Affective and Cognitive Consequences of Temporal and Textural Aspects of Background Music

A Pupillometry Study

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Abstract

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Background. Affective, physiological and cognitive consequences of musical sound are well documented, however they have rarely been studied simultaneously, and no such study employed pupillometry. In this experiment, subjective and pupillary indices of arousal were monitored while participants carried out a colour-word Stroop test with concurrently presented musical excerpts varying in tempo and degree of percussiveness. **Objectives.** It was investigated whether increases in tempo are associated with greater self-reported arousal as well as greater tonic pupillary responses and if effects of tempo on both indices of arousal are moderated by the degree of percussiveness of the musical excerpt. It was also assessed whether background music affects performance on the colour-word Stroop test and to what extent these effects are mediated by self-reported and autonomic arousal. Additionally, pupillary responses were investigated in terms of responses to Stroop stimuli during exposure to music in order to clarify the relative influences of arousal and cognitive load on pupillary responses. **Methods.** 32 participants took part in this within-subjects experiment, which assessed subjective and pupillary indices of arousal to musical excerpts varying in degree of percussiveness, and which were edited to produce three versions of each musical piece that varied in tempo (slow, moderate and fast). Participants completed a manual response colour-word Stroop task in silence and during exposure to each of the nine musical stimuli while an infra-red remote eye-tracker monitored changes in pupillary diameter. Reaction times to congruent and incongruent Stroop stimuli were recorded. **Results.** Both pupillary and subjective measures were found to be influenced by tempo although tempo influenced subjectively reported arousal to a much greater extent. Some evidence for the moderating role of percussiveness was also found. However, there were no cognitive consequences observable in the Stroop test latencies. Pupillary Stroop effect failed to replicate and due to this very limited inferences concerning priority of cognitive load over arousal in pupillary responses can be drawn. **Conclusions.** Despite a great body of research suggesting that background music has cognitive consequences mediated by musically-induced arousal, findings of the present experiment indicate that subjective and physiological arousal is not inevitably reflected in cognitive processing.

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1 Introduction

In the recent decades there has been a renewed interest in music psychology. This rapidly growing interest most likely stems from a tremendous increase in accessibility of music and its ever-growing prevalence in virtually every aspect of our lives following digital revolution (Hargreaves, Miell and MacDonald, 2002). Perhaps the most widely researched topic is that of the relationship between music and affective states of the listeners. Music communicates emotion and people are able to recognize the emotion expressed by musical pieces independently of their cultural background (Fritz et al., 2009).

The main dimensions across which the musical sound is defined are time, pitch and texture (Bruner, 1990). In music psychology the most studied time-related feature is tempo (Kämpfe, Sedlmeier & Renkewitz (2011). Although the notion of tempo in musical theory is much more complex, music psychology research typically construes tempo as 'beats per minute' (BPM) and it is beyond the scope of the present study to discuss possible pitfalls of this construct. Tonality (mode) is a musical attribute relating to the pitch dimension which has received most attention in music psychology research. Mode describes the configuration of intervals between pitches or the tonal shifts of notes and the most well-known and studied are the diatonic major and minor modes (Hevner, 1935*)*. There is a consensus that uptempo pieces in major mode typically sound joyful, while downtempo compositions in minor mode usually sound sad or melancholic (Kim, et al., 2010). Timbre and orchestration constitute the third dimension of musical sound -texture, which is seen as a key determinant of musical genre (Bruner, 1990). Textural attributes of music have received less attention in music psychology research, yet, as it will be argued, textural features might modulate expressiveness of such time-related attributes as tempo.

However, music is not only a powerful communicator of emotion, but is also capable of inducing affective states in the listeners, which are mirrored in bodily responses. It has been argued that this emotion inducing capacity of music is the primary motivation for music listening (Gabrielsson, 2001) and the mediator of the widely documented effects of music on cognition.

1.1 Capacity of music to induce affective states in the listeners

Findings obtained both using self-report measures and physiological indices of affect suggest that music is capable of inducing affective states in listeners. It has even been shown that as little as 1 second of exposure to music suffices to elicit affective reactions in listeners (Bigand, Filipic & Lalitte, 2005). Arousal is a key component of affective states (Sloboda & Juslin, 2001) and the single most important auditory feature influencing both subjective reports and physiological indices of emotional arousal seems to be musical tempo. However, the relationship between tempo and arousal does not seem to be straight-forward and some findings suggest that musical texture might be moderating the strength of tempo's influence on arousal. A limited number of studies renders these findings inconclusive and points to the need of a more thorough examination of the interaction between tempo and textural properties of sound in terms of arousal inducing capacity.

Evidence from self-report measures. Subjective assessments of music-induced affect typically construe the notion of affect as consisting of two dimensions, namely mood (positive vs. negative) and arousal or intensity associated with experience (Sloboda & Juslin, 2001). This construct of affect is very closely related to Russell's (1980) circumplex model of emotions which is comprised of two orthogonal dimensions, namely 'activation' or arousal, and valence. Due to this, the most widely used measure of music-induced affect has been Russell's Affect Grid. Studies which used alternative measures have still assessed affective influence of music using the broadly defined valence and arousal dimensions.
An attempt to introduce a three-dimensional model of affect which distinguishes between tension and arousal has been made. This model suggests that arousal represents energy levels or vigilance and the-dimensional model does not allow distinguishing between such emotions as fear and anger since they are both associated with negative valence and high energy levels. The suggestion is that the notion of arousal in fear is more anticipatory in nature and thus better described by tension (Ilie & Thompson, 2006) . However subjective ratings of tension and arousal highly correlate (van der Zwaag, Westerink & van den Broek, 2011; Gingras, Marin, Puig-Waldmüller & Fitch, 2015) suggesting redundancy of the third dimension.

A few mechanisms by which such affective induction arises have been proposed, such as associations and elicited memories of particular compositions or specific tonalities, but the primary research interest lies in pinpointing the universal structural components of musical sound which trigger emotional responses (Gabrielsson, 2001). Research on effects of different musical attributes suggests that mode of the musical piece generally affects self-reported mood with major mode leading to positive mood and minor mode more often resulting in negative mood (Hevner, 1937; Kastner & Crowder, 1990; Kellaris & Kent, 1991). That is, mode of a musical piece tends to influence the valence (negative vs. positive) dimension of affect. Tempo is known to exert greatest influence on arousal, with increases in BPM monotonically leading to greater self-reported arousal (Hevner, 1937; Gabrielsson, 2001*;* Sweeney and Wyber, 2002; Kellaris & Kent, 1991). In their meta-analytic review of effects of background music on listeners, Kämpfe et al. (2011) concluded that tempo is the single most important determinant of arousal elicited in the listeners.

Arousal has been an easier construct than valence to modulate and predict from structural features of musical pieces (Gingras, Marin & Fitch, 2014; Leman, Vermeulen, De Voogdt, Moelants & Lesaffre, 2005; Schubert, 2004; Eerola, Lartillot & Toiviainen, 2009). Contextual, experiential or cultural and mood-state differences among the listeners have been suggested as explanations for this low predictability of valence modulation (Bigand et al.., 2005; Leman, 2003; Gabrielsson, 2001*).* Tempo has also been shown to be more generalizable across genres than valence (Eerola, 2011). Furthermore, by manipulating tempo (fast or slow) and mode (major or minor) of the same musical piece Husain, Thompson, & Schellenberg (2002) demonstrated that effects of arousal and mode can be dissociated. Tempo manipulations exclusively influenced arousal and mode induced changes in mood but not arousal. Due to this dissociation and lower generalizability of effects of mode modulation on affect, the present paper focuses primarily on arousal dimension of affect and its modulation by different tempi.

It has been suggested that effects of tempo on arousal are likely to interact with the texture (in particular genre) of music, with pieces emphasising percussion being more affected by changes in tempo (Holbrook & Anand, 1990). That is, the effect of tempo on arousal should be more pronounced for music orchestrated to emphasize the beat or pulse, such as pop music, because music's ability to arouse derives principally from its temporal dimension. Given this, it seems that increases in tempo in pop/dance music should contribute to arousal more than for the kind of music which does not typically have an emphasis on percussion. Kellaris & Kent (1993) investigated this interaction by presenting participants with pop and classical music pieces specifically composed for the study and varying tempo. As predicted by Holbrook & Anand (1990) increases in tempo led to significantly greater arousal for pop-like music, but not for classical music. Originality of compositions used by

Kellaris & Kent (1993) also precludes confounding effects of familiarity and thus the study lends strong support for genre-mediated tempo effects on arousal. Eerola (2011) investigated genre-specificity of musically induced affective states by analysing nine separate datasets consisting of classical (three sets), film music (two), popular music (two), and mixed genre (two). Regression analyses with different musical features were used to construct models for predicting self-reported arousal and tempo was found to be a much stronger predictor of self-reported arousal for pop music than for any other genre. This again lends strong support for idea that effects of musical tempo on arousal are mediated by textural qualities of music.

Physiological indices of music-induced affect. However, self-report measures of affect, as any self-report instruments, are subject to a strong response bias. For example, listeners might deduce their self-reported scores of arousal based on their interpretation of how certain musical pieces or variation in structural musical components should make them feel. This interpretation is favoured by the 'cognitivist' school of thought that insists that music does not induce emotions, but that emotions communicated by music can be deduced from certain cognitive recognition cues in the musical piece (Kivy, 1990). However, a number of physiological studies have confirmed that music does in fact elicit affective responses in the listeners and thus supported the 'emotivist' approach to the relationship between music and affect (for review see Hodges, 1996). Indices of music-induced emotions have been demonstrated with such measures as skin conductance, heart rate, and facial electromyography (e.g., Rickard, 2004; Gomez & Danuser , 2007; Lundqvist, Carlsson, Hilmersson & Juslin , 2009).

Physiological studies lend preliminary support for tempo (variation in BPM) being a structural feature modulating physiological arousal. However, these studies also seem to suggest that the extent to which tempo influences physiological arousal is at least partially dependent on textural properties of music. Carpentier and Potter (2007) chose classical and rock music pieces of slow and fast tempi and demonstrated that skin conductance level (SCL) showed greater activation with fast-paced than slow-paced music. However SCR frequency interacted with genre with faster tempo leading to greater frequency only for classical music, while reduction in SRC frequency with increase in tempo was observed for rock music. These results are inconsistent with the findings of Kellaris and Kent (1993) who reported that tempo increment led to greater self-rated arousal for pop but not classical music. Carpentier and Potter (2007) attempted to find support for the reduced frequency of SRC to fast tempo rock music being mediated by familiarity with the genre and the presumed tempo expectations of each genre. Since participants were college students, it was assumed that they had more exposure to rock than classical music. Their experiment additionally included swing genre since it was making a comeback into popular culture at the time and was very prevalent on the radio. If familiarity was responsible for the pattern of results in Experiment 1 it was expected that swing genre would also show decreases in SRC frequency. However this was not found to be the case and results remain inconclusive.

The study by van der Zwaag et al. (2011) used 16 different pop and 16 rock pieces varying in tempo and did not find any interactive effects of genre and tempo on the SCR and cardiovascular measures. Increases in tempo correlated with subjective reports of arousal and tension. SCR was increased by exposure to high tempo pieces and heart rate variability decreased (consistent with responses with non-musically induced tension (Haag, Goronzy, Schaich & Williams, 2004). As mentioned above, the approach of using different types of music is problematic due to multi-dimensional nature of music. However, the study of van der Zwaag and colleagues is important as it included level of percussiveness into analysis. Half of the pop and half of the rock pieces had a high level of percussiveness while the other half had a low degree of percussiveness. This feature was found to correlate both with self-reported arousal as well as with greater SCR. Most importantly the level of percussiveness was found to moderate effects of tempo, with increases in tempo leading to greater self-reported arousal and SCRs for pieces with high level of percussion. This finding is consistent with the original motivation for the prediction of tempo exerting greater influence on arousal for pop- or dance-like music as compared to many other genres, namely - the emphasis of percussion. Findings of van der Zwaag and colleagues thus suggest that it might not be genre *per se* but the degree of percussiveness that might be modulating effects of the number of BPM on arousal induced by music.

1.2 Pupillometry

Since musically-induced arousal is routinely accompanied by autonomic nervous system changes, it seems relevant to explore whether variation of tempo could be effectively monitored by changes in pupillary dilation. Given that SCRs to arousing stimuli are known to correlate with pupil dilations (Bradley, Miccoli, Escrig & Lang, 2008) and that there is some evidence suggesting that tempo affects SCRs (Carpentier and Potter, 2007; van der Zwaag et al., 2011), it seems reasonable to expect that arousal manipulated by changes in tempo will also be mirrored in pupillary dilations.

Pupillary diameter is primarily controlled by the dilator and contractor muscles of the iris and changes in pupillary diameter first of all occur due to changes in luminance levels, with dilations up to 7mm in a dim light (MacLachlan & Howland, 2002) and constrictions resulting in a pupil as small as 3mm in bright light (Wyatt, 1995). However, it is well established that pupillary response does not only reflect luminance changes, but is also a useful indicator of intensity of cognitive (Kahneman & Beatty, 1966; Piquado, Isaacowitz & Wingfield, 2010) and affective processing (Janisse, 1973; Bradley et al., 2008; Van Steenbergen, Band & Hommel, 2011). These pupillary dilations driven by cognitive and affective aspects are much smaller and do not typically exceed 0.5 mm change (Laeng, Sirois, & Gredebäck, 2012). Some evidence suggests that these luminance-independent pupillary changes reflect activation of the locus coeruleus (LC) and norepinephrine (NE) system which are indicative of arousal, thoughts, emotions and cognitive flexibility (Koss, 1986; Sara & Bouret, 2012). Activity of LC is thought to operate in two different modes with the phasic mode of LC activation when processing task-relevant stimuli (top-down attention) and the tonic mode when LC cells are more responsive to novel and arousing (bottom-up attention) rather than task-relevant stimuli (Aston-Jones & Cohen, 2005). Both phasic and tonic pupillary responses occur spontaneously and they cannot be controlled voluntarily or be suppressed at will and are thought to be preconscious and thus able to indicate the processes that occur below the threshold of consciousness (Laeng et al., 2012). Furthermore, pupillometry is less invasive than most other physiological measures.

Pupillometry of music. Although pupillary dilations representing tonic mode of LC activity have been demonstrated in response to arousing stimuli for other stimulus modalities such as visual (Bradley et al., 2008; Kuchinke, Trapp, Jacobs & Leder, 2009), there are very few studies investigating pupillary changes in the presence of auditory stimulus and especially music (Hodges, 2010). Stelmack & Siddle (1982) found no reliable pupillary changes to sound intensity level (60, 75, and 90 dB) using 1000-Hz pure tone. This finding is at odds with studies reporting that the level of sound correlates with subjective indices of arousal (Scherer,1989; Ilie and Thompson, 2006). However, other studies using pure tones did report increases in pupil size for greater sound intensities (Nunnally, Duchnowski & Parker, 1967; Hirano, Inoue, Uemura & Matsunaga,1994). Partala & Surakka (2003) have also found enlarged pupil responses to arousing environmental sounds (such as a baby crying or laughing) when compared to neutral sounds (typical office background noise). Pupillary changes also corresponded with subjective reports of arousal. Importantly, valence dimension of sound stimuli did not affect pupil dilations, that is, equivalent increases in pupillary diameter were observed for stimuli rated as both negatively and positively arousing.

The first study on pupillary responses in relation to musical sound is that of Slaughter (1954) who reported increases in pupillary dilation to stimulating music and constrictions of the pupil during exposure to sedative music. However, the subjective and observational nature of the methodology does not allow for any strong conclusions to be drawn. Increases in pupil size were also found to vary as a degree of preference (i.e. ratings of liking and disliking) for musical and noise excerpts (Mudd, Conway & Schindler,1990).

Very few recent studies investigated emotional arousal induced by musical stimuli. Laeng, Eidet, Sulutvedt & Panksepp (2016) measured changes in pupil diameter while participants listened to favourite self-selected musical pieces which were chosen based on the strength of 'music chills' associated with the pieces. Musical chills are defined as intense emotional responses characterized by intense pleasure and often accompanied by bodily reactions such as a chilling or gooseflesh type of skin sensation, moistness of eyes and racing heart and therefore are very great candidates for musically-induced physiological arousal. Pupillary size increases were observed within the chills-related time-windows (±1 s around reported chill as indicated by key responses). Laeng and colleagues have thus demonstrated that musically-induced emotions can be reliably tracked by changes in pupillary size. However no inferences can be made as to which auditory features led to these emotional reactions since self-selected musical pieces were used and familiarity and strong preference with the pieces was of key importance. Therefore the findings of Laeng and colleagues are not informative with respect to musical affect-modulating features such as genre, sustained tempo or level of percussiveness

Gingras et al., (2015) have also provided strong support that musical stimuli can induce activation of central norepinephrine system. A large sample of 6-s excerpts of classical music from romantic period (chosen due to the assumption that this genre is unfamiliar to most participants), pre-rated for arousal, tension and valence by a separate group of subjects, was played while the pupillary responses were monitored. Arousal ratings of experts was found to be a reliable predictor of changes in pupil diameter with greater arousal ratings of the excerpts predicting larger pupil dilation when compared to the baseline pupil size, while valence did not have any predictive power. Gingras and colleagues have demonstrated that unfamiliar musical excerpts can induce arousal that is trackable by pupillary changes. However researchers did not report if any patterns with respect to any auditory components such as tempo could be found in the pupil data. Furthermore, the tempo and percussiveness of the pieces was most likely low, due to the specific genre chosen. Thus although the study lends strong support for musically-induced arousal being mirrored in the pupil, again no conclusions can be drawn about the structural features of music responsible for these effects on the pupil.

1.3 Effects of music on cognitive task performance

There is an extensive body of literature investigating effects of musical background on cognitive performance (for a review see Kämpfe et al., 2011) and the findings suggest that music primarily affects cognitive performance via arousal. Although tempo is the single most powerful mediator of arousal, relatively little research has assessed cognitive consequences of background music by explicitly manipulating tempo. Furthermore, the findings are conflicting and point to lack of theoretical frameworks for discussing existing research and generating new meaningful hypotheses.

A lot of earlier investigations on effects of music on cognition focussed on the so-called ‘Mozart effect’ which refers to enhanced spatial abilities following exposure to music composed by Mozart (Rauscher, Shaw & Ky, 1993; 1995). One of the explanations offered was that patterns of neural activation during exposure to Mozart’s sonata are very similar to those instantiated during spatial tasks. This misguided researchers and led to over-focus on music composed by Mozart (and generally classical music) and spatial tasks. However, a number of later studies demystified Mozart effect by demonstrating that arousal and mood are mediating the cognitive consequences of exposure to Mozart’s sonata. For example Husain et. al, (2002) who manipulated tempo (60 or 165 BPM) and mode (minor or major) of a famous Mozart sonata demonstrated that spatial task performance was enhanced following exposure to the fast rather than slow version and to the major rather than minor mode version. Consistent with previous research on musical emotions it was found that tempo influenced only arousal ratings while mode affected valence. Furthermore the findings suggest that not only arousal and valence ratings induced by respective structural auditory features can be dissociated, but so can effects of arousal and valence on cognitive performance.

Although follow-up research on the Mozart effect was fruitful in terms of elucidating the mediating role of arousal, this research focussed exclusively on effects of pre-task musical exposure and was mostly limited to tasks requiring spatial skills. However, in everyday life we often chose to or are involuntarily exposed to music during execution of a number of tasks. Facilitation of cognitive abilities has been demonstrated witch such versatile tasks as episodic memory (Ferreri et al., 2014), IQ tests (Cockerton, Moore & Norman,1997), arithmetic performance (Hallam & Price,1998), learning a new language (Kang & Williamson, 2014) and tasks assessing verbal and visual processing speed (Angel, Polzella & Elvers, 2010). Musically induced arousal again seems like a good candidate for explaining performance enhancements. This hypothesis is corroborated by the findings that performance systematically improves with music which elevates reported levels of arousal, and this facilitatory effect of arousal seems to not depend on its valence dimension (Bottiroli, Rosi, Russo, Vecchi & Cavallini, 2014).

Interpretation of arousal as the key determinant of the documented effects of background music on cognitive performance is in line with findings on non-musically manipulated arousal and cognitive processing (Arent & Landers, 2003). Effects of arousal on performance are known to follow an inverted U-shaped function with best performance under intermediate levels of reported arousal (Berlyne, 1967; Sarason, 1980). This pattern seems to describe a great deal of the findings on the influence of musically-induced arousal on performance (Chie & Karthigeyan, 2009). However, there is also evidence that mildly arousing background music can also impair performance. Detrimental effects of background music have been reported for efficiency of surgeons learning new procedures (Miskovic et al., 2008), reading efficiency (Madsen, 1987), visual associative memory performance (Reaves, Graham, Grahn, Rabannifard & Duarte, 2015), and mathematical problem solving (Bloor, 2009). Detrimental effects of concurrent music have also been reported for tasks requiring cognitive control and flexibility, such as the famous colour-word Stroop-test, which requires to disregard the written word meaning and to concentrate instead on the colours of the displayed words (Stroop, 1935). Incongruent instances (when the words refer to colour terms different from the word colours, i.e. when the word ‘red’ appears in blue or any other colour than red) inevitably result in more errors and greater response latencies. Parente (1976) found that the number of incorrect responses in the Stroop test was greater with background music than in silence. However these studies were not informative with respect to elucidating which auditory features could be mediating these detrimental cognitive consequences of background music, nor did they suggest what mechanisms could be mediating these results.

In a (dim) light of Kahneman's cognitive capacity framework. A general theoretical framework for explaining effects of background music on cognitive performance is needed in order to reconcile conflicting findings and to generate informative predictions. It is likely that attention is moderating cognitive consequences of background music (Jones, 1999; Norman & Bobrow, 1975). Kahneman's "cognitive capacity model" (Kahneman, 1973) is the most widely used theoretical framework for discussing attentional resources and contextual modulation of attentional resource distribution. This model describes attention as a limited mental capacity, which allows only a certain amount of information processing at a single time.

This framework thus might be able to accommodate the documented negative effects of background music on cognition, since musical background might compete with concurrent tasks and overtax attentional resources. From this perspective both decision making processes and music listening are construed as cognitive processes requiring attentional resources, and thus competition for these resources can impair the overt cognitive task performance (Jones, 1999). On this view, background music constitutes a distractor.

However, arousal plays an important role in the cognitive capacity model and is closely related to availability of attentional resources. That is, higher levels of arousal are thought to increase availability of attentional resources. This would for example mean that higher arousal will lead to pronounced selectivity of task-relevant information (Jones, 1999). On this view background music would fulfil the role of arousal inducer.

Thus, according to Kahneman's model, background music can lead both to improvement and impairment of cognitive performance. That is, when concurrent to the task, music competes for the limited attentional resources. In doing so it fulfils a distractor role and should impair performance. However, if music induces arousal and increases availability of cognitive resources, then background music should facilitate task performance. These contrasting aspects of the theory make it hard to generate testable predictions about cognitive consequences of background music.

However, investigating cognitive performance while varying musical tempo seems like a promising approach since, as discussed above, tempo is known to increase arousal levels. Thus, if arousal promotes greater availability of attentional resources, faster music should improve cognitive performance by allowing better concentration on the task-relevant information. In line with this prediction, fast music has been repeatedly demonstrated to increase the speed of a number of activities. McElrea & Standing (1992) have demonstrated that fast-tempo, as opposed to slow-tempo music leads to faster speed of drinking while Milliman (1982) reported that fast music increased the speed of in-store traffic flow. Thus faster tempi increase the speed of simple activities. However it is hard to see these findings as elucidating in terms of effects of music on tasks requiring concentration.

It has also been demonstrated that exposure to fast music led to better performance in an experiment requiring business students to collect stock prices and calculate the changes in stock prices. Interestingly, facilitation of performance was observed even though participants reported greater perceived level of distraction in the fast music condition (Mayfield & Moss, 1989). However, these findings do not allow a clear interpretation as to whether tempo was the mediating factor as the slow music condition was represented by a classical music piece, while the piece used for the fast music condition was in the rock genre. Fast music was also found to increase the speed of a self-paced line tracing task (Nittono, Tsuda, Akai and Nakajima, 2000) and the rate and efficiency of reading business news (Kallinen, 2002). Bottiroli et al. (2014) also found that fast music increased the processing speed in the visual modality, namely the speed of matching abstract shapes to the associated numbers, associations between which were indicated on the top of the same sheet of paper. All of this indicates that the role of music with respect to its effects on attentional resources during concurrent activity might be that of arousal inducer rather than distractor.

However, it could be argued that the studies mentioned above do not shed much light on the conflicting arousal inducer vs. distractor role of background music, since the influence of background music on concurrent cognitive task performance is modulated by both multidimensional nature of music (Kellaris & Kent, 1993) and task (Furnham & Bradley, 1997). Complexity of the task in question might be important, since ability to engage in a few mental activities simultaneously relies on the demands of each of the activities executed in isolation (Kahneman, 1973). Based on the cognitive capacity model, more complex tasks require more attentional resources and, if the task is conducted during exposure to music, the supply of these momentary mental resources might not meet the demands. In line with this reasoning, there is some evidence suggesting that the likelihood of detrimental effects of background music increases with increases in complexity of the task (Furnham, & Bradley, 1997; Furnham & Allass, 1999).

It has also been argued that arousing music is more cognitively demanding (Kiger, 1989) and, due to simultaneously drawing on limited processing capacity, arousing music and highly demanding task should result in poorest cognitive performance (North, & Hargreaves, 2009). This suggestion is in line with findings of Cassidy & MacDonald (2007) who demonstrated that musical pieces pre-rated as highly arousing led to greatest interference (most incorrect responses) on the colour-word Stroop test, which is thought to be highly cognitively demanding due to requiring inhibition of very automatic responses (MacLeod, 1991). Similarly, North & Hargreaves (1999) found that in a driving simulation game high arousal music (fast tempo and greater sound level) led to much worse performance. This finding is seen as supporting the idea that music during cognitive tasks is distracting, especially since performance was the worst in the highest cognitive load condition (with highly arousing music and a concurrent backward-counting task).

However, other studies do not seem to support the hypothesis that music becomes distracting if the task in question is demanding. Amezcua, Guevara & Ramos-Loyo (2005) presented participants with a highly demanding visual selection task without music and with Bach's music in slow and fast tempi, while also monitoring ERPs. Fast tempo version led to faster stimuli evaluation and hence faster responses and reduction in ERP latencies. Furthermore, Day et al. (2009) demonstrated that multi-attribute decision-making was more accurate and executed more quickly under exposure to fast tempo than slow tempo music. Importantly, this tempo-mediated performance improvement was only evident when participants were instructed to use a harder strategy. Performance-enhancing effects of fast tempo music during the harder task were also evident from the eye-tracking data, which revealed a more intra-dimensional pattern of eye fixations (the values of a few alternatives on a single attribute were processed before information on a second attribute was processed). Higher tempo music judged as arousing was also found to facilitate performance of both visual processing speed and to also enhance performance of a more demanding task assessing declarative memory (Bottiroli et al., 2014). Importantly this study was conducted with older adults in order to specifically assess cognitive effects of background music in light of limited cognitive capacity framework. Aging is accompanied with deficits in selective attention and inhibition (Parks, 2007) meaning that the availability of attentional resources and control over them diminishes as we age. Due to this, if background music taxes attentional resources, detrimental effects of music should be especially evident in the aging population. However, the opposite was found to be the case. In light of these findings, effects of background music on cognitive performance seem to be more compatible with the role of music as a facilitating arousal inducer, however no firm conclusions can be drawn from such few studies.

1.4 Arousal vs. cognitive load in pupillary responses

Although a few studies mentioned above investigated cognitive consequences of background music varying in tempo while monitoring physiological indices of arousal, no such study has employed pupillometry. Such a study might not only aid understanding of tempo-mediated cognitive consequences of arousal, but also help to shed some light on the nature of pupillary responses. Pupillometry has been construed both as a measure of arousal and intensity of cognitive processing but it remains unclear which of these processes has priority in pupillary expression. Due to this examining pupillary responses during cognitive tasks executed with arousing background music might be a useful framework for detangling the relative influences of arousal and cognitive processing on pupillary dilations.

It is worth noting that the conceptual distinction between the two constructs is not that clear-cut either, but arousal is usually defined as an automatic response to salient or attention-grabbing stimuli, while cognitive load (CL) is construed as cognitive processing demands of activities and tasks and is usually thought to require voluntary engagement (Kahneman and Peavler, 1969).

Early interpretation of changes in pupillary diameter favoured arousal/emotionality interpretation and suggested that pupillary changes to a greater extent reflect arousal than cognitive processing. Many of the early studies of pupillary responses used stimuli which could be described as emotional or interest instigating stimuli (for review see Janisse, 1973). More recent studies also suggest that pupillary diameter changes reliably mirror arousal resulting from tonic LC activity. Both positive and negative emotional images were shown to result in pupil dilation when compared to neutral imagery (e.g. Bradley et. al, 2008). Similar conclusions can be drawn from pupillary studies of affective stimuli in other modalities (Partala & Surakka, 2003).

