THE INFLUENCE OF ACOUSTIC BACKGROUND ON VISUAL STROOP TASK PERFORMANCE

by

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Abstract

Living environments are seldom, if ever, devoid of all background auditory stimuli. However, the relationship between particular structural components of acoustic backgrounds and cognitive task performance remains unclear. Two experiments were completed to examine the influence of sound on a visual selective attention task. Participants performed the Stroop task (Stroop, 1935) while silence or background acoustic patterns of various complexities were presented over headphones. No effect of background sound on performance was found. A post-hoc analysis indicated that in comparison with participants who do not regularly listen to music while studying, participants who regularly listen to music while studying performed better on the Stroop task when a structured auditory pattern that included variation in both frequency and time interval was presented in the background. These results indicate that distinct structural components of background auditory sequences may interact with individual characteristics to influence cognitive performance on a task involving selective attention.

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Humans are surrounded by sound in the course of everyday living. Consequently, background sound permeates our environment during the performance of countless activities, from driving in rush-hour traffic to studying for a final exam. How does the presence of background music and sound impact information processing and task performance? Can it impede or can it facilitate cognitive functioning? With the advent of new technologies like in-car satellite radios, instantly-accessible streaming music on the internet, and mp3 players, the importance of identifying the influence of music and sound on cognitive performance has perhaps never been greater.

Does background music help people pay attention to a product or a task or does it interfere with attentional processes? Whereas marketing studies have been aimed at elucidating the effects of music on emotional responding (e.g., Kellaris & Cox, 1989), recent psychological studies have explored the cognitive effects of music such as the 'Mozart effect', the observation of improved spatial cognitive task performance after listening to Mozart (e.g., Rauscher, Shaw, & Ky, 1993). However, the effects of particular structural aspects of background sequences on cognitive performance are still not well understood. Given the pervasiveness of extraneous sound in our surroundings, this study is aimed at examining the effects of concurrent presentation of auditory patterns during a visual processing task that requires selective attention.

A great deal of animal work has been aimed at elucidating the mechanisms underlying visual selective attention. Investigations into how vast amounts of environmental sensory information is processed and filtered are ongoing. Early research by Hartline on frog and crab visual systems indicated that the activity of distinct optic nerve fibres is dependent on stimulus features such as light type, movement and brightness (Hartline & Graham, 1932; Ratliff, 1974). Furthermore, when particular nerve cells become active and fire, others nearby become inhibited in order to increase contrast and improve clarity of vision (Barlow, 1953). In monkeys, Hubel and Wiesel (1968) showed that specific visual system neurons respond to distinct features of visual stimuli only when presented to those neurons' receptive fields. More recently, models attempting to explain the filtering and processing of complex images have been tested in cats (Zhang, Rosenberg, Mallik, Husson, & Issa, 2007). Animal research has yielded invaluable information regarding the functioning and capability of visual systems in a variety of species, and much of this work is applicable to the human visual system.

As humans, we seem to be able to attend to specific environmental stimuli and ignore seemingly meaningless, inconsequential stimuli. When listening to a song, people are seemingly able to attend to the vocal melody sung by the singer and attend minimally to the drums or bass guitar. On the other hand, people cannot completely tune out all environmental stimuli unrelated to a particular task. For instance, imagine yourself hurriedly making changes to a manuscript that needs to be sent out the next morning for publication. Upon beginning the daunting task, a fire alarm next to your office goes off. For obvious reasons, humans cannot ignore all stimuli seemingly unrelated to the task at hand. People are constantly noticing changes in their environment and integrating information of various modalities from multiple sources simultaneously (Pirolli & Card, 1999). As good as people are at tuning out distracting or irrelevant information, there remains a tendency for attention to be drawn to novel information (see Lynn, 1966; Sokolov, 1963).

The intrinsic conflict that exists between the ability to target specific stimulus dimensions and ignore irrelevant ones while integrating diverse sources of environmental information has been termed the *paradox of selection* (Melara & Algom, 2003). Attempts to attend selectively to a certain stimulus are not always entirely successful. A screeching guitar may detract from a song's vocal melody. Although one might be pressed for time as a deadline approaches for the completion of a manuscript, the ringing of a fire alarm will tear even the most dedicated writer from the task. To function optimally, humans must be able to simultaneously isolate *and* integrate environmental information. A cognitive task that effectively probes the interaction of attending to certain stimulus aspects while ignoring others is the Stroop task (Stroop, 1935).

The Stroop Task

During performance of the Stroop task, participants must focus on the relevant aspects of a task while ignoring irrelevant information (Stroop, 1935). Irrelevant information is simultaneously presented within the same stimulus as the relevant information. Results from innumerable Stroop-related studies have revealed that the irrelevant information undermines participants' ability to selectively focus on the appropriate aspect of a stimulus. The Stroop task, dubbed the 'gold standard' of attentional measures (MacLeod, 1992) was utilized in the current study to elucidate the effects of sound exposure on selective attention.

In the original Stroop study, John Ridley Stroop (1935) conducted a series of experiments that revealed individuals have difficulty ignoring the semantic content of words. In the first experiment, participants were asked to read colour words presented on cards. In the control condition, colour words were printed in black ink. In the experimental condition, colour words were printed in an ink colour inconsistent with the written word. For example, the word RED was printed in blue ink, with “red” being the requisite answer. There was no difference in the time it took participants to read the words between conditions. Stroop concluded that colour processing did not interfere with reading the colour words.

In a second experiment, rather than reading words, participants were asked to name the ink colour in which words were written. The control condition included cards on which rectangles were printed in the same colours as the words. Unlike the previous experiment, the time that it took participants to name the coloured rectangles was significantly less than the time it took to name the ink colour of words written in incongruent colours. The Stroop effect, as it has come to be known, is the demonstration of increased reaction time in naming the ink colour of colour words when the semantic meaning of the word differs from the colour of ink in which it is printed. Similarly, Stroop asymmetry is defined as the reaction time discrepancy between reading incongruent colour words and naming the colour of incongruent colour words.

In his third experiment, Stroop (1935) attempted to determine if practice could explain his results. As participants were more experienced at reading than at naming the colour of words, Stroop reasoned that training participants to name ink colours would reduce or eliminate the interference effect observed in Experiment 2. After training participants on the colour naming task for eight days, interference, as measured by the difference in time to name the ink colour of incongruent colour words and coloured rectangles, decreased substantially. Furthermore, participants trained on the colour naming task took longer to read incongruent colour words than did untrained participants. Stroop concluded that the degree of experience in reading compared to naming colours accounted for the asymmetrical effects.

Various theories have been proposed to explain Stroop's original finding of asymmetrical interference in the reading and naming of colour words (MacLeod, 1991). According to the speed of processing account, given that any response generated can only enter a single output channel at any time point, and that word reading is faster than colour naming (e.g., Cattell, 1886; Fraisse, 1969), word reading generates a response in less time than does colour naming. Accordingly, the Stroop asymmetry is explained by the imbalance in the time needed to generate a response for each process. As a response for word reading is generated before a response for colour naming, not only is the response for colour naming slower than for word reading, but the time to resolve the conflict in responding further adds to the response time.

Stemming from studies that challenged the relative speed of processing explanation for the Stroop effect (e.g., Dunbar & MacLeod, 1984), other theoretical approaches were proposed. The automaticity account of the Stroop asymmetry is based on the idea that the lifetime of practice adults accrue in reading words have made this activity relatively involuntary or automatic. In contrast, the naming of ink colours has remained a relatively effortful, controlled process (Hasher & Zacks, 1979; LaBerge & Samuels, 1974; Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Shiffrin &

Schneider, 1977). The Stroop task asymmetry occurs as participants attempt to override the automatic tendencies to read and process the meaning of incongruent colour words. According to this approach, the Stroop effect occurs because words are read automatically even when the task is to name the ink colour. When the task is to read the words however, the controlled process of naming the ink colour does not interfere with performance. People do not process the colour of the word automatically, like they do the meaning, so ink colour does not interfere with word reading.

Although some studies have found evidence to support the automaticity account of Stroop's (1935) findings (e.g., MacLeod & Dunbar, 1988), others have disagreed with this explanation (e.g., Danziger, Estevez, & Mari-Beffa, 2002). Models such as Logan's (1980) weighted-evidence model and Cohen, Dunbar, and McClelland's (1990) connectionist parallel-distributed processing (PDP) model have attempted to incorporate both the speed of processing and automaticity approaches into cognitive frameworks to explain Stroop's findings.

Logan's (1980) model suggests that evidence for the identity of a stimulus is accumulated on each trial both for the colour and the word. This evidence is based upon weights assigned to the fixed relationship between the colour and word, and the validity of a distractor in target prediction. The degree of automaticity between colour and word remains constant, reflecting a facilitatory (congruent) or inhibitory (incongruent) effect on responding. On the other hand, distractor validity, the extent to which semantic meaning of the colour word corresponds to the target response, varies throughout the experiment. Logan proposed that word meaning primes colour processing, and the extent to which meaning corresponds with the correct response is in constant flux during the experiment. The more the distractor corresponds with the target response, the higher the weight assigned to the validity of the distractor. A response is generated when combined evidence from the assigned weights reaches a response threshold. As evidence accumulation takes longer to achieve the threshold during an incongruent trial in comparison to during a congruent trials, responding occurs later on incongruent trials.

In the PDP model (Cohen et al., 1990), independent pathways for colour naming and for word reading are presumed to exist. The relative strength of each pathway is actively adjusted in order to meet task demands. This model suggests that interference between colour names and word reading decreases as the proportion of incongruent items are increased within an experimental session. As the percentage of incongruent trials are boosted in the colour naming task, the pathway leading to a response of colour name should be strengthened; whereas the pathway leading to a response of word reading should be weakened. In essence, Cohen et al.'s model predicts that performance on the Stroop task should be improved if the proportion of incongruent trials is increased. Studies have found evidence to support a proportion-congruent effect (Lindsay & Jacoby, 1994; Logan, 1980, 1988, 2002; Tzelgov, Henik, & Berger, 1992), and even an item-specific congruent effect (Jacoby, Lindsay, & Hessels, 2003).

Common to all cognitive accounts of the Stroop effect is the tendency to generate an incorrect response hampers correct responding. The irrelevant dimension of the colour word leads to a delay in the generation of the appropriate response. Interference occurs regardless of whether the generation of the incorrect response is faster, more automatic, or associated with a stronger pathway than the correct response. Whatever the case may be, differentiating between alternative explanations of the Stroop effect is beyond the scope of the proposed study. Rather, the present study is concerned with examining the role of extraneous sound on a task of selective attention. In this context, of particular interest are the findings suggesting that Stroop task performance may be affected by the presence of extraneous auditory stimuli.

Effect of Background Sound on Stroop Performance

Houston and Jones (1967) conducted a study in which they attempted to reduce interference on the Stroop task caused by the irrelevant dimension (word name). They postulated that if Stroop performance is dependent on inhibition of a prominent (faster, automatic, stronger) response, then interference could be decreased by concurrent presentation of other to-be-ignored stimuli. Purposeful inhibition of distracting noises (e.g., trains, gibberish, and electronic music) should enhance performance on a task requiring inhibition, the Stroop task.

In the study, all participants completed a Stroop colour word task in which the words green, blue, orange and red were randomly presented in incongruent colours, and a colour-naming task in which participants were asked to name the colour of a set of five coloured asterisks. One group of participants completed the Stroop task during exposure to distracting noises. A second group also completed the Stroop task while listening to distracting noises but the word “tap” was interspersed among the noises. This group was required to tap a pencil on the table whenever the word tap was heard. A third group performed the Stroop task in silence. After comparing the difference between time taken to complete the Stroop colour word task and the colour naming task, the mean completion time for the group that listened to the to-be-ignored distracting noises was significantly less than for the other two conditions. Thus, it appeared that through the addition of a to-be-ignored irrelevant stimulus, even a stimulus of a different modality, interference of an irrelevant dimension was reduced.

In a follow-up project, Houston (1969) modified the previous study to address an issue that arose from the original experiment. In the prior study, it took significantly more time for participants to complete the Stroop colour word task than the colour naming task. Noise may have facilitated Stroop task performance simply because it was a more difficult task than the colour naming task, and not because it required more inhibition. Two versions of each task type were created to examine the possibility that Stroop task difficulty interacts with noise. Task difficulty was manipulated by reducing the discriminability of ink colours. Six colours were employed in the high difficulty tasks whereas only three were presented in the low difficulty versions. Moreover, overall saturation and brightness of the colours were reduced in the high difficulty versions of the tasks to make the colours even less discernable. Compared to the corresponding quiet conditions, time taken to complete the Stroop colour word task in the presence of noise was reduced in both the high and low difficulty versions. Conversely, time to complete the colour naming task was greater in the noise condition than the quiet, again in both versions. Houston supposed that inhibition of attending to noise improves performance on a task requiring inhibition, but not on a similar task that does not require inhibition. Taken together, Houston concluded that the concurrent presentation of stimuli requiring supplementary inhibition reduces interference on the Stroop task.

A glaring problem with Houston’s (1969) proposition that one type of inhibition interacts with another to improve performance on tasks of selective attention is that it has not received empirical support in the literature. The current theory that may best explain the findings of a decrease in the magnitude of the Stroop effect in the presence of noise is in fact the attention approach in the context of stress or arousal.

Before entering into a discussion on attention and arousal, some of the extensive early research that focused on the influence of noise on cognitive tasks should be noted (see Broadbent, 1979 for a review). In general, concurrent exposure of white noise while completing a task has been found to be disrupting (e.g., Broadbent, 1953, 1958, 1979; Jones, Smith, & Broadbent, 1979). Jones et al. (1979) found even noise of moderate intensity to disrupt performance on the Bakan vigilance task, a task requiring the participant to identify a particular sequence of digits in a long series. Intermittent noise has been found to disrupt performance on a mental arithmetic task, involving both the memorization and subtraction of numbers (Woodhead, 1964), a forced-choice serial reaction time (Fisher, 1972), and recall tasks (Salamé & Wittersheim, 1978). Noise frequency has been found to differentially affect cognitive task performance, with noise of higher frequency inducing more errors on a serial reaction task (Broadbent, 1957). Very loud continuous noise (over 95 dB) seems to be detrimental to both vigilance tasks and reaction time tasks (Broadbent, 1979). Although the majority of studies that have examined the effects of noise on cognitive performance have found an impairment effect, other studies have revealed some improvements in performance, especially in the context of lowered arousal levels.

