important to suggest alternative concepts that might have played a complementary role in the outcomes of this present study, and would therefore be important to explore in future studies. Working memory capacity (WMC) and inhibitory control are two executive functions on which cognitive flexibility is based (Diamond, 2013; Nweze & Nwani, 2020), and have both been linked to divergent thinking (Benedek et al., 2012). Indeed, divergent thinking requires working memory to keep multiple ideas in mind to compare and associate them to a task. WMC also impacts an individual's susceptibility to distraction by background noise when performing visual-verbal tasks (Sörqvist & Rönnberg, 2014). This proposes that those with a higher WMC have the ability to control their attention to the task whilst avoiding auditory distractions (Sörqvist, 2010). In addition, learners with a high WMC performed better on a comprehension task in the presence of background music in contrast to learners with low WMC who performed better without background music (Lehmann & Seufert, 2017). Concurrently, inhibitory control interacts with the impact of background noise on children's divergent thinking performance (Massonnié et al., 2019), however associations are age and task-specific.

Associations between inhibitory control and divergent thinking are complex. Inhibitory control allows the suppression of irrelevant information during idea generation tasks to overcome cognitive fixation (Camarda et al., 2018). This means that the individual can ignore the obvious, non-creative ideas to come up with creative ones (Cassotti, Agogué, Camarda, Houdé & Borst, 2016). However, decreased inhibition has also been found to be beneficial for the idea generation process because of the capacity to hold a range of information in working memory. This links back to the idea of defocused attention (Kaufman et al., 2010) as individuals are not constrained to a fixed goal during idea generation. This can therefore be an important area of research to explore.

6. Conclusions

To our knowledge, this is the first study to investigate the impact of ambient noise on divergent thinking along with a behavioural measure of cognitive flexibility. This study continues the discussion on the impact of noise on creativity and further contributes to the literature by exploring how an individual's level of cognitive flexibility influences the relationship between ambient noise and creativity, in particular divergent thinking performance. The findings shed light on the benefits of ambient noise for those with higher levels of cognitive flexibility. This provides implications for setting up environments where creativity and noise take place, such as the home, universities, coffee shops, libraries and community settings. These locations might benefit from establishing ambient noise and quiet areas to suit a variety of individuals. Overall, noise is not always bad. Depending on the individual, a moderate level of ambient noise may help to generate more ideas.

Author statement

JM and PM conceptualised the study and designed the experiment. PM collected the data. PM and JM analysed the data. PM wrote the first draft of the manuscript. PM and JM revised the manuscript.

Declaration of Competing Interest

None.

Data Availability

The authors do not have permission to share data.

Acknowledgments

No such involvement or support from funding sources were provided in the conduct of the research and/or the preparation of the article. We would like to thank [blind for review] for helpful comments on the first draft of this manuscript.

Appendix A

Information sheet and consent form

The Impact of Noise on Creativity and the Role of Executive Functions in Undergraduate Students

Information Sheet

Thank you for your interest in participating in this study. This information sheet aims to outline the purpose of this study and what your involvement will entail, so that you can voluntarily choose to take part.

Who is running the study?

My name is X and I am a Masters student from the X at X. As part of my X degree, I will be undertaking a dissertation, which will be supervised by X. This study has been reviewed and has obtained the necessary ethical approval it needs by the Ethics department.

What is the project's purpose?

This research project wishes to investigate the impact of noise on creativity in university students. I am interested in finding out whether moderate noise influences a student's ability to generate creative ideas, and if this depends on their capacity to be 'cognitively flexible'. This is a thinking skill that helps us to deal with information and situations.

What will it involve?

You will be asked to complete the tasks in a calm, quiet environment with no distractions. You will need a laptop and headphones.

The series of tasks will measure cognitive flexibility and an idea generation in a creativity task. Session 1 involves a sorting game where you will sort according to colour or shape. This should take less than 10 min and should be completed in silence.

Session 2 involves two creative activities. You will be shown two images of common objects and will have 3 min to list alternative uses for them. The tasks will be completed once in moderate noise and once in quiet. This task should take under 10 min.

You will then answer a short question regarding how you perceived the noise and will be asked to describe the noise environment you are in during the quiet conditions. (e.g. Describe what you could hear).

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part, you should indicate your agreement by ticking the consent boxes. You can still withdraw at any time without giving a reason. If you don't proceed until the end of the experiment, your data won't be analysed.