However most of the studies using pupillometry conceptualise phasic pupillary dilations as indication of greater cognitive processing (Beatty, 1982; Alnaes et al., 2014; Verney, Granholm & Dionisio, 2001). The seminal study lending support for cognitive load view demonstrated that exposure to harder multiplication problems led to greater pupil dilation than exposure to easier multiplication tasks (Hess and Polt, 1964). This finding has been successfully replicated many times (Janisse, 1973). Even stronger support for CL view of pupillary changes comes from a study by Kahneman and Beatty (1966) who demonstrated that words to be memorized, which were presented on a second-by-second basis showed such a second-by-second pupil dilation, and when recalled one-by-one showed equal constriction back to the baseline size. Pupillometry has even been used with such tasks as the classic colour-word Stroop test. Greater increases in pupil diameter for incongruent than congruent stimuli are referred to as ‘Pupillary Stroop Effects’ (Laeng, Ørbo, Holmlund & Miozzo, 2011; Siegle, Steinhauer & Thase, 2004; Brown et al., 1999). Given that phasic LC activity reflects greater concentration and signals demandingness of the task, this finding is not surprising. ‘Pupillary Stroop Effect’ lends strong support for the view that increases in pupil size reflect increases in cognitive load.

Few studies, however, investigated the arousal and CL hypotheses by manipulating both cognitive demands and arousal. Kahneman, Peavler & Onuska (1968) varied the difficulty of a digit transformation task and monetary incentive for correct response on a trial-by-trial basis. Incentive modulated pupil dilation only on the trials of easier task. Similarly, Stanners, Coulter, Sweet & Murphy (1979) co-varied task demands (presence or absence of explicit arithmetic task) and arousal (presence or absence of a threat of shock) and found that manipulation of arousal was only reflected in the pupil in the absence of the cognitively demanding task. Surprisingly very few recent studies investigated to what extent pupillary effects of arousal and CL can be dissociated. Chen & Epps (2013) provided support for cognitive load priority over arousal in pupillary responses. Pupillary diameter increases were found in response to pre-trial emotionally-laden visual stimuli, but this was only the case for low and not high cognitive load arithmetic task.

Based on this it is believed that pupillary responses can be indices of both arousal and CL, but that CL has priority and in highly cognitively demanding conditions pupillary responses correspond to increased CL and not arousal. This suggestion is also compatible with the tendency of studies which found pupil dilation to emotionally arousing stimuli to use such cognitively undemanding tasks as passive viewing or listening (Partala and Surakka, 2003).

1.5 The present study

The aims of the current study were several-fold. Firstly, the present empirical work aims to assess affective consequences of tempo manipulations in unfamiliar music and to investigate whether these affective consequences are moderated by such textural features as genre or the degree of percussiveness. Secondly, it is investigated whether such tempo manipulations have physiological consequences, specifically if tempo manipulations lead to pupillary diameter changes and if these effects are moderated by musical genre or percussiveness. Thirdly, it was of interest whether manipulations of tempo have cognitive consequences in colour Stroop test performance and if these consequences are moderated by genre or degree of percussiveness of the musical piece. Finally, it attempted to clarify the relative effects of arousal and cognitive load (CL) on pupillary dilations and in particular to re-assess if CL has priority over arousal in pupillary changes.

Subjective reports of arousal. Based on the research of arousal-inducing capacity of tempo and the suggestion that musical texture might mediate effects of tempo on self-reported arousal, it was of interest whether increases in tempo affect reported arousal differently based on the level of percussiveness of the musical piece. In the present study, to elucidate whether percussiveness mediates effects of tempo on self-reported arousal, tempo was manipulated in three musical pieces with varying degrees of percussiveness. Non-percussive classical music piece and an electronic music (tech-house) piece (by definition having an emphasis on repetitive percussion) were subjected to tempo manipulations. To further clarify if effects of tempo are better described as genre-dependent or percussiveness-dependent a highly percussive minimalist classical piece, tempo of which was also manipulated, was included. It was hypothesized that:

H1) Regardless of musical genre, increases in tempo will systematically increase self-reported arousal
H2) Self-reported arousal induced by tempo will vary as function of percussiveness, with greatest increases in arousal ratings for highly percussive pieces (tech-house and classic minimalist) and smallest effects of tempo on reported arousal for non-percussive classical piece.

Note: although the self-report instrument used, namely the Russell Affect Grid, also assessed valence dimension, due to low generalizability of the findings on ability of auditory features to modulate valence (eg. Leman et al., 2005) no specific predictions regarding this dimension of affect were made. The Russell Grid was primarily chosen due to conventions and in order to prevent a possibility that negatively arousing excerpts would be judged as more arousing than the positively arousing ones.

Pupillary indices of arousal. Based on the findings on physiological indices of musically-induced arousal, the present work specifically investigated whether tempo increases have physiological consequences trackable with pupil diameter changes. In particular, it was of interest whether higher tempi lead to greater arousal detectable by increases in tonic pupil diameter.

Pupillary response, which is thought to measure arousal independently of stimulus valence (Partala & Surakka, 2003) is an ideal candidate for assessing tempo modulated physiological arousal. It was thus hypothesized that:

H1) Tonic pupil diameter will systematically increase with increases in musical tempo
H2) The tempo-induced increase in pupil diameter will be greatest for the two musical pieces with high degree of percussiveness
H3) Tonic pupil diameter will correlate with subjective arousal ratings
If these hypotheses were supported the findings would lend strong support for capacity of single auditory features such as tempo to moderate activity of autonomic nervous system.

Cognitive consequences of arousal mediated by musical tempi.

Based on inconsistent findings and Kahneman's (1973) theoretical framework for division of attentional resources, it seems that background music might affect cognitive performance at least in two different ways. Firstly, due to competing for attentional resources with concurrent task, music might serve the role of distractor and impair cognitive performance. However, arousing music might also increase availability of attentional resources and improve concentration on task-relevant cues. A third possibility is that cognitive consequences of arousing music are task-dependent with detrimental effects of background music becoming more pronounced with increases in task complexity.

The colour-word Stroop test which has been used to assess selective attention, inhibition and cognitive flexibility for almost a century seems like an ideal candidate for assessing cognitive consequences of background music. Given extremely wide usage of the colour Stroop test, it is surprising that so little research has been done on effects of background music on the Stroop test performance. The Stroop task seems particularly suitable for tapping into effects of arousing music on cognitive performance since it seems to suffice as a toolbox for assessing the conflicting predictions on the cognitive effects of background music, since the congruent Stroop stimuli can be construed as a task with low cognitive demands, while incongruent Stroop trials as more cognitively demanding. The couple of studies which found detrimental effects of background music on Stroop-test performance, did not assess response latencies and are uninformative with respect to potentially dissociating effects of processing speed for congruent versus incongruent trials.

The present experiment manipulated tempi of musical excerpts in order to investigate cognitive effects of background music varying in arousal-inducing capacity. Furthermore, it was attempted to at least partially take into account the multidimensional nature of music, by choosing musical pieces varying in their degree of percussiveness, which has been suggested to moderate arousal inducing capacity of tempo. Thus, if musically induced arousal has cognitive consequences, these consequences should be greatest for highly percussive music. Irrespective of background music it was hypothesized that:

H1) The RTs for incongruent trials will be slower than RTs for congruent trials (the Stroop effect)

Conflicting predictions (derived from Kahneman's limited capacity framework of attention) about cognitive consequences of arousing music are outlined in Table 1.1 below.

Table 1.1

The summary of conflicting predictions about cognitive consequences of music varying in tempo

Background music as a distractor	H2) Exposure to background music, when compared to Silence, will lead to slower RTs H2a) Fast tempo music will lead to slower RTs for both congruent and incongruent Stroop trials H2b) Fast tempo will lead to slowest RTs (for both congruent and incongruent trials) with exposure to highly percussive music H2c) RTs will negatively correlate with subjective arousal ratings H2d) RTs will negatively correlate with tonic pupil size

Background music as arousal inducer	H3) Exposure to background music, when compared to Silence, will lead to faster RTs H3a) Fast tempo music will lead to faster RTs for both congruent and incongruent Stroop trials H3b) Fast tempo will lead to fastest RTs (for both congruent and incongruent trials) with exposure to highly percussive music H3c) RTs will positively correlate with subjective arousal ratings H3d) RTs will positively correlate with tonic pupil size
Complexity of task determines cognitive consequences of background music	H4) Exposure to background music, when compared to Silence, will lead to faster RTs for congruent trials and slower RTs for incongruent trials H4a) Fast tempo music will amplify the Stroop interference by leading to faster RTs for cognitively undemanding congruent trials and slower RTs for cognitively demanding incongruent tasks H4b) This effect of tempo will be moderated by degree of percussiveness, with tempo increases in the most percussive pieces amplifying Stroop interference the most H3c) RTs will positively correlate with subjective arousal ratings for congruent Stroop trials while a negative correlation will be observed between arousal ratings and RTs of incongruent trials H3d) RTs for congruent trials will positively correlate with tonic pupil size while there will be a negative correlation between incongruent trial RTs and tonic pupil size

If RTs will correlate with tonic pupil size, the findings would lend support for cognitive consequences of tempo variations being mediated by changes in autonomic arousal.

Assessing the relative influence of arousal and cognitive load on pupillary responses. Based on the well documented ‘Pupillary Stroop Effect’ it was hypothesized that:

H1) During silence condition pupillary diameter will be greater for incongruent than incongruent trials - Pupillary Stroop Effect

There also is a theoretically motivated reason to investigate pupillary responses during Stroop test with concurrent music presentation. As outlined earlier, there is no consensus with respect to the degree to which pupillary responses measure cognitive load as opposed to arousal. There is a lot of evidence that pupillary changes can track both of these processes, however few attempts have been made to assess which of the mental processes has priority in a situation where both arousal and CL are manipulated.

Concurrent exposure to arousing music during Stroop test seems to provide a useful approach to re-investigate relative capacity of pupillary changes to track CL under arousing context and vise versa. Incongruent Stroop trials represent high CL task, while congruent trials are very undemanding. If arousal is represented in pupillary changes only under low task demands, arousing music should lead to pupil diameter increases only for congruent trials and potentially result in vanishing of pupillary Stroop interference because pupillary responses will no longer be significantly different between congruent and incongruent trials. Thus based on the previous pupillary findings pointing to priority of CL over arousal it was hypothesized that:

H2) Under exposure to fast (and especially fast percussive pieces), pupillary Stroop effect will be diminished or will disappear entirely, while no such pattern will be observed for slow (and especially slow music lacking percussion).

2 Methods

2.1 Design

A repeated-measures experimental design was employed to assess pupillary changes and reaction times (RTs) of participants while they completed a colour-word Stroop task under exposure to different musical pieces varying in tempo or under silence condition. Subjective arousal and valence scores following exposure to each of the combinations of musical stimuli were recorded. Congruent and incongruent Stroop trials were presented with musical excerpts varying in tempo (80, 110 and 140 BPM) and genre (classical, minimalist and tech-house music). The dependent variables were reaction times (RTs), changes in pupil diameter and subjective arousal and valence ratings. The experiment was approved by the Department of Psychology's Research Ethics Committee at the University of Oslo.

2.2 Participants

Thirty-two non-musicians (17 females), 18-36 years of age (M = 29.03, SD = 3.89) volunteered for the experiment. Most participants were either native Norwegian or native English speakers. Remaining participants were from varying linguistic backgrounds but were studying at the time/have studied before at university level in English language. Participants were recruited among students and staff at the University of Oslo. All participants had normal or corrected to normal (by contact lenses) eyesight and did not have any history of hearing disorders. One participant was excluded from the analyses because of poor pupil calibration. All participants signed a written informed consent before taking part in the experiment.

2.3 Materials and stimuli

Apparatus. The SMI RED500 remote eye-tracking device by SensoMotoric Instruments (SMI, Teltow, Germany) was used to collect pupillometry data. The spatial resolution of the system is 0.03° of visual angle and detects fixations with of 80 ms or more and with dispersion below 100 pixels. Eye positions were sampled at a rate of 60 Hz.
The experiment was run on a Dell Latitude E6530 (Intel i7-3520M) , CPU at 2.9 GHz, 4 GB RAM, and running Windows7 at 32 bit. SMI software iView 3.2® Experiment Center was used for presenting the experiment stimuli, presented on a Dell P2213 VGA LCD monitor

(18.5” with diagonal length 47 cm) with the display resolution of 1680 x 1050 pixels. Behavioural data was collected with the use of a Dell L30U keyboard. Musical excerpts were presented via Philips SHP2000/97 Stereo headphones.

Musical excerpts. Careful attention was paid to the selection of musical stimuli. The choice of musical pieces, namely ‘Liebesleid (Violin)’ by Fritz Kreisler, ‘In C’ by Terry Riley and ‘S.T.’ by Donato Dozzy (original tempi 137, 110 and 122 respectively) was firstly based on their representation of the respective musical genres: classical, minimalist classical and electronica (tech-house). The secondary motivation behind the choices was the varying degree of percussiveness with a couple of musicians judging ‘Liebesleid’ as the least percussive of all and the other two pieces having comparable levels of percussion. Furthermore, a separate sample of participants (n=21) was asked to judge their familiarity with these pieces on a scale of 1 to 5 and the mean familiarity scores did not exceed 2.7 and provided some confidence that any observed results will not be mediated by familiarity. ‘Liebesleid (Violin)’ by Fritz Kreisler and ‘S.T.’ by Donato Dozzy are pieces in minor mode and ‘In C’ by Terry Riley is in major mode. The mode was not manipulated and dominance of minor mode in the selections was based on the findings that self-reported arousal, which is of primary interest for the present study, was greater for minor mode (van der Zwaag et.al, 2011).

Tempi of the pieces in mp3 (MPEG-2 Audio Layer III) format were manipulated using Amazing Slow-downer (2015) software which allows for tempo manipulations while keeping all the other musical features (e.g. pitch) constant. Three versions of each musical piece were created, namely 80 BPM, 110 BPM and 140 BPM. 120 second excerpts (starting at the beginning of compositions) were then obtained using a web-based platform Mp3cut.net (2016). Linear fade-in and fade-out were applied to the first and last 30 ms of each excerpt. For the purposes of better sound quality the nine generated versions (‘Liebesleid’ (Violin) by Fritz Kreisler in 80 BPM/110 BPM/140 BPM; ‘In C’ by Terry Riley in 80B PM/110 BPM/140B PM and ‘S.T.’ by Donato Dozzy in 80 BPM/110 BPM/140 BPM) were converted into WAW (Waveform Audio File) format.

Stroop test stimuli. There were four colour words, namely *yellow, green, blue* and *red.* Colour words were shown in either congruent colours (e.g., *red* in red) or incongruent colours (e.g., *red* in blue). Stroop test stimuli were prepared using Microsoft

Powerpoint RGB values (red, green, blue) for colours were as follows: yellow (RGB 255, 255 ,0), green (RGB 146, 208, 80), blue (RGB 0, 51, 204) and red (RGB 192, 0, 0).

Half of the words fell into congruent and the other half in incongruent category. One block consisted of all the twelve possible incongruent word stimuli combinations and the congruent stimuli weighed by four in order to produce twelve congruent word stimuli. Words were presented centrally over a grey background (RGB 127, 127, 127) in upper-case Calibri (Headings) font 70 and subtended no more than 7 degrees of visual angle . Fixation slide consisted of four centrally presented plus symbols in black (RGB 0, 0, 0), namely '++++' in Calibri (Headings) font 70 and was presented over a grey background (RGB 127, 127, 127).A set consisting of 24 stimuli (12 congruent, 12 incongruent) and 24 fixation slides was generated. The order of Stroop test stimuli was semi-randomised. That is, firstly 10 different random sequences were generated using Microsoft Excel V14.0. and the original sequence of stimuli was manipulated according to these sequences creating 10 separate stimuli slide sets. However this led to sequences which often looked anything but random, with e.g. most of congruent stimuli in the first half of the sequence and incongruent in the second half. Due to this, and in order to avoid instances which lead to reduced performance due to negative priming (i.e when. the colour to-be-named in one item is the same as the colour ignored in the immediately preceding item (MacLeod, 1991), the stimuli in sequences were shuffled manually.

These 10 sets, each consisting of 24 stimuli (12 congruent, 12 incongruent) and 24 fixation slides, were saved one-by-one as PNG (Portable Network Graphics) format files and carefully named by noting the number of the slide in a given block, the type of the slide (fixation or stimulus), and, for stimuli slides, the (pixel) colour and whether they belonged to congruent or incongruent conditions.

These ten sets of PNG files were then attributed to one of the 9 musical excerpts or the silence condition, meaning that the same pre-determined semi-random order of stimuli was always associated with the same musical excerpt. Stroop test stimuli and musical excerpts were imported into Experiment Center V.23 software and stored as 10 separate experiments named according to the musical excerpt they contained (or the silence condition).

Instrument for monitoring subjective affect. Paper-based 'Russell Affect Grid' (1980) was used for assessment of subjective arousal and valence ratings.

2.4 Procedure

Participants were tested individually in a windowless and soundproof room. Participants were seated in a comfortable chair and firstly red the Plain Information Sheet (Appendix A) and signed the Informed Consent Form (Appendix B). All participants were aware that they will be taking part in an eye-tracking study investigating effects of different musical pieces which have been manipulated by adjusting certain auditory features, however neither pupillometry nor tempo were explicitly mentioned. The subjects then re-read the Russell Affect Grid instructions (all participants were sent detailed instructions containing examples (Appendix C) via email and asked to read them before arriving for the experiment) and were then asked if they had any questions. Instructions given explained that the X axis of the grid represented the extent to which your current mood is negative versus positive. The left side of the scale indicated negativity, while the right side positivity. The Y axis was said to represent the intensity level of their experience or in other words arousal level. The lower half represented low levels of arousal, while the upper part indicated high levels of arousal. Participants were instructed to start with the X axis, that is, to firstly choose the one of the 6 horizontal positions (where the most left position indicates the most negative experience and the most right position indicates the most positive state). Participants were then instructed to shift their attention to the Y axis and choose one of the 6 horizontal positions (where the uppermost position indicates that your arousal levels are very high and the lowermost position indicates the lowest level of arousal) which they feel best described the intensity level of their current state. They were then provided with a sheet of paper containing ten (numbered) Russell Affect Grids which were used throughout the experiment.

A chin rest, adjusted individually, was used to minimize head movement. Participants were facing the computer monitor at a distance of 62 cm. Instructions for the Stroop test were firstly given verbally, namely participants were told that they will be presented with colour-naming words, one at a time, centrally positioned over a grey background on a monitor and that on some occasions the meaning of the word will be the same as the ink (pixel) colour, while on other occasions there will be a mismatch between the meaning and the colour in which the word is presented. Regardless of the meaning of the word participants were instructed to respond, as accurately and quickly as possible, to the actual colour in which the word was presented. Responses were collected via key-presses of V, B.N and M on QWERTY keyboard marked with red, yellow, green and blue stickers respectively. Key-presses were made using index finger of the right hand (only two subjects were left-handed and reported being just as comfortable using right hand for keyboard responses). Participants were also asked to focus on fixation '++++' between the presentations of words. They were informed that '++++' will be presented for one second and following this the word stimulus will appear on the screen for four seconds. See Figure 1 for illustration of one trial of the Stroop paradigm.

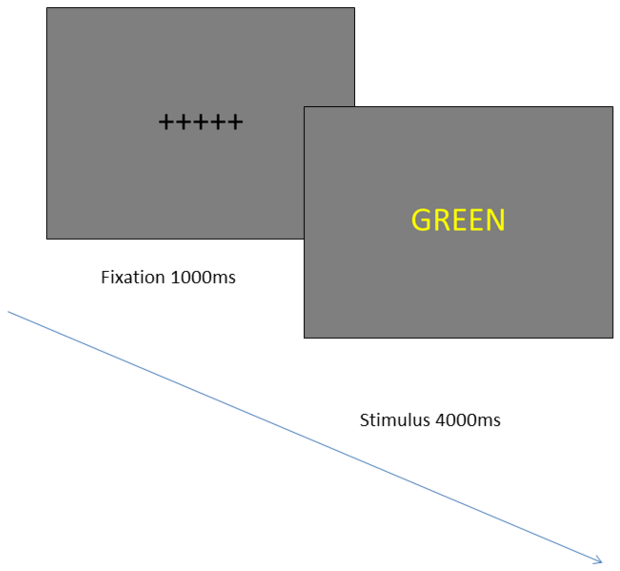

Figure 1. Illustration of an incongruent Stroop trial.

However, participants were told that although the word stimulus will stay on the screen for four seconds, responses should be made as quickly as possible and that for most people it rarely takes more than one second to respond. Since accuracy scores were expected to be very high and in order to further encourage quick responding, participants were also assured to not worry if they felt that all of their responses were correct, since the primary interest was in the speed of their responses. Participants were also told that no feedback will be provided as to whether their response was correct or not and that the stimuli will change automatically.

It was explained that the task will be done 10 times for 120 seconds each time and with a slightly different musical excerpt (and on one occasion in silence) and that the subjective arousal and pleasure they felt during exposure to music will have to be indicated on Russell Affect Grids (numbered from one to 11, since the first grid corresponded to the baseline) provided as soon as the task and music stop. It was stated that is completely fine if no change in the felt arousal or pleasantness took place and that the responses should be made genuinely, and not based on the emotional changes participants thought were expected of them. It was also clarified that only three different compositions, certain aspects of which had been manipulated, will be used, so nothing went wrong if participants felt they have heard the excerpt already. It was also made clear that short breaks in between experimental blocks could be taken.

Before proceeding to experimental blocks of the Stroop task, participants were firstly played thirty second excerpts of the three chosen compositions in their original tempo and asked to indicate the degree of familiarity with the pieces and the extent to which they liked the compositions on a 5-point scale (1 - completely unfamiliar/ not enjoyed pieces and .5 - very familiar and enjoyed very much). The familiarity and preference ratings were noted prior to experimental presentation, because during the Stroop test different participants heard the same musical piece for the first time in different tempi. The order of presentations of the nine musical excerpts and the silence condition was varied block-wise using a Latin square (see Appendix D), while congruency of the Stroop test stimuli was varied trial-wise in the manner described above. The excerpts were played via headphones at the sound intensity of 65dB. The same sound intensity was used during experimental procedure and headphones were not removed during silence condition. Each experimental block began with a standard calibration procedure, which was repeated if visual deviation was above 1 ° on the X or Y axis. Following calibration an instruction slide, reminding participants to respond as quickly and accurately as possible to the colour and not the meaning of the word, appeared on the screen. One practice trial of incongruent stimulus was then demonstrated twice. Every experimental block began with a monitor screen instructing participants to ‘press spacebar to begin when ready’. Experimenter stayed in the room throughout the experimental session. After completion of the Stroop experiment, participants were fully debriefed (Debriefing Sheet available in Appendix E). The Stroop test experiment lasted twenty minutes (10x120 sec), and with the breaks taken, never longer than half an hour. The whole experimental session, including instructions, questionnaire and debriefing never took longer than forty-five minutes.

2.5 Data pre-processing and analysis

Data was stored and extracted using BeGaze V2.3 software. Reaction times for each STROOP test slide were extracted and left eye pupil diameter in mm for every stimulus and preceding baseline slide were obtained. Phasic pupillary responses time-locked to Stroop test stimuli were extracted for the 1000ms-2000ms period following stimulus presentation. This decision was based on the well-established general pupillary response pattern, namely the observation that pupillary changes are usually observed not sooner than 1000ms following stimulus onset and typically peak at around 1500ms (Laeng et al, 2012). Most importantly for the present experiment, pupillary Stroop effect reported by Laeng et al. (2011) emerged in the 1000ms to 2000ms time window. Tonic pupil diameters were extracted using the second half (500ms) of fixation slides, since the eye-tracker recorded this as a baseline. Eye fixations for which the data was missing (most likely an artifact of blinking) were removed from the dataset. This led to exclusion of 12.7% of the data. The pupil diameter was then averaged across the number of fixations for each stimulus and base slides using Microsoft Excel V14.0. Further pre-processing of phasic pupillary data involved removing pupillary data of error trials and obtaining baseline-corrected pupil diameters by subtracting the baseline pupil diameter from the raw pupil diameter after stimulus onset. RTs for error trials were also removed from analysis and so were RTs exceeding 1500 ms. All statistical analyses were done using IBM SPSS Statistics V22.0

3 Results

3.1 Subjective reports

Familiarity and appealingness ratings. In order to see if there were significant differences between the musical pieces in terms of their appealingness ratings a repeated measures ANOVA with type of music (classical, minimalist classical and tech-house) was conducted. Mean appealingness rating was M = 3.19 ± .21. (SE) suggesting that participants enjoyed the music. The ANOVA revealed significant difference for musical excerpts in their appealingness ratings (F(2, 31) = 9.77, p < .001, partial η^2 = .240). Appealingness ratings on average corresponded to 3,47 ± .16 (SE) for classical; 2,59 ± .19 (SE) for minimalist and 3.50 ± .20 (SE) for tech-house pieces. Familiarity ratings were also subjected to ANOVA with type of music (classical, minimalist classical and tech-house) as a within-subjects factor. Mean familiarity rating was M = 2.29 ± .22. (SE) suggesting that participants were not too familiar with the excerpts. The ANOVA found that mean familiarity ratings for different musical excerpts were reliably different (F(2, 31) = 13.97, p < .001, partial η^2 = .311). Minimalist piece was judged as least familiar M = 1.75 ± .20 (SE), tech-house excerpt as slightly more familiar M = 2.16 ± .21 (SE) and classical piece sounded as most familiar M = 2.97 ± .24 (SE). Overall analyses suggest that the musical excerpts used were moderately enjoyed and were not too familiar to the subjects. Results are summarised in Table 1.

Table 1.2

Mean appealingness and familiarity ratings (on a 5-point scale) for each musical piece

4		5	Classical			6	Minimalist			7	Tech-house		
8		*9*	*M*	*10*	*SE*	*11*	*M*	*12*	*SE*	*13*	*M*	*14*	*SE*
15	Appealingness	16	3.47	17	.16	18	2.59	19	.19	20	3.50	21	.20
22	Familiarity	23	2.97	24	.24	25	1.75	26	.20	27	2.16	28	.21

Russell's Affect Grid ratings. To investigate if manipulations of tempo and type of music influenced self-reported affective states, a within-subjects ANOVA with tempo (80

BPM, 110 BPM and 140 BPM) and type of music (classical, minimalist classical and tech-house) was conducted for each affective rating, namely valence and arousal. Mean valence rating across all conditions was M = 4.02 ± .17 (SE). A main effect of tempo was found (F(2, 31) = 8.23, $p < .001$, partial $\eta^2 = .155$, with valence ratings increasing with increases in tempo. Valence ratings on average corresponded to 3.73 ± .13 (SE) for 80 BPM; 3.91 ± .11 (SE) for 110 BPM and 4.15 ± .11 (SE) for 140 BPM.. There were no reliable differences between the mean valence ratings for different types of music (F(2, 31) = 1.06, $p < .352$), nor was there an interaction between tempo and type of music (F(4, 31) = .658, $p < .622$).

A repeated measures ANOVA with tempo (80 BPM, 110 BPM and 140 BPM) and type of music (classical, minimalist classical and tech-house) was then conducted on arousal ratings. Mean arousal rating across all conditions was M = 3.85 ± .15. ANOVA revealed significant effects of tempo, F(2, 31) = 13.95, $p < .001$, partial $\eta^2 = .310$, with highest arousal ratings for 140 BPM (M = 4.19, SE = .16), lower arousal ratings for 110 BPM (M = 3.77, SE = .17) and lowest arousal ratings associated with 80 BPM (M = 3.57, SE = .17). There was also a significant effect of type of music F(2, 31) = 9.23, $p < .005$, partial $\eta^2 = .229$, with classical music rated as least arousing (M = 3.43, SE = .21), tech-house rated as more arousing (M = 3.89, SE = .18) and minimalist piece rated as most arousing of all (M = 4.21, SE = .17). The means and standard errors for each type of music in different tempi are presented in Table 2.

Table 2.

Mean arousal ratings (on a 6-point scale) for the classical, minimalist and tech-house musical pieces in 80 BPM, 110 BPM and 140 BPM

29		30	Classical			31	Minimalist			32	Tech-house		
33		*34*	*M*	*35*	*SE*	*36*	*M*	*37*	*SE*	*38*	*M*	*39*	*SE*
40	80BPM	41	3.28	42	.24	43	4.03	44	.23	45	3.41	46	.25
47	110BPM	48	3.40	49	.24	50	4.09	51	.22	52	3.81	53	.22
54	140BPM	55	3.63	56	.27	57	4.50	58	.17	59	4.47	60	.18

Although the interaction between tempo and type of music was not significant F(4, 30) = 1.47, $p < .216$, partial $\eta^2 = .45$, the trend was in the expected direction. That is, arousal ratings for tech-house and minimalist genres increased more with increases in BPM. See Figure 1.

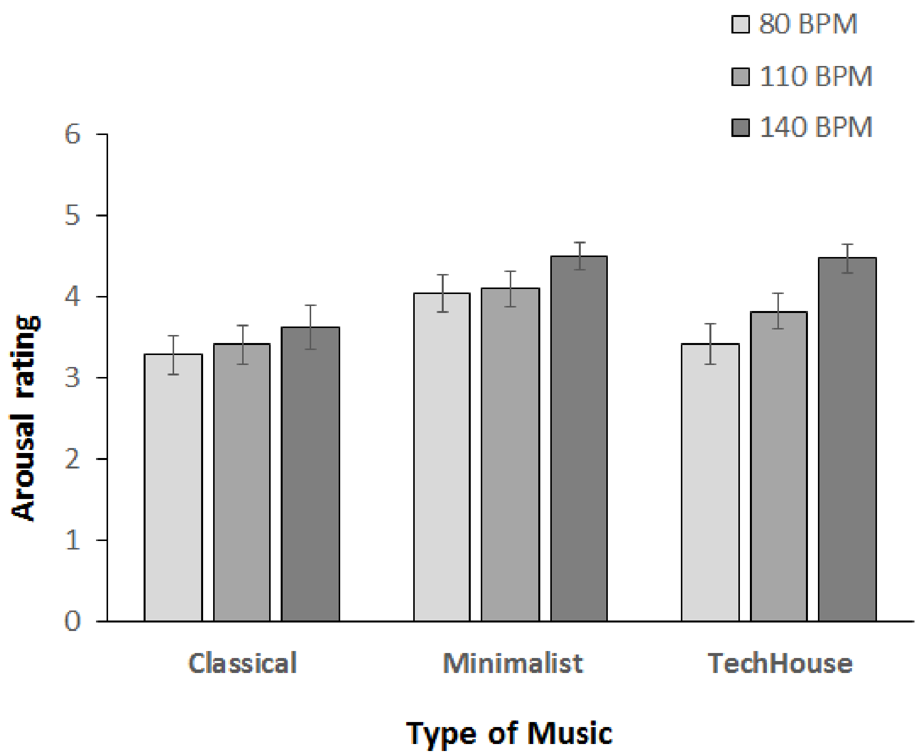

Figure 1. Mean arousal ratings for the classical, minimalist and tech-house musical pieces in 80 BPM, 110 BPM and 140 BPM. Error bars represent standard errors.

3.2 Tonic pupillary responses with exposure to music

In order to assess if tonic pupil diameter varied as a function of different background music, pupil diameters recorded for the second half (500ms preceding word onset) of fixation symbols were used to obtain average values for each participant.

Firstly, using these tonic pupil diameters a paired samples t-test was conducted to compare pupillary diameter during silence and music conditions. There was a significant difference in the pupillary diameter for silence ($M = 4.36$, $SE = .12$) and music ($M = 4.44$, $SE = .11$); $t(31) = -2.7$, $p = .01$, see Figure 2.

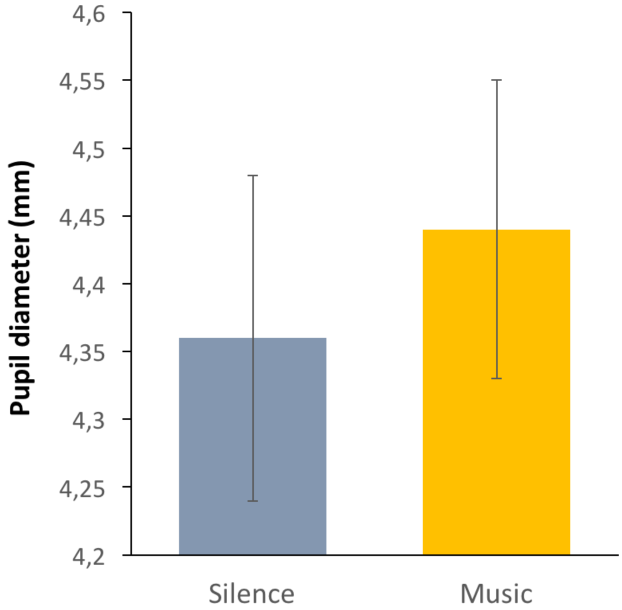

Figure 2. Mean tonic pupil diameter during Silence and during all the music conditions collapsed together. Error bars represent standard errors.

A repeated measures ANOVA with factors of tempo (80 BPM, 110 BPM and 140 BPM) and type of music (classical, minimalist classical and tech-house) was then carried out in order to assess if musical excerpts with different arousal-inducing potentials affected tonic pupil diameter. Mean pupil diameter across all conditions was (M = 4.45, SE = .11). Neither effects of tempo ($F(2, 31) = 1.98$, $p < .146$), nor type of music ($F(2, 31) = .12$, $p < .884$) were significant. The interaction of the two factors also did not reach significance ($F(2, 30) = 1.59$, $p < .180$).

However, since previous studies investigating physiological effects of tempo manipulations used tempi with less gradual variation in BPM (e.g. Carpentier and Potter, 2007) there might be a significant difference between 80 BPM and 140 BPM. To assess this, a repeated measures ANOVA with only two levels of tempo (80 BPM and 140 BPM) and three types of music (classical, minimalist classical and tech-house) was conducted. This analysis revealed a main effect of tempo $F(1, 31) = 4.41$, $p < .044$, partial $\eta^2 = .45$, with slightly smaller pupillary responses to 80 BPM (M = 4.41, SE = .11) than to 110 BPM (M = 4.47, SE = .10). Main effect of type of music was not significant $F(2, 30) =.356$, $p < .702$).

Interaction between tempo and type of music was not significant ($F(4, 30) = 1.95$, $p <$ .151), but as it can be seen in Figure 3, the main effect of tempo seems to mostly be driven by the difference in tech-house music.

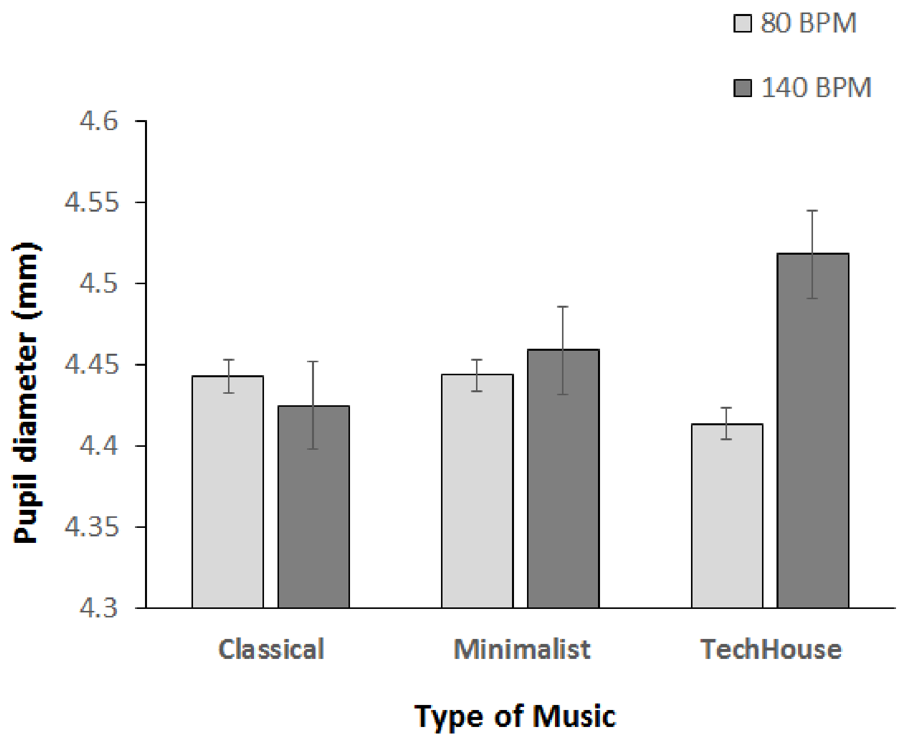

Figure 3. Mean pupil diameter for the classical, minimalist and tech-house musical pieces in 80 BPM and 140 BPM. Error bars represent standard error.

3.3 Behavioural data

Stroop Test Accuracy. *E*rror (incorrect colour names) occurred very rarely and with similar rates for congruent (0.29%) and incongruent trials (0.35%), therefore they were not analysed any further.

Stroop Test RTs. In order to test if a Stroop interference occurred and if it was modulated by the presence of music, a repeated measures ANOVA for RTs was conducted with condition (colour-congruent vs. colour-incongruent) and music (music vs. silence). Mean RT was (M = 925.50, SE = 26.40). The only significant effect was that of condition ($F(1, 31) = 9.66$, $p < .004$, partial $\eta^2 = .322$) and indicated faster RTs for congruent Stroop trials (M = 911.40, SE = 25.41) than incongruent Stroop trials (M = 939.61, SE = 28.10). Mean RTs for music vs. silence were not reliably different ($F(1, 31) = .06$, $p < .415$). The interaction between the music vs. silence factor and condition also did not reach significance ($F(2, 31) = 2.30$, $p < .139$).

To investigate if RTs were modulated by different musical conditions another repeated measures ANOVA was run on RTs with factors of condition (colour-congruent and colour-incongruent), tempo (80 BPM, 110 BPM and 140 BPM) and type of music (classical, minimalist classical and tech-house). Mean RT across all conditions was (M = 932.48, SE = 23.73). Again, the only significant effect was that of condition ($F(1, 31) = 8.11$, $p < .007$, partial $\eta^2 = .159$), with faster RTs for congruent Stroop trials (M = 922.40, SE = 23.39) than incongruent Stroop trials (M = 942.07, SE = 24.63). See Figure 4 for illustration of the differences in RTs for Silence and Music conditions and Figure 5 for the differences in RTs collapsed across silence and all the musical conditions.

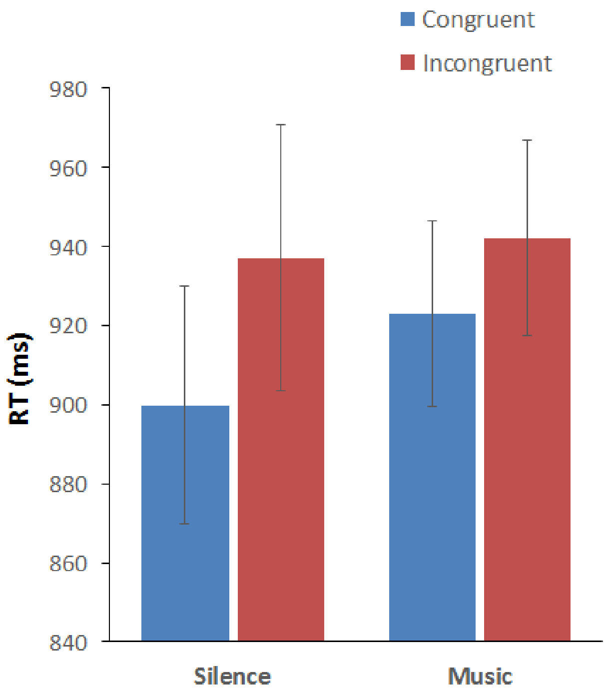

Figure 4. Mean RTs for congruent and incongruent Stroop stimuli for silence and music conditions

Mean RTs were not reliably different with different tempi ($F(2, 31) = 2.09$, $p < .132$), nor type of music ($F(2, 31) = 0.374$, $p < .689$). None of the two-way interactions were significant either, with obtained *F* values being *F*(2, 31) = 1.13, $p < .328$), *F*(2, 31) = 1.23, $p < .299$ and *F*(4, 31) = 1.79, $p < .133$ for condition and tempo, condition and type of music and type of music and tempo respectively. The three-way interaction between condition, tempo and type of music also did not reveal any reliable differences in the mean RTs (*F*(4, 31) = 0 731, $p < .573$).

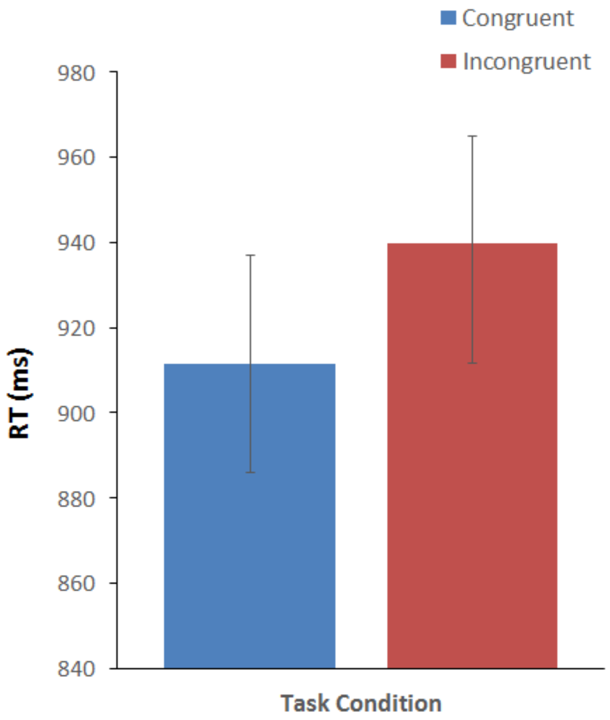

Figure 5. Mean RTs for colour-congruent and colour-incongruent Stroop stimuli when collapsed across all the conditions

3.4 Phasic (stimulus-evoked) changes in pupil diameter

Pupil diameters recorded for the second half (500ms preceding word onset) of fixation symbols were subtracted from the pupillary diameters recorded for correct responses within the 1000- to 2000-ms interval. The obtained baseline-corrected data on mean change in pupillary diameters was determined separately for colour-congruent and colour-incongruent trial.

In order to test if pupillary responses to congruent and incongruent Stroop stimuli differed for silence and music conditions, averages for each participant's baseline-corrected data for colour-congruent and colour-incongruent conditions were entered into a repeated measures ANOVA with condition (colour-congruent vs. colour-incongruent) and music (music vs. silence). The analysis revealed a significant main effect of music ($F(1, 31) = 4.24$, $p < .048$, partial $\eta^2 = .120$), with bigger pupil diameter for silence (M = .035, SE = .026) than music (M = .004, SE = .025). The baseline-corrected pupil diameters were not reliably different for colour-congruent and incongruent conditions ($F(1, 31) = .38$, $p < .54$), however as evident in Figure 4, for silence there is a tendency for the opposite pattern than pupillary Stroop effect.

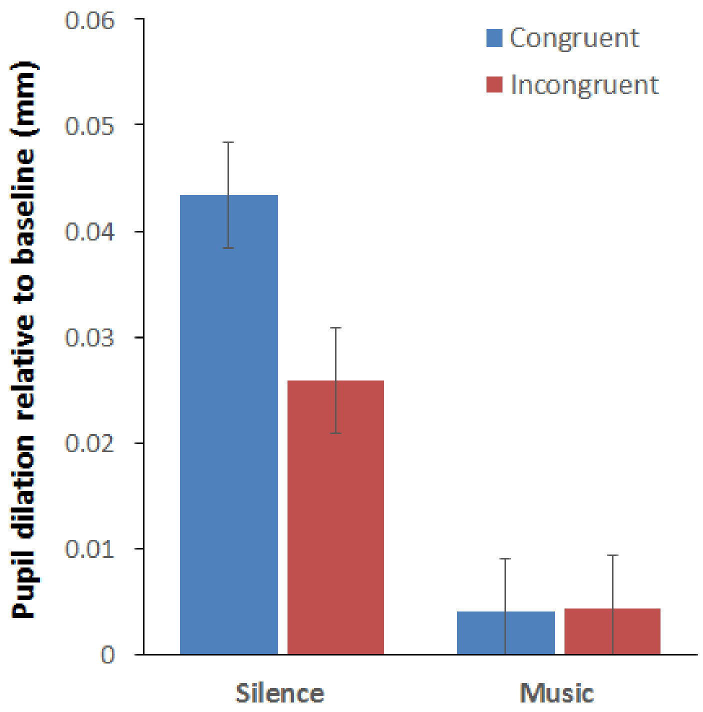

Figure 4. Baseline-corrected pupillary responses to colour-congruent and colour-incongruent Stroop test stimuli during silence and with background music

Interaction between condition and music vs. silence factor was not significant ($F(1, 31) = .465$, $p < .500$).

In order to see if pupillary responses to congruent and incongruent stimuli differed for musical pieces varying in their arousal-inducing potential, averages for each participant's baseline-corrected data for colour-congruent and colour-incongruent conditions were entered into repeated measures ANOVA with condition (colour-congruent vs. colour-incongruent), tempo (80 BPM, 110 BPM and 140 BPM) and type of music (classical, minimalist classical and tech-house). Neither condition ($F(1, 31) = .001$, $p < .972$), nor the type of music ($F(2, 31) = 2.08$, $p < .133$) affected phasic pupillary responses to Stroop stimuli. Main effect of tempo was not far from significance ($F(2, 31) = 2.66$, $p < .08$, partial $\eta^2 = .079$), with no differences between 80 BPM (M = .010, SE = .027) and 110 BPM (M = .010, SE = .026), but a slight decrease in pupil diameter for 140 BPM (M = -.008, SE = .025) with 95% CI [-.06, .04]. Two-way interactions did not reach significance with *F* values for condition and tempo interaction being $F(2, 31) = .805$, $p < .452$, condition and type of music $F(2, 31) = .101$, $p < .904$ and tempo and type of music $F(4, 31) = .588$, $p < .672$.

A three-way interaction between all the factors was found to be significant ($F(4, 31) = 3.74$, $p < .01$, partial $\eta^2 = .108$). However, since no main effects or two-way interactions were found, a three-way interaction is most likely an indication of spurious effects rather than any intelligible pattern.

3.5 Inter-correlations between the measures

Preliminary correlations were obtained condition by condition for subjective arousal and valence ratings and RTs, subjective arousal and valence ratings and tonic pupil size, as well as for RTs and phasic pupillary changes. Correlations were also obtained for familiarity and appealingness ratings and tonic pupil size by type of music, familiarity and appealingness ratings and RTs by type of music. None of the obtained correlations were significant in line with the lack of similar patterns for the measures obtained from ANOVAs. Due to this it was not proceeded with regression models.

4 Discussion

Affective, physiological and cognitive consequences of musical sound have rarely been studied together. In this study, pupillary responses were monitored while participants carried out a colour-word Stroop test with concurrently presented musical excerpts varying in tempo and degree of percussiveness. It was hypothesized that increases in tempo will be associated with greater self-reported arousal as well as greater pupillary responses and that effects of tempo on both indices of arousal will be moderated by the degree of percussiveness. Both pupillary and subjective measures were found to be influenced by tempo although tempo influenced subjectively reported arousal to a much greater extent. Some evidence for the moderating role of percussiveness was also found. It was also investigated whether musically-induced arousal has cognitive consequences observable in the Stroop test latencies, however this was not found to be the case. Additionally, pupillary responses were investigated in terms of responses to Stroop stimuli during exposure to music in order to clarify the relative influences of arousal and cognitive load on pupillary responses. Pupillary Stroop itself effect failed to replicate and, due to this, very limited inferences concerning priority of cognitive load over arousal in pupillary responses can be drawn.

4.1 Subjective reports

Familiarity and appealingness of musical selections. Overall musical pieces were enjoyed and not too familiar. Both familiarity and appealingness ratings were similar to those reported in previous studies (eg. Gingras et al., 2015) and suggest that limiting musical selection to one unpopular genre, as done by Gingras and colleagues, is not necessary. It is, however, important to note that the very construct of familiarity might be somewhat ambiguous. In the present study it was stressed to participants that the interest lies in the degree of familiarity with these particular musical pieces. However, a number of participants reported difficulties when providing familiarity ratings since some pieces sounded very familiar, yet participants were sure this was the first time they heard the specific musical selection. Given that familiarity is known to be closely related to preference for music (Schubert, 2007) and since virtually all studies investigating affective or cognitive consequences of music include familiarity ratings, more careful attention should perhaps be paid to specific instructions for assessing familiarity with musical pieces. It is unlikely that the present study was the only one in which participants found it hard to understand the familiarity question as straightforward. Familiarity is known to moderate enjoyment of music (Van Den Bosch, Salimpoor & Zatorre, 2013) and it could be suggested that the present study corroborates this relationship, since the least enjoyed musical piece (minimalist) was also judged as the least familiar. However, this seems unlikely since participants repeatedly reported finding the minimalist excerpt stressful and overwhelming. Musical complexity seems like a better candidate for explaining relatively low appeal of the minimalist piece, since the composition was intricate and the relationship between preference and musical complexity is known to follow an inverted U-curve (North & Hargreaves, 1995).

Subjective reports of arousal and valence. In accord with previous findings (Sweeney and Wyber, 2002; Kellaris & Kent, 1991, Husain et al.,2002), increases in tempo systematically led to greater reported arousal with the lowest arousal ratings for 80 BPM and highest for 140 BPM. Based on Holbrook & Anand’s (1990) proposal that musical texture might modulate the influence of tempo on arousal it was predicted that increases in tempo will lead to greatest increases in arousal scores for the two musical excerpts pre-rated as highly percussive. There was a tendency towards this direction, with arousal increases with tempo being greatest for the tech-house piece, however results did not reach significance as in the study of Kellaris & Kent (1993) who found that tempo increases led to greater arousal ratings for pop music than for classical. Thus the present study does not lend strong support for the modulatory role of musical texture in terms of tempo-mediated arousal. However, the present study lends some support for percussiveness, irrespective of tempo variation, as an independent auditory feature affecting subjective arousal. It was found that the classical excerpt which lacked percussion altogether was rated as least arousing, while minimalist composition was rated as most arousing. Importantly, these findings also suggest that an additional feature exerting influence on arousal is complexity of the composition. As mentioned above, the minimalist piece is rhythmically complex and frequent new instrumental entries unravel in a rather sophisticated and dissonant soundscape. The minimalist composition was also judged as arousing even at 80 BPM. Since the minimalist piece and tech-house were considered equally percussive, complexity of the composition seems like a good candidate for the greater arousal-eliciting potential of the minimalist piece.

Musical mode was not manipulated in the present study and no explicit predictions regarding its effects on valence or arousal were made, due to the lesser generalizability of mode-mediated affective consequences. Although there is some evidence suggesting that major mode typically positively influences valence ratings (Kastner & Crowder, 1990; Kellaris & Kent, 1991) findings of the present study failed to support this, since the only piece in major mode was the minimalist composition, which was judged the least positively. Although the negative evaluation of the minimalist piece is likely better explained by its complexity, there is also evidence suggesting not only that major mode can fail to elicit positive feelings, but that compositions in minor mode, which sound sad, can also be found pleasurable (Brattico, et al., 2016). Thus the relationship between musical mode and valence dimension of affect is not straightforward and the current study also points to this lack of a clear relationship.

However, in the present study variation in tempo influenced valence ratings. That is, increases in tempo were found to systematically lead to greater ratings of valence. This finding is not in accord with the findings of Husain et al. (2002) who reported that tempo variation exclusively affected arousal ratings, while valence was only influenced by manipulation of mode. Thus, the purported dissociation between tempo and mode in terms of their exclusivity of mediating separate dimensions of affect is not supported by the findings of this study. Some previous findings indicated that moderate tempi are rated as most pleasurable (Berlyne, 1974; Holbrook & Anand, 1990). However, the notion of moderate tempo is usually lower than 140 BPM, which was rated most positively. Some early investigations suggested that optimal tempo is around 100 BPM (Fraisse,1982). More recently, however, it was suggested that tempi in the range of 120 to 130 BPM are preferred the most (Moelants, 2002). This suggestion still fails to accommodate the findings of the present study, since the tempo rated most positively was higher, namely 140 BPM. However, it is possible that concurrent monotonic task (the Stroop test) and multiple presentation of the same musical excerpts (although varying in tempo) resulted in boredom and most stimulating versions of musical pieces induced most positive states. This explanation is in line with suggestion that affective consequences of music depend not only on the musical components and their interplay, but also on the context of musical exposure (Juslin, & Västfjäll, 2008). However, the capacity of tempo to influence pleasure is in general disputable, since there is a lack of evidence that increases in tempo promote activation in any of the pleasure centres of the brain (Bishop, Wright & Karageorghis, 2014).

limitations and future directions.

It is worth noting that assessment of self-reported affect in the present study is limited by a few factors. Firstly, changes in affective states were assessed while exposing participants to musical pieces while they were performing a task. It is possible that passive listening might yield different subjectively reported arousal and valence. It is, for example, possible that concurrent engagement in the task also amplified ratings of arousal as the task was an additional source of stimulation. In order to eliminate this possibility it would be useful to assess influence of the same musical excerpts on affective states during passive listening. Furthermore, it is possible that temporary mood states might influence affective musical processing (Vuoskoski & Eerola, 2011), thus assessment of participants' mood at the start of the experiment using a mood questionnaire might have been useful. Other auditory features, such as spectral flux and spectral entropy were found to influence self-reported arousal to an even greater extent than tempo (Gingras et al., 2014) and future studies attempting to elucidate affective consequences of tempo should take the spectral aspects of music into account. Importantly, future research would benefit from manipulating tempo of musical pieces with very different original tempi and assessing if deviation from original tempo influences reports of affect. This consideration is largely overlooked, however, it is especially relevant for research deploying classical music, since the frequency of vibrations produced by string instruments stays the same when tempo of the musical piece is manipulated using computer software. This might result in a rather unnatural sound, and such a remark was in fact made by a few participants of the current study. The original tempo of the classical excerpt was 137 BPM and the 80 BPM version sounded slightly off. Recording the musical pieces at different tempo is costly, thus classical music might, although overly emphasised in music psychology research, not be very suitable for studies manipulating musical tempo.

However, limitations taken into consideration, the present study lends support for the capacity of music to communicate emotion and suggests that manipulation of single auditory features might suffice to alter affective states of the listeners. Importantly, the current study points to importance of taking multi-dimensionality of music into consideration and encourages to future research to investigate affective consequences resulting from the interplay of different auditory aspects.

4.2 Pupillary indices of tempo-mediated arousal

Physiological arousal was found to be affected by background music, however to a lesser extent than in the previous studies on bodily indices of musically-induced arousal. Firstly, it was found that music, when compared to silence, increased tonic pupil diameter, suggesting that listening to music contributes to physiological arousal. This is consistent with previous findings of Krumhansl (1997) who reported differences in skin conductance and heart rate following exposure to music when compared to a pre-music interval. Involuntary increases in bodily manifestations of arousal following musical exposure are not surprising, since the human body physiologically reacts to changes in light and temperature as well. Auditory stimuli are thus expected to induce similar adaptive reactions. It is however worth noting that greater pupillary response during exposure to music might also reflect cognitive processing associated with musical exposure (Kiger, 1989). This is a greatly overlooked concern in studies assessing physiological consequences of musical exposure, since these studies typically simply assumed that resulting bodily responses reflect arousal or other affective states rather than cognitive processes. However skin conductance response (SCR) is also used for assessing intensity of cognitive processing (Nourbakhsh, Wang, Chen & Calvo, 2012). Thus, it must be noted that studies of physiological consequences of musical exposure do not allow disentanglement of cognitive processing from affective processing with great certainty.

The present study found some support for tempo-mediated increases in pupillary responses, while no differences were found between the minimalist piece in major mode and the pieces in minor mode. This is in line with findings, such as those of VanderArk and Ely (1992, 1993) who reported that stimulating music regardless of valence communicated by the musical piece elevated SCR. Findings of the present study are also consistent with those of Carpentier and Potter (2007) and van der Zwaag et al. (2011) who reported greater activation of skin conductance level (SCL) following exposure to fast-paced music. However, since these studies did not manipulate tempi of the same musical excerpt, but rather used different musical pieces, their findings lend only weak support for tempo mediating physiological responses. Importantly, the present study found that pupillary responses were only different when comparing 80 BPM and 140 BPM, that is, 140 BPM lead to greater pupil dilations when compared to 80 BPM. The moderate tempo of 110 BPM was used since it is thought to most closely resemble optimal tempo (Fraisse, 1982) and since most musical compositions have tempi ranging from 110 BPM to 125 BPM (Moelants, 2002). However, effects of tempo on pupillary responses were found to be statistically significant only when the medium tempo was removed from analysis. This is perhaps not surprising since studies investigating affective, physiological and cognitive consequences of music varying in tempo typically use two very different tempi. For example the fastest tempo representing slow-paced music in Carpentier and Potter’s (2007) study was 74 BPM while the slowest representing fast-paced music was 136 BPM. Similarly, Day et al., (2009) for fast tempo condition used a musical excerpt increased in speed by 25% of its original speed and for the slow tempo the same musical piece decreased in pace by 25% was used. Such a range of tempi does not involve moderate tempi and this suggests that rather large differences in tempo are needed for physiological changes to take place. This should not be overlooked, because music we encounter in our daily lives is rarely so slow- or fast-paced as the tempi used in most research. Therefore, findings on affective and physiological consequences of stimulating music might have poor ecological validity. This is especially important as a great deal of studies on musically-induced affective states are market-driven, that is, concerned with effects of arousing music on consuming behaviours (Kellaris & Kent, 1991; North & Hargreaves, 2009). It is also important to note that greater pupillary dilations elicited by fast tempo could also be explained by both greater cognitive engagement and greater pleasure associated with faster compositions. Since faster tempi communicate information at a faster rate (Crozier, 1981) they can be seen as requiring more cognitive processing. Due to this, music in faster tempi might also sound more interesting and increase pleasure of the listeners. This speculation is supported by the finding that increases in tempo in the present study monotonically increased valence ratings.

The present study was also concerned with the potentially tempo-moderating role of textural aspects of music, however only a slight trend indicative of this relationship was found. Based on the findings that tempo increases in pop-music increased self-reported arousal more than tempo increases in classical music (Kellaris and Kent, 1993) and that the level of percussiveness was found to moderate effects of tempo on SCR (van der Zwaag et al., 2011), it was expected that pupillary dilations to fast tempo percussive pieces will be greater than pupillary responses to fast non-percussive classical piece. A tendency toward this direction was found with effects of tempo variation on pupillary response mostly driven by the differences in slow- and fast-paced versions of the highly percussive tech-house piece. However, this relationship cannot be asserted with any confidence, since results did not reach statistical significance. It is also important to note that the findings of van der Zwaag and colleagues (2011) are also far from straightforward since the musical pieces used were very well known (music making it into ‘The Charts’) and they all had vocal parts. This is problematic in a few respects. Firstly, it cannot be ruled out that familiarity and associations the listeners had with the musical selections influenced the SCR. However, the present study did not find pupillary responses to be associated with familiarity ratings and Carpentier and Potter (2007) also did not find influence of familiarity on SCL. However, processing speech and especially degraded speech, which can be descriptive of singing, is known to increase activation of the autonomic nervous system (Zekveld, Heslenfeld, Johnsrude, Versfeld & Kramer, 2014) and the findings of van der Zwaag and colleagues (2011) cannot be clearly interpreted since virtually all the pieces had vocal parts. Thus, any potentially tempo-moderating role of textural aspects of music remains unclear.

The findings of the present study are also only partially in accord with the previous studies on pupillary responses to music. Laeng et al. (2016) reported that pupillary responses reliably tracked musically-induced ‘chills’. However, musical ‘chills’ by definition are emotional responses which are time-locked to a certain auditory event and ‘chills’ only last a few seconds. Therefore the findings of Laeng and colleagues are not informative with respect to musical affect-modulating features such as genre, sustained tempo or level of percussiveness. Importantly, musical pieces in the study by Laeng and colleagues were self-selected based on strong preference. However, music selected by other participants also induced musical ‘chills’, just to a lesser extent, suggesting that familiarity might not have been the most important factor.

Yet, it can still be argued that emotional arousal descriptive of ‘chills’ is different from arousal induced by tempo variation and that emotional arousal is necessary for increases in physiological activation. Rickard (2004) has provided some evidence that only ‘emotionally powerful’ musical pieces led to greater SCR and not the musical piece simply described as arousing yet emotionally unmoving. However, ‘emotionally powerful’ musical excerpts were self-selected by participants and do not provide any insights into the difference between emotional arousal and arousal *per se*, except for pointing to importance of familiarity and associations with musical pieces. Furthermore, Gingras et al., (2015) found that unfamiliar arousing musical excerpts led to significant increases in pupillary response. The findings of the present study are somewhat in accord with this, since the highest tempo judged as most arousing led to greatest pupillary dilation. However, Gingras and colleagues did not report which auditory features might have led to greater pupillary responses the tempo and percussiveness of the pieces was most likely low, due to the chosen genre, namely romantic classical. Importantly, Gingras et al. (2015) found that subjective arousal ratings predicted pupillary responses very well, while the present study found no direct associations between tonic pupil diameter and subjective arousal ratings. However, the present study required participants to concurrently complete a Stroop test while listening to music, and cognitive processes deployed for the task, as well as the visual nature of the task might have distorted any music-related pupillary effects of arousal. Furthermore, Gingras and colleagues recorded pupillary responses to 6-second musical excerpts, which is likely a better approach for investigating associations between subjective and physiological indices of arousal, since 2 minutes of musical exposure likely captures other cognitive and affective processes not related to music.

limitations and future directions.

The biggest limitation of the present study in terms of assessing tempo-mediated arousal is the presence of the concurrent task. Although tonic pupillary responses (baseline measure) were used, the possibility that presence of the task affected tonic pupillary responses cannot be ruled out. Anticipation of an upcoming Stroop test trial might have mediated the results, since anticipation can also result in pupillary dilations (Polt,1970; Vanderhasselt, Remue & De Raedt, 2014). Furthermore, there is some evidence that pupillary responses to affective stimuli are different for depressed individuals (Oguro, H., Suyama, N., Karino, K., & Yamaguchi, 2016) thus depression screening could have been used. An additional concern for any studies using pupillometry for assessing musically-induced affect is that inhibition of movement might result in frustration (Rossberg-Gempton & Poole,1992) which might be reflected in pupillary responses. This is especially relevant for studies using musical selections which have an emphasis on repetitive percussion since such musical texture is specifically concerned with making the listeners want to dance (Moelants, 2003). Future studies should take individual differences of the listeners into account, since some evidence suggests that psychophysiological responses to highly arousing music differ based on such personality traits as novelty-seeking and harm avoidance (Gerra et al., 1998).

Overall, the present experiment lends partial support for tempo-modulated increases in physiological arousal. Because the size of the pupil is regulated by the autonomic nervous system, the results of this study suggest that the autonomic nervous system is slightly affected by variation in musical tempo. However, there is no reliable support for the suggestion that textural aspects of music modulate arousal-inducing potential of tempo.

4.3 Performance on the Stroop test

In order to assess if tempo-induced arousal has cognitive consequences, the colour-word Stroop test (Stroop, 1935) was used with concurrent exposure to music varying in tempo. The Stroop test seemed like a good task to use since relatively little research concerned with cognitive consequences of musical background has used tasks requiring selective attention and especially inhibition. Furthermore, the Stroop test seems especially suited to assess effects of background music on cognitive performance in terms of Kahneman's (1973) limited capacity framework of attentional resources. This is because the Stroop task consists of both easy congruent trials with low cognitive load and rather cognitively demanding incongruent trials which require inhibition of a highly automatic response. Assessing response latencies on the Stroop test thus could suffice to assess if increases in tempo of background music facilitate or impair cognitive processing, and importantly if these effects are different based on demandingness of the task.

Firstly, the classical Stroop interference was replicated in this study, that is, response latencies for incongruent trials were greater than for congruent ones. However, this effect was significantly smaller than reported by most other studies. For example, in the study by Laeng et al. (2011) Stroop interference (RT difference between incongruent and congruent trials) was over six times greater than the Stroop interference observed in the present study. There are a few reasons for this, the most important of which is likely the so-called 'proportion congruency effect' which refers to systematic decreases in Stroop interference with increases in proportion of incongruent trials (Logan & Zbrodoff, 1979). Half of the Stroop test trials in the present study were incongruent, while Laeng et al. (2011) had only ¼ of incongruent trials. This to a large extent explains the small Stroop interference observed in the present study. Furthermore, Laeng and colleagues required participants to read the Stroop test stimuli out loud, while the current study used manual (key-press) responding. Although key-press responses have been used with Stroop tasks, they typically lead to smaller response latencies than verbal responding (Ikeda, Hirata, Okuzumi, H. & Kokubun, 2010), which likely stems from more practice with reading out words than responding to them manually and thus verbal responding requires more inhibitory processing (Sharma & McKenna, 1998).

Finally, responses in the present study were not speeded. The time-window for responding was the whole duration of stimulus presentation, namely four seconds. Non-speeded Stroop tasks are also known to produce lesser Stroop interference (MacLeod, 1991). All of these factors have likely contributed to the small Stroop interference observed in the present experiment.

Inconsistent with previous findings musical background did not affect Stroop test performance. Namely, Parente (1976) and Cassidy & MacDonald (2007) found that presence of background music led to more errors on incongruent trials. However, the measure assessed in the present study was that of response latencies, since as expected, the accuracy scores were very high. Furthermore, both Parente (1976) and Cassidy & MacDonald (2007) used vocal responding, thus it is hard to make a meaningful comparison of their findings and those of the current experiment. Neither of the studies involved a tempo manipulation, however Cassidy & MacDonald (2007) found that musical excerpts pre-rated as arousing led to greatest number of errors and the present study did not find such effects. Findings of the present study are also inconsistent with the effect that noise exerts on Stroop performance. When compared to silence, noise seems to facilitate response speed for both congruent and incongruent Stroop stimuli (Houston and Jones, 1967; Houston, 1969). Booth & Sharma (2009) also demonstrated that increasing the number of congruent Stroop stimuli, which usually leads to increased Stroop effect, did not affect Stroop effect size in a loud white noise condition while it did in so in silence. These findings would seem to suggest that concurrent auditory stimulation facilitates selective attention and cognitive flexibility. However, effects of noise and music on task performance generally tend to dissociate (Mayheld & Moss, 1989; Nittono et al., 2000).

Due to the lack of effects of background music in the present study it is difficult to discuss the findings in terms of Kahneman's (1973) model of attention. However, given that the small Stroop interference suggests that the task failed to be cognitively demanding, we are at least in a position to say that exposure to background music did not facilitate performance of an easy task. This is inconsistent with the previous reports of facilitating effects of background music on the processing speed of simple tasks (Milliman 1982; Nittono et al., 2000). Since higher tempo excerpts in the present study were rated as more arousing and the highest tempo led to greater pupillary response, it could be argued against the facilitating cognitive effects of musical background. However, since subjective arousal measures somewhat dissociated from pupillary responses, which were affected by tempo to a much lesser extent, it could also be the case that greater increases in physiological arousal are required to adequately assess if musically induced arousal can improve the processing speed of simple tasks.

Furthermore, it is possible that only phasic rather than tonic pupillary dilations might aid performance on the Stroop test since Stroop task requires filtering of temporally-specific sensory information. Although phasic LC cell activity is usually referred to as an increase in attentional resources devoted to task-relevant stimuli, the coupling in time of task-irrelevant physiological arousal, which activates LC system, and task stimuli, might lead to enhanced performance (McGinley, et al., 2015). This is compatible with a neurophysiological model of LC activation called 'adaptive gain' (Aston-Jones & Cohen, 2005) which suggests that sudden increases in physiological arousal reflected by phasic pupillary dilations result in optimal encoding of sensory information by increasing the signal-to-noise ratio. That is, because phasic LC-NE activation typically occurs when processing task-relevant stimuli, sudden activation of LC system by task-irrelevant arousing stimuli might actually result in enhanced processing of task-relevant information.

Although due to the limitations discussed above the Stroop task as a whole might have failed to be highly cognitively demanding, the small Stroop interference which was found suggests that incongruent Stroop stimuli were at least slightly more demanding. Given this, it is surprising that the highly rhythmically complex and dissonant minimalist piece did not increase response latencies to incongruent stimuli. Such highly dynamic and complex compositions are defined as ‘high information load’ music (Kiger, 1989). Thus, based on Kahneman’s model, if music fulfils the role of distractor, attentional resources during incongruent stimuli processing with concurrent exposure to highly cognitively engaging music should overtax attentional resources. Since this was not found to be the case even with the highest tempo version, it can be argued that music listening does not utilise cognitive resources. This line of thinking is not in accord with Kahneman’s (1973) view, nor with other prominent constructs of the nature of musical engagement (Konecni, 1982).

Importantly, findings (or rather the lack of them) of the current experiment suggest that cognitive consequences of background music might be exaggerated in the literature. Very few studies reported not finding that musical exposure impaired or facilitated concurrently executed task. A few studies reported no effects of background music on efficiency of verbal learning (Jäncke & Sandmann, 2010; Jäncke, Brügger, Brummer, Scherrer & Alahmadi, 2014), however so-called null results are generally neglected and do not make it into academic journals. This publication bias in psychological science is an important concern since it likely distorts the real picture of a given issue. As Ferguson & Heene (2012) suggest, publication bias violates the replicability requirement of science, as a replication has limited meaning if the failures of replications are neglected. This in turn does not allow for an adequate mechanism of theory falsification.

limitations and future directions.

Due to deploying a very undemanding task the current experiment is rather limited in terms of inferences it allows about the cognitive ramifications of background music. In order to explicitly test conflicting predictions inherent in Kahneman’s (1973) framework of attention future studies should ensure that both cognitively demanding and cognitively undemanding aspects of the task are in place. In case of the Stroop test, responses should be speeded and proportion of incongruent Stroop stimuli should be decreased. An ideal set up would require verbalised responses. Given that Stroop interference diminishes with practice (Reisberg, Baron & Kemler,1980) and that pupillary arousal indices differed only between the lowest and highest tempi, only two tempo manipulations should suffice subsequently reducing the number of total trials or allowing to increase the number of trials per condition. Individual differences, specifically extraversion should also be taken into consideration as a number of previous findings suggest that introverts are more susceptible to distraction by background music (Furnham & Allass, 1999). Impairment on the Stroop test performance during exposure to high-arousing was also found to be greater for introverts than extraverts by Cassidy & MacDonald (2007). Thus, in order to generate comprehensive theoretical models of effects of background music, characteristics of the listeners must be taken into account.

Overall, the present experiment suggests that background music might have no cognitive consequences, even when the subjective and to a lesser degree physiological indices of arousal are in place. Thus, arousing background music might not influence cognitive performance, at least for not very demanding tasks requiring inhibitory processing.

4.4 Relative influence of arousal and cognitive load on pupillary responses

In order to clarify the extent to which pupillary responses measure arousal versus cognitive load, effects of arousing music on pupillary responses during the Stroop task were examined. Based on the previous findings suggesting that arousal affects the pupil only under low cognitive load (Kahneman et al., 1968; Stanners et al., 1979; Chen & Epps, 2013), it was expected that the pupillary Stroop effect during silence, will diminish or disappear with exposure to arousing music, since arousing music will lead to pupil dilation during undemanding colour-congruent trials and will level-out pupillary responses to congruent and incongruent stimuli.

However, the present experiment does not allow to meaningfully assess whether arousal or cognitive load have priority in pupillary responses, since the pupillary Stroop effect itself failed to replicate even in the absence of background music. The reasons for this are probably similar as the limitations of the Stroop experiment outlined in the previous section.

Given that Stroop interference in response latencies was so much greater in other studies which found pupillary Stroop effect (Laeng et al., 2011; Siegle et al., 2004), this probably explains the null results of the present study. However, the lack of pupillary Stroop interference is unlikely to stem from the absence of time pressure in the test, since pupillary responses have been found to exhibit the Stroop interference pattern even when no overt responding was required (Brown et al., 1999; Paulsen & Laeng, 2006). Thus the lack of effect is likely best explained by the proportion-congruency factor described above. Brown, Van Steenbergen, Kedar, & Nieuwenhuis (2014) have demonstrated that increases in proportion of congruent trials might diminish pupillary Stroop effect to an even greater extent than for response latency interference. This is compatible with the neuropsychological 'conflict-monitoring hypothesis' which proposes that frequent occurrence of conflict-inducing stimuli leads to an overall greater activation of the cognitive control system (Botvinick et al., 2001). Overall, the lack of pupillary Stroop interference is likely explained by the low cognitive demandingness of both congruent and incongruent trials.

More interestingly, the present study not only found the lack of pupillary Stroop effect, but also a tendency for a reverse pattern of pupillary responses in the silence condition. That is, phasic pupil dilation was greater for congruent than incongruent trials. This is an unexpected finding, which might reflect participants' cognitive reappraisal or affective consequences of such reappraisal. Given that the phasic pupillary responses were locked to a 1000ms -2000ms epoch after stimulus presentation and that the average reaction time response latency was below 1000ms, it is possible that pupillary responses mirrored participants 'reflections' to their responses. Awareness of participants that incongruent Stroop trials are more cognitively demanding might have led to satisfaction about having made the correct response and it is this satisfaction that might have been reflected in pupillary dilations. Increases in autonomic arousal following correct responses to more difficult tasks have been reported before (Wessel, Danielmeier & Ullsperger, 2011). Braem, Coenen, Bombeke, Van Bochove & Notebaert (2015) have recently argued that increases in autonomic arousal following correct responses to more difficult tasks might reflect surprise about having made the correct response. Researchers corroborated this hypothesis by demonstrating pupillary dilations following correct responses to difficult trials of the Eriksen flanker task which requires responding to centrally positioned target stimulus which is flanked by a number of distractors. Easy (congruent) trials are ones where the target stimulus is the same as the distractors framing it, while in the difficult trials the target stimulus is different. Braem and colleagues suggested that pupillary dilations following correct difficult trials indicate autonomic arousal occurring due to surprise at having made the correct response. This idea is further supported by the observation that pupillary dilations also occurred following incorrect responses to easy trials. Since task accuracy in the current experiment was very high, phasic pupillary responses to incongruent trials exclusively represent correct responses to the Stroop test and the increased autonomic arousal following these trials is most likely explained by the relative surprise or satisfaction.

Given the lack of pupillary Stroop effect in silence and a very small Stroop interference in RTs, the incongruent trials seem to have failed to be demanding enough in order to assess the proposal of cognitive load priority over arousal in pupillary responses. Furthermore, manipulation of tempo seems to have also exerted only minimal influence on stimulus-locked responses further preventing any clear interpretations of the findings.
As evident from the tonic pupillary response analysis, this is explained by redundancy of the medium (110 BPM) tempo.

However, since phasic pupillary responses during music were very minor when compared to silence, and because there was no difference between dilations to congruent and incongruent stimuli, it can be inferred that at least during easy cognitive tasks arousal (in this case induced by music) is reflected in pupillary responses. That is, since stimulus-locked phasic pupil dilations are baseline-corrected, the lack of stimulus-evoked pupillary response for both congruent and incongruent trials suggests that musically-induced arousal was evident in the stimulus-locked pupillary responses during execution of the task as well. In other words, the tonic and stimulus-locked pupillary responses were very similar, suggesting that low cognitive demands of the Stroop test did not suffice to induce phasic LC-NE mode. This is consistent with theories which posit that increases in tonic pupillary response signal disengagement with the task (Wessel, Danielmeier & Ullsperger, 2011).

limitations and future directions.

Due to not being cognitively demanding as a whole, the Stroop experiment in this study does not allow for drawing conclusions about the relative influence of arousal vs. cognitive load in pupillary expression. Future studies should therefore exert greater control in making sure that the demandingness of the task manipulation and arousal-induction are successful.

It is important to note that manipulating arousal via incentives as in previous studies (Stanner et al., 1979; Kahneman et al., 1968) is not a promising approach, since this might also motivate participants to focus on the task more and incentive-induced pupillary responses might actually reflect greater mental effort rather than arousal. Thus musically-induced arousal still seems like a good candidate. However, both pre-trial and steady arousal states (as in this study) should be investigated.

Such research might also provide a new take on the relationship between background music and cognitive performance in terms of Kahneman's (1973) limited capacity framework. That is, if musically-induced arousal was mirrored in pupillary responses only during easy tasks, it could be suggested that due to limited attentional resources, only either a cognitively demanding or arousing stimulus can be processed at one time, and since cognitive load has priority in pupillary expression, attentional resources have priority for task-relevant stimuli. Interestingly, this means that arousing music would be more likely to impair performance on easy tasks. A tendency towards this direction was observed in the present study since exposure to music seems to have led to slightly greater response latencies for congruent trials only. Future studies should explore this possibility further, while also taking into account individual differences, since findings like those of Cassidy & MacDonald (2007) suggest that introverts might have fewer attentional resources.

5 Conclusion

Results of this empirical investigation suggest that both pupillary and subjective measures are affected by tempo. However, influence of tempo on subjective arousal was much greater than on pupillary indices of autonomic arousal. The findings also lend some support for the idea that the strength with which tempo influences arousal is at least partially moderated by degree of percussiveness of the musical piece. However, there were no cognitive consequences observable in the Stroop test latencies. Pupillary Stroop effect failed to replicate and, due to this, very limited inferences concerning priority of cognitive load over arousal in pupillary responses can be drawn.

Due to the ever-growing prevalence of music in our lives, investigating affective and cognitive effects of music has never been more important. This growing body of research, however, seems somewhat handicapped due to the lack of systematic research methodology as well as the lack of broader theoretical frameworks, which could help to generate more informative predictions. In order to tap into the underlying mechanisms of affective and cognitive consequences of music, more studies should incorporate phyisiological measures. This is vital, since capacity of music to communicate emotion somewhat diverges from its affect-inducing capacity, since subjective reports and indices of autonomic nervous system arousal can dissociate. Furthermore, investigations of musically-induced affective states should take the multidimensional nature of musical sound into account, while not dismissing the importance of understanding arousal-inducing potential of separate features of musical sound. Thus, affective potential of music should be investigated on a fine-grained level, but attempts should be made to also provide a bigger picture describing the interplay between different auditory features, characteristics of the listener as well as the context of musical exposure. All of this is important if we are to elucidate the mechanisms mediating effects that background music can have on cognitive processing. However, the current empirical investigation suggests that cognitive consequences of background music are not as ubiquitous as previously thought.

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Appendix A

Information sheet

An eye-tracking study investigating effects of musical tempo and genre on cognitive task performance

<u>Research background:</u>

I would like to invite you to participate in this project, which is concerned with effects that a musical background has on cognitive performance. Previous research has demonstrated that variation of different attributes of music, such as tempo, genre and pitch elicits different reactions in the listeners. However, most previous studies have only used self-report measures (i.e. questionnaires) when assessing effects of music on the listener. This study aims to expand on previous research by investigating whether effects of music on the listener are pronounced enough to affect cognitive performance. An eye-tracker will be used to track the eye movements thus allowing us to further clarify the cognitive processes affected by manipulation of music.

<u>Relevance of research:</u>

The relevance of research is most obvious when considering ways that music can influence cognitive performance when driving vehicles, since drivers often listen to music while driving. This research can also inform the choices of music in workplaces as different music can affect productivity for certain tasks differently.

<u>Why am I doing the project?</u>

The project is part of my final year for my master's degree in Cognitive Neuroscience. My thesis will be based on the data collected in this experiment.

<u>What will you have to do if you agree to take part?</u>

The session will consist of a couple of brief paper-based questionnaires and an experimental session. The experimental session will require you to perform a task known as Stroop task. You will be presented with a number of words one at a time and your task will be to identify the font (ink) colour of the word. The words presented will be name of colours. On some occasions the name of the colour word will match the ink colour in which the colour word is presented and sometimes it will not. Your task is to always name the colour of the ink regardless of the colour word presented. You must attempt to do the task as quickly and accurately as possible. You will have 4 seconds to make a response. Responses will be made using a computer keyboard. You will have to press the button denoted with the sticker of the same colour as your response. More detailed instructions and practice trials will be provided shortly on the computer screen.

The task will be split in a few ‘blocks’ and you will be able to take breaks in between them.

The task will be done while listening to pre-selected musical pieces via headphones provided at the sound level that you find comfortable.

Your eye movements will be monitored with a remote eye-tracking device while completing the task.

On a few occasions during the experiment you will be asked to indicate your mood on a scale provided.

After the experiment is complete you will be fully debriefed about the nature and goals of the study.

<u>How much of your time will participation involve?</u>

One session lasting no more than 1 hour.

<u>Will your participation in the project remain confidential?</u>

If you agree to take part, your name will not be recorded on the questionnaires or related to the cognitive performance or eye-tracking data collected. All the responses will be coded with a number and your name will not be associated with your responses.

The information will not be disclosed to other parties. Your responses to the questions and the data collected will be used for the purpose of this project only and I will not have access to any of your medical records. You can be assured that if you take part in the project you will remain anonymous.

<u>What are the advantages of taking part?</u>

You may find the project interesting. When I have completed the study I will produce a summary of the findings which I will be more than happy to send you if you are interested.

Do you have to take part in the study?

No, your participation in this project is entirely voluntary. You are not obliged to take part. If you do not wish to take part you do not have to give a reason and you will not be contacted again. Similarly, if you do agree to participate you are free to withdraw at any time during the project if you change your mind.

What happens now?

You will have to sign an informed consent form indicating that you are familiar with the background of the study and what it will involve and that you are aware that all the information you provided is confidential.

I will show and explain to you the mood rating scale that will be used throughout the experiment.

We will then adjust the sound level of the headphones and proceed to the experiment.

You will then get a few practice trials to get a taste of the task.

After the experiment proper you will complete two very brief questionnaires.

Finally, you will be fully debriefed, meaning that all the details about the meaning of collected responses will be fully revealed and the predictions regarding results will be outlined.

Contact information:

Leading investigator Austeja Tamaliunaite austejat@student.sv.uio.no; +4748649293
Project supervisor Bruno Laeng bruno.laeng@psykologi.uio.no

Appendix B

Informed consent form

By signing this document you indicate that:

- You have read and understood the information provided in the information sheet. That is, you are familiar with the nature of the experiment, what it will involve and how much of your time it will take.
- You know that all the personal information provided is confidential and that the data collected will not be associated with your name.
- You are aware that you are free to withdraw from completing the study at any point during the experiment.
- The full debriefing will be provided after the study is completed (or withdrawn from, if such is the case).
- You have been provided with the contact information of the lead investigator and told that you will be provided with the results of the experiment if you request them, and you will be free to ask any questions.

Please indicate with your signature on the space below that you understand your rights and agree to participate in the experiment.

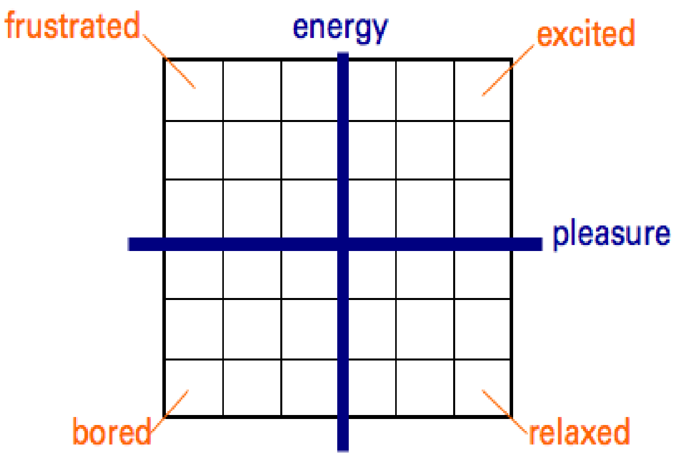
Your participation is solicited, yet strictly voluntary. All information will be kept confidential and your name will not be associated with any research findings.

Signature of Participant	Signature of investigator
--------------------------------	---------------------------------
Print Name of Participant	Name of investigator
------------------------------------	--------------------------------

Date: _______________

Appendix C

Russell's affect grid instructions



Instructions

The X axis: the X axis of the grid represents the extent to which your current mood is negative versus positive. The left side of the scale indicates negativity, while the right side positivity.

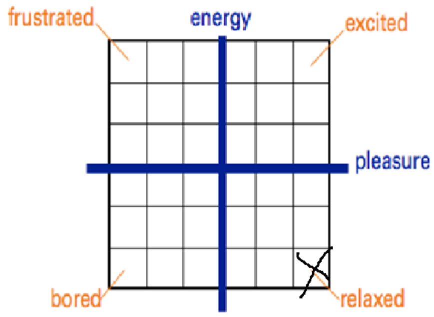
The Y axis: the Y axis represents the intensity level of your experience or in other words arousal/energy level. The lower half represents low levels of arousal, while the upper part indicates high levels of arousal.

When making a response always start with the X axis, that is, firstly chose the one of the 6 horizontal positions (where the most left position indicates the most negative experience and the most right position indicates the most positive state) which you feel best describes your current state.

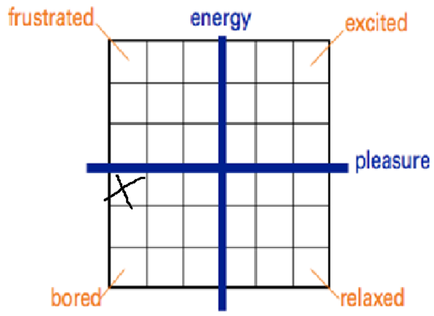
Then, shift your attention to the Y axis. Chose one of the 6 vertical positions (where the uppermost position indicates that your arousal levels are very high and the lowermost position indicates the lowest level of arousal) which you feel best describes the intensity level of your current mental state.

Select (by putting an 'X') the square which is at the intersection of the positions you chose on the X and Y axes.

Example 1: if I was feeling very low on energy, yet my experience was positive I would make this response:



Example 1: if I was feeling moderate amount of energy, yet my experience had a strong negative component I would make this response:



Appendix D

Latin square composed for the nine musical and one silence excerpt

Participants exposed to the corresponding order of treatments	Order of presentation
1; 11; 21; 31	1 2 10 3 9 4 8 5 7 6
2; 12; 22; 32	2 3 1 4 10 5 9 6 8 7
3; 13; 23	3 4 2 5 1 6 10 7 9 8
4; 14; 24	4 5 3 6 2 7 1 8 10 9
5; 15; 25	5 6 4 7 3 8 2 9 1 10
6; 16; 26	6 7 5 8 4 9 3 10 2 1
7; 17; 27	7 8 6 9 5 10 4 1 3 2
8; 18; 28	8 9 7 10 6 1 5 2 4 3
9; 19; 29	9 10 8 1 7 2 6 3 5 4
10; 20; 30	10 1 9 2 8 3 7 4 6 5

Note: numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 correspond to Classical music 80BPM, Classical music 110 BPM, Classical music 140 BPM, Minimalist 80 BPM, Minimalist 110 BPM, Minimalist 140 BPM, Tech-house 80 BPM, Tech-house 110 BPM, Tech-house 140 BPM and Silence respectively.

Appendix E

Debriefing sheet

This experiment is concerned with effects that a musical background has on cognitive performance and the cognitive mechanisms responsible for these effects. Namely, it was investigated how variation in tempo and genre affects arousal and appealingness of a musical piece and if and how this is reflected in performance of the STROOP task and the size of your eye pupil.

Previous research has demonstrated that increases in musical tempo steadily increase arousal, while music is rated as most appealing at moderate tempi. Little is known about whether the way tempo variations affect us depend on a musical genre in question. A proposal has been made in the literature that effects of tempo and arousal should be more pronounced for genres of music orchestrated to emphasize repetitive percussion. However, research which has previously been conducted to investigate this question failed to lend support for this prediction. It is possible that inconsistencies in the findings are due to self -report measures of arousal and appealingness used in those studies, as self-report measures are prone to bias. Pupilometry (tracking changes in the size of your pupil) was used as an indirect and therefore less bias-prone measure, which has previously been shown to reliably track changes in arousal. In order to see if concurrent exposure to arousing music affects cognition, Stroop task was used.

The relevance of this line of research is perhaps most evident when considering driving performance as people usually drive while listening to music and driving requires similar cognitive capacities as those measured in the STROOP task (accuracy, vigilance and inhibition).

Please contact leading investigator Austeja Tamaliunaite austejat@student.sv.uio.no; +4748649293 or project supervisor Bruno Laeng bruno.laeng@psykologi.uio.no if you have any questions regarding this study.

THANK YOU AGAIN FOR YOUR CO-OPERATION