To investigate whether noise disrupts performance of under-aroused individuals, Wilkinson (1963) investigated the combined effects of noise and sleep loss on the performance of a serial reaction task. Whereas continuous white noise at 100 dB led to performance decrements in participants who had a normal amount of sleep compared to normal-sleep, no-noise controls, participants who had been awake for approximately 32 hours prior to testing showed results that were similar to controls. Thus, performance benefited under conditions of white noise in sleep-deprived subjects by reducing the adverse effect of noise. As sleep deprivation decreases arousal (Wilkinson, 1962), the author concluded that noise increased the arousal levels of sleep-deprived participants to a more optimal state for task performance; yet, excessively heightened arousal of participants who had a normal night's sleep. These results indicate that white noise can heighten the arousal levels of individuals and improve cognitive performance of under-aroused participants.

According to Easterbrook (1959), as stress or arousal increases, attentional focus begins to narrow. Attention becomes concentrated on aspects of items most relevant to the present task, and attention paid to irrelevant aspects is diminished. Performance on tasks involving selective attention is improved under stress due to the exclusion of irrelevant features. This *attentional narrowing* is a consistent effect of many different types of arousing stressors (e.g., Wells & Matthews, 1994).

It has been suggested then that stress differentially affects attention paid to relevant and irrelevant task attributes. As attentional resources decrease, a greater proportion of attention is concentrated on relevant aspects of the task. This improved selectivity leads to more efficient processing of task-relevant dimensions (Hockey 1970a, 1970b). Attention is thought to be diverted away from task-irrelevant features leading to decreased interference imposed by their processing. Importantly, Hockey (1970b) concluded that "a funneling of attention" arises, and not a narrowing of the perceptual field. Increased attention was paid to centrally-located cues when cues located in central locations were to be attended; but participants focused on peripheral cues when cues in the periphery were highly relevant to the task at hand. Thus, cue selectivity is increased under conditions of high arousal, not attention to just the most *centrally-located* cues.

Some have argued that heightened stress, caused by a background sound for instance, may also steal attentional resources from a primary task (e.g., Broadbent, 1971; Chajut & Algom, 2003). Stress-induced resource depletion causes attention to be directed or focused toward the most relevant aspect(s) of the task (Easterbrook, 1969; Huguet, Galvaing, Monteil, & Dumas, 1999). The inability to process the excess irrelevant information leads to more efficient processing of the task-relevant features. In terms of the Stroop task, irrelevant information posed by the meaning of the colour word should produce less interference on processing of the ink colour in the presence of an additional irrelevant auditory stimulus.

Chajut and Algom (2003) found evidence for the attention theory in the context of the Stroop task. In their second experiment, participants were played continuous noise at a sound pressure level (SPL) of 84 dB in a high-stress condition and 55 dB in a low stress condition during performance of the visual Stroop task. Average ratings of stress indicated that participants found the high stress condition significantly more stressful than the low stress condition. Notably, the magnitude of the overall Stroop effect was clearly diminished in the high stress condition in comparison with the low stress condition. In the low stress condition, mean reaction times for the incongruent colour words was 641 ms in comparison to 600 ms for the congruent colour words, a statistically significant difference. In the high stress condition, the difference in mean reaction times for the incongruent (595 ms) in comparison to the congruent colour words (592 ms) was only 3 ms. These findings indicate that attentional selectivity improved under high stress. In accordance with the attention theory, increased selectivity led to a focusing on the task-relevant attribute.

In striking contrast to the attention view is the capacity-resource theory (Bargh, 1989; Kahneman, 1973). Akin to the attention theory, the capacity-resource theory posits that narrowing of attention occurs under the stress induced by presentation of irrelevant stimuli. Contrary to the attention theory, this narrowing does not lead to a focusing of attention on the most task-relevant stimulus dimension, but rather on the most automatically accessible dimension. As attention is both an effortful process and of limited capacity, and irrelevant sound detracts from attentional resources, the most salient aspects of the stimulus become even more prominent. If the most accessible stimulus dimension is irrelevant to the demands of the task, performance will worsen.

This theory posits that the Stroop effect should be augmented, and performance impaired, in the presence of irrelevant sound. Attention to the least accessible task feature, the ink colour in the Stroop task, will be diminished. Accordingly, not all studies of the interaction of noise and performance have found improved Stroop performance in the presence of an irrelevant auditory stimulus. Noise has been found to have little effect (Jones & Broadbent, 1979; Smith & Broadbent, 1980) or to be detrimental to Stroop and other cognitive task performance (Cassidy & MacDonald, 2007; Hartley & Adams, 1974 Experiment 1; Ogden, Rieck, & Coates, 1979). Cassidy and MacDonald (2007) found impairment of performance on the Stroop task in the presence of either music or noise in comparison to silence. Furthermore, Ogden et al. (1979) found that median reaction times on a word reading task were unaffected by noise levels of 85 dB in comparison to 65 dB. Colour-naming, on the other hand, took longer in the louder noise condition. Furthermore, participants had increased reaction time for naming the colour of words in a high variability noise condition compared with a low variability noise condition. Conversely, no reaction time difference was found on the word reading task. Thus, noise has been found in some cases to impede Stroop performance, pulling into question the reliability of Houston and Jones' (1967) and Houston's (1969) results.

When attempting to predict whether an increase in stress-induced arousal levels will lead to impaired or improved cognitive performance, the Yerkes-Dodson law (1908) law should be considered. The Yerkes-Dodson law describes task performance level as an inverted U-shaped function of arousal level (Yerkes-Dodson, 1908)**.** The inverted U-shape describes the link between arousal and performance, with an intermediate level of arousal generally leading to best performance.

This inverted-U shaped relationship between arousal levels and cognitive performance is not specific to humans. In fact, animal work has implicated specific hormones, such as glucocorticoids and catecholamines in this relationship (McEwen & Sapolsky, 1995). Both experimentally elevated and depleted levels of the glucocorticoid cortisol have shown to disrupt associative alarm-call learning in ground squirrels (Mateo, 2008). Moreover, secretion of intermediate levels of glucocorticoids has been found to enhance the plasticity of hippocampal neurons by stimulating long-term potentiation; yet, higher levels of glucocorticoids inhibit long-term potentiation. There is evidence from both animal and human studies of a relationship between stress-induced arousal and learning, and adrenal hormone levels may mediate this relationship (see Lupien & McEwen, 1997; Roozendaal, McEwen, & Chattarji, 2009).

Although theories that predict the effect of extraneous sound on cognitive performance differ in terms of attentional focus, this theoretical divergence may be somewhat attributable to discrepancies in both task demands and baseline arousal levels of participants. Irrelevant sound may improve performance when both task demands and cortical arousal levels are low, but may impair performance when the task is complex and participants` arousal levels are already near optimal (Berlyne, 1969; Easterbrook, 1959; Hebb, 1955; Johnson & Proctor, 2004; Kahneman, 1973; Yerkes & Dodson, 1908). Nevertheless, studies using seemingly similarly-arousing auditory stimuli during the visual Stroop task (e.g., Houston, 1969; Jones & Broadbent, 1979) have found discrepant results in terms of the effects of sound on cognitive performance. Bearing in mind the conflicting theories concerning a stress or arousal-based explanation of the effects of sound on Stroop task performance, examining the role of sound on other cognitive tasks may shed some light on the topic.

Irrelevant Speech Effect

The question remains: How might the presence of sound increase reaction time for naming the colour of incongruent colour words on the Stroop task? Many studies have been conducted to explain the finding of irrelevant speech on remembering a list of items, usually verbal stimuli (for a review, see Smith, 1989). Originally, this irrelevant speech effect concerned the finding of impaired serial recall on a visually-presented short-term memory task when irrelevant speech was presented concurrently with the memory task (see Jones, Madden, & Miles, 1992). However, studies have found an effect of irrelevant auditory stimuli even when presented in a foreign language or in the form of tones, and when the task does not involve memory for serial position (Colle & Welsh, 1976; Jones et al., 1992; Surprenant, 1998).

Research into the effects of particular aspects of the irrelevant information has revealed that increased variability of irrelevant speech leads to detrimental effects. Several studies have failed to find an effect of irrelevant speech when the irrelevant stimulus was a single, repeating item (Jones, 1994; Jones et al., 1992; Jones & Macken, 1993). Jones et al. (1992, Experiment 3) presented participants with either a single, repeating syllable (C, H, J, or U) or all four syllables presented randomly in quadruplets during a serial recall task. Whereas the presence of a single, repeating syllable led to a slight, non-significant impairment in memory, a significant detriment was found for the four-syllable condition. These results suggest that increased variability of the irrelevant stimuli increased the degree of memory disruption. In Experiment 4, Jones et al. investigated the existence of an effect of predictability. The four syllables were either presented in a predictable, repetitive, set-order ([“CHJU”] [“CHJU”], etc.) or in random order ([“HJUC”], [“CUHJ”], etc). As in Experiment 3, presentation of the four syllables was more disruptive than a single, repeated syllable. Interestingly, there was no significant difference between either of the four-syllable conditions. Thus, predictability did *not* moderate the effect of irrelevant speech. In general, it appears as though variability, but not predictability, of the irrelevant auditory sequence is positively related to the magnitude of the irrelevant speech effect (Jones et al., 1992; Jones & Macken, 1993, 1995a, 1995b, 1995c; LeCompte, 1994, 1995).

The changing state hypothesis, a part of Jones's (1993; Jones & Macken, 1993; Jones, Macken, & Murray, 1993) object-oriented episodic record model, was proposed in order to explain the irrelevant speech effect. The changing state hypothesis posits that irrelevant sounds access memory stores during the task and confuse cues to serial order. Cues to serial order, or order tags, establish relationships with the visual items in memory rehearsal. Tags from the irrelevant speech or non-speech can replace the visual items in memory leading to the association of order cues with the auditory stimulus.

The changing state hypothesis predicts that any speech or nonspeech auditory pattern will disrupt serial recall, so long as the pattern changes to a sufficient degree from one token or segment to the next (Jones et al., 1992). A simple, repeated sound does not hold any cues to changing state and will not induce an effect of irrelevant speech. No appreciable change in the auditory stimulus from one token to the next (no mismatch) will create only one representation of the event within memory. However, change in the auditory stimulus will lead to more order tags being produced. As a consequence, the changing state hypothesis predicts that auditory stimulus variability should be associated with the degree of memory impairment during irrelevant speech tasks. Initially, it was thought that the greater the mismatch, the greater the resulting disruption of serial recall.

Evidence suggests that changes in the auditory stimulus and disruption are linearly related only up to a certain point (Jones, Alford, Bridges, Tremblay, & Macken, 1999). In Experiment 3, Jones et al. (1999) manipulated the degree of auditory event mismatch over a range of pitch changes. The authors varied the pitch difference of the vowel “i” or a synthesized tone by 2, 5 and 10 semitones. Each utterance or tone was presented for 100 ms with an interstimulus interval of 75 ms. Three sequences with alternating high and low pitches and one steady sequence with no separation of successive tones were presented during a serial recall task. In accordance with the changing state hypothesis, increased disruption was observed up to the level of 5-semitone separation. However, in both the speech and nonspeech conditions, performance at the 10-semitone level improved relative to the 5-semitone level. These results indicate that a nonmonotonic relationship exists between serial recall disruption and pitch change.

This non-linear relationship is thought to be based on the concepts of auditory fission and temporal coherence (van Noorden, 1975). When each successive tone in a sequence is perceived as being connected, the sequence is considered to have temporal coherence. Fission is defined as when a sequence is perceived as two or more separate streams (van Noorden, 1975, 1977).

Temporal coherence and fission are related to both frequency change and tone repetition rate (van Noorden, 1975). If the frequency interval between successive two tones, “ABAB”, is small (e.g., 1 semitone), the sequence will be temporally coherent. The two tones will be heard as alternating in a single stream even if the repetition rate is very fast (e.g., 10 tones per second; van Noorden, 1975). Conversely, if the frequency interval is increased to a substantial degree (e.g., 10 semitones) and the sequence presented at the same rate, fission is prone to occur as two separate tonal strings (high and low) develop. Tones at greater frequency intervals and higher rates of repetition generally lead to a greater likelihood of fission. Complimentarily, the smaller the frequency interval between the tones and the longer the tone repetition times, the more likely successive tones appear as belonging to a single stream. If successive tones are too close together in time however, the tones may fuse together and become perceived as a single tone burst. If tone repetition times are greater than 2 seconds, the tones will not appear to exhibit temporal coherence no matter how similar the frequency of the tones. Thus, the phenomenon of fission relies on both temporal and physical characteristics of successive tones in a sequence.

For a repetition rate of approximately 6 tones per second, a critical point on the order of approximately 5 semitones must be reached before fission occurs (van Noorden, 1975). Jones et al. (1999) suggested that at the level of the 10-semitone difference, fission occurred. Perceptually, the sequence broke up into two auditory streams. Notably, in the context of the changing state hypothesis, each of the two streams consisted solely of unchanging pitches. As a result, minimal changing state information was contained within each stream. The authors concluded that reduced disruption of serial recall occurs when the auditory pattern is perceived as two unchanging streams in comparison to when it is perceived as a one highly variable stream.

A key flaw however in the changing state hypothesis is the stipulation that only in tasks requiring serial order processing will the irrelevant speech effect be present. Studies conducted by Surprenant (1998) and LeCompte (1994, 1996) have found irrelevant speech to have an effect on tasks that appear independent of serial processing. Surprenant (1998) presented participants with a yes-no recognition task free from any serial recall components and still observed an effect of irrelevant speech. LeCompte (1994) conducted eight experiments in order to investigate whether the irrelevant speech effect was limited to serial recall tasks. Experiments 1-4 revealed the irrelevant speech effect on a free-recall and Experiments 5A-5C showed the effect with a recognition procedure. Although these experiments revealed that the irrelevant speech effect was not limited to tasks of serial recall, participants could have been rehearsing items in a serial manner during both the free-recall and recognition tasks regardless of the lack of demand of serial output. In Experiment 6, participants were encouraged to use a type or processing unrelated to serial rehearsal. Participants were presented with 12 pairs of words. At the end of the list, one word from a single pairing was re-presented and participants were tasked to recall the other member of the pair. This type of task was thought to dissuade participants from using serial rehearsal as rehearsing each of the pairs in serial order was not beneficial to correct responding. Again, an effect of irrelevant speech was found. Thus, irrelevant speech appears to exert an effect on tasks that do not involve any processing of serial order.

Another account of the irrelevant speech effect, the feature model (Nairne, 1988, 1990), assumes that items in memory are represented as feature vectors. Each feature corresponds to a very small proportion of the represented item. Similar to dual-coding models, there exist two kinds of features in Nairne’s model. Modality-independent features are aspects of an item that have identical representations no matter the mode in which that item was presented. Internally-generated items, through inner voice or imagery, consist only of modality-independent features. Conversely, modality-dependent features are unique to the modality of presentation. Thus, both abstract (modality-independent) and representational (modality-dependent) aspects of each stimulus are held in memory.

Additionally, the feature model presumes two distinct memory stores. Primary memory represents the location where cues are processed and stored. Items are actually recalled from secondary memory. Proper retrieval of an item is dependent on the match between an item in secondary memory and the potentially degraded (due to retroactive interference) memory trace or cue in primary memory. In regards to the irrelevant speech effect, modality-independent features of to-be-remembered stimuli are obstructed by irrelevant auditory stimuli. In a process termed feature adoption, modality-independent cues in primary memory of relevant stimuli are replaced by features of simultaneously-presented irrelevant stimuli.

In contrast to the phonological store hypothesis (Baddeley 1986, 1992) and the changing state hypothesis, the feature model does not limit the effects of irrelevant speech to tasks involving serial recall. Feature adoption leads to increased cue degradation in primary memory. Accordingly, reintegration of discrete stimulus aspects in primary memory is impaired by irrelevant speech regardless of whether the task involves any processing of order information.

Both the changing state hypothesis and the feature model may be construed to suggest that increased variability of concurrently-presented auditory stimuli may impair performance on another task. Specifically, the feature model predicts that increasing the variability of the auditory stimulus presented during the visual Stroop task should lead to increased feature adoption. Modality-independent cues from the auditory stimulus may replace cues formed by the relevant stimulus (the ink colour). An important caveat concerning this prediction, however, is that the feature model is specific to recall and recognition tasks, and may not be of relevance to performance on the visual Stroop task. The Stroop task may not be intimately tied to cues stored in memory.

Research into the effects of sound exposure during the performance of the Stroop task has led to equivocal results. Jones and Broadbent (1979) found no difference in reaction times between those exposed to extraneous noise and those exposed to silence on colour-naming of incongruent colour words. In contrast, some studies have found impaired (Hartley & Adams, 1974 Experiment 1; Ogden, Rieck, & Coates, 1979) whereas others have found improved Stroop performance in the presence of auditory stimuli (Chajut & Algom, 2003; Houston, 1969; Houston & Jones, 1967). Accordingly, opposing theories have been proposed in order to account for the effects of sound on cognitive functioning. Houston’s (1969) interaction of inhibition model and Easterbrook’s (1959) attention theory both predict that the presence of irrelevant sound should lead to improved Stroop task performance. In direct contrast, the capacity-resource theory (Bargh, 1989; Kahneman, 1973) predicts that background sound will focus attention on the most accessible dimension, the irrelevant dimension. Studies examining the irrelevant speech effect (e.g., Baddeley, 1986, 1992; Jones et al., 1992, 1999; LeCompte, 1994, 1998) have also provided some evidence to suggest that extraneous sound may lead to impaired cognitive processing. Although both the changing state hypothesis and the feature model would predict that performance on the Stroop task may be impaired during exposure to extraneous sound, evidence gathered by Jones et al. (1999) may be used to qualify this prediction as the degree of disruption may ultimately rely on how listeners perceive the auditory sequence. The divergent results of studies that have examined the effect of sound on selective attention led Loeb (1986) to conclude that stress induced by irrelevant sound may lead to an “increase, decrease, or leave unchanged the magnitude of the Stroop effect” (p. 187). The general aim of the following experiments is to investigate the particular effects of auditory pattern variability and auditory streaming on performance of the visual Stroop task.

The current study was designed to investigate if structural components of auditory patterns influence cognitive performance. Specifically, the experiments examined how the concurrent presentation of tone sequences to which attention is not required affects performance of a visual Stroop task. As research into the effects of auditory stimuli on visual task performance has seemingly yielded contradictory results, these studies have been designed to clarify the relationships between the characteristics of auditory sequences and Stroop task performance.

Experiment 1

In Experiment 1, participants heard a complex pattern, a simple pattern, or silence while performing separate blocks of the visual Stroop task. If Stroop performance is impaired during exposure to the complex pattern and the simple pattern relative to the silence condition, then auditory patterns may interfere with a task requiring visual selective attention. If, on the other hand, the magnitude of the Stroop effect is diminished in the presence of background auditory patterns, then this indicates that selective attention to task-relevant information is facilitated by the presence of irrelevant tone sequences.

A considerable number of studies have attempted to define and measure *musical* pattern complexity (e.g., Coyle & Shmulevich, 1998; Essens, 1995; Lerdahl & Jackendoff, 1983; Madsen & Widmer, 2006; Parncutt, 1994; Povel & Essens, 1985; Shmulevich & Povel, 2000). These studies have indicated that perceived pattern complexity increases as variation in frequency increases and repetitiveness decreases. In accordance with this research, the complexity of the auditory patterns used in the present study was defined by these two characteristics. Thus, the complex pattern in Experiment 1 incorporated changes in tone frequency and reduced repetitiveness in comparison to the simple pattern.

Method

Participants

Forty-four participants were recruited from the University of Manitoba Introduction to Psychology course. Participants received course credit for their involvement in the study. All participants were required to have no hearing or vision impairments, including colour-blindness (all according to self-report). Only those who reported normal, or corrected to normal, hearing and vision participated. In addition, participants for whom English was a second language were asked whether they had any trouble reading the four colour words. No one reported such difficulties. Three participants were excluded due to a misunderstanding of task directions (error rates higher than 30% on incongruent trials). A total of 30 females and 11 males were included in the analyses.

Materials

Computer and sound system. The experiment was run on Dell Precision T5400 desktop computers, each equipped with a 20.1" widescreen flat panel LCD monitor. Both visual and auditory stimuli were presented with E-Prime software system (Psychology

Software Tools, Inc., 2002). Sounds were emitted through Sony MDR-7506 professional stereo headphones at a comfortable listening level of approximately 65 dB SPL.

Sounds. All auditory patterns were comprised of a sequence of pure sine wave tones. Each tone was 100 ms in duration including 5 ms onset and offset ramps. The sound sequences were presented in stereo with a sampling rate of 44.1 kHz. All sounds were generated using Adobe Audition 1.5 (Adobe Systems Inc., 2005).

The simple pattern consisted of a single, repeating tone in the form "AAAAAAA". The tone 'A' represents a tone at a pitch of C4, at a frequency of 261.626 Hz. The time between the end of one tone and the beginning of the next (the inter-stimulus interval or ISI) was set to 75 ms, and thus, the time between the onset of one tone and the next (the tone repetition rate) was set to 175 ms.

The complex pattern consisted of a sequence of tones in the form "ABA_ABA_". In this pattern tone 'A' again represents a tone at a pitch of C4. Tone 'B' represents a pitch at 5 semitones higher than tone "A" (F4, a frequency of 349.228 Hz). Within each tone triplet, the ISI was set to 75 ms as in the simple pattern. ISI between the end of one tone triplet and the beginning of the next was set to 175 ms.

Visual stimuli. The participants' task was to identify the font colour in which individual letter strings (usually words) appeared on a computer screen. When words were presented, the font colour and word meaning could be congruent (e.g., the word RED presented in red), or incongruent (e.g., the word RED presented in green). On neutral trials, a string of four Hs was presented. Words and letter strings were presented in equal proportions blue, green, red and yellow. All colours were clearly visible against a light grey background screen.

Procedure

Participants completed three blocks of 72 experimental trials. For each trial, participants were required to indicate as quickly and accurately as possible the font colour in which a single word or letter-string appeared. Participants were instructed to press one of four colour-labeled keys on the computer keyboard corresponding to the appropriate font colour.

At the beginning of the session, participants were presented with a set of instructions regarding the task. The instructions were followed by a set of 12 practice trials in order for participants to familiarize themselves with the procedure. Examples of neutral, congruent and incongruent trials were presented within the practice set. Each experimental block of 72 trials was split equally into 24 neutral, 24 congruent and 24 incongruent trials in random order. Participants completed the experimental blocks in the presence of the complex pattern, simple pattern or silence. The order in which the three acoustic background conditions were presented was counterbalanced across participants. Each auditory sequence was presented continuously throughout an entire block of 72 trials.

Each block of trials, including the set of practice trials, began with a centrally-located fixation cross (‘+’). The auditory background sequence (if any) commenced simultaneously on presentation of the fixation cross. A word or letter-string was presented 100 ms after the onset of the fixation cross, and remained visible until the participant responded. A centrally-positioned fixation cross appeared immediately following each response and the next visual stimulus was presented 500 ms following its onset. Both accuracy and reaction time measurements were recorded. Accurate responses were defined as those for which participants pressed the button on the keyboard corresponding to the correct font colour of the presented word or letter-string.

Results