Reporting and dissemination

A written report will be submitted to X as part of my X degree. Participants who request it will be forwarded a short summary of the findings once complete.

How will the information be protected?

The only people to have access to the data will be myself and my supervisor. Your identity will be kept confidential and anonymous. The data from the participants will be stored on a password protected, encrypted laptop and iCloud. Data will be kept for 10 years in accordance with X Research Data Policy.

Data protection privacy notice

The data controller for this project will be X. The X Data Protection Office provides oversight of X activities involving the processing of personal data, and can be contacted at X. X's. The Data Protection Officer can also be contacted at X.

Further information on how X uses participant information can be found here: XXXX

The legal basis used to process *special category personal data* will be for scientific and historical research or statistical purposes/ explicit consent.

Your personal data will be processed so long as it is required for the research project. If we are able to anonymise or pseudonymise the personal data you provide we will undertake this and will endeavour to minimise the processing of personal data wherever possible.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact X in the first instance at X.

How can you get involved?

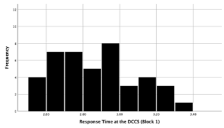
If you agree to take part, please complete the consent form that will follow. Should you have any questions, please email me at X.

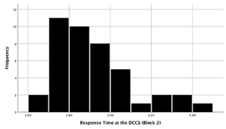
Consent

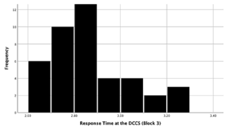
- I confirm that i have read and understood the information sheet and have had the opportunity to ask any questions
- I confirm that i give my consent to take part in this study
- I understand that my participation is voluntary and have the right to withdraw at any time without a given reason
- I understand that the study has been reviewed and approved by the Ethics Committee at X

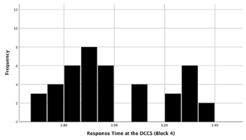
Appendix B

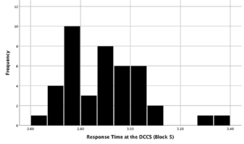
Distribution of scores for each variable

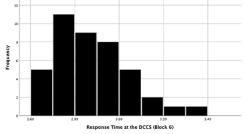


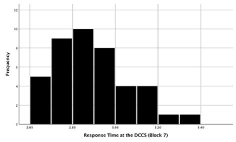


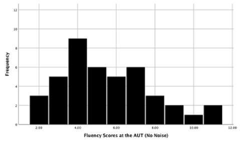


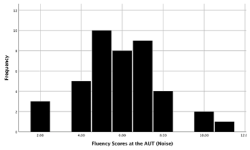


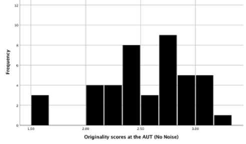


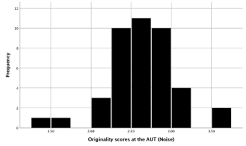












Appendix C

Comparison AUT Fluency Results with and without Outliers

AUT Fluency	Results with Outliers	Results without Outliers
Main Effect of Noise	$F(1,38) = 6.57$, $p = 0.014$, $\eta p^2 = 0.15$.	$F(1,34) = 6.55$, $p = 0.02$, $\eta p^2 = 0.16$
Interaction Between Noise & Cognitive Flexibility	$F(1,38) = 6.20$, $p = .017$, $\eta p^2 = 0.140$.	$F(1,34) = 6.28$, $p = .02$, $\eta p^2 = 0.16$

Appendix D

Comparison AUT Originality Results with and without Outliers

AUT Originality	Results with Outliers	Results without Outliers
Main Effect of Noise	$F(1,38) = 0.30$, $p = .584$, $\eta p^2 = 01$.	$F(1,34) = 0.00$, $p = .96$, $\eta p^2 = 0.00$
Interaction Between Noise & Cognitive Flexibility	$F(1,38) = 0.26$, $p = .25$, $\eta p^2 =0.01$.	$F(1,34) = 0.01$, $p = .94$, $\eta p^2 = 0.00$

Appendix E

Participants' Field of Study

Subject	Frequency
Health and Social Care	1
History	1
Marketing	1
Physical Education	1
Drama	1
Pharmacy	2
Accounting/Finance	2
Architecture	2
Law	2
Communication	2
Graphic Design	2
Biomedical Science	2
Medicine	3
Nursing	3
Economics	4
Psychology	6
Business	7
TOTAL	**42**

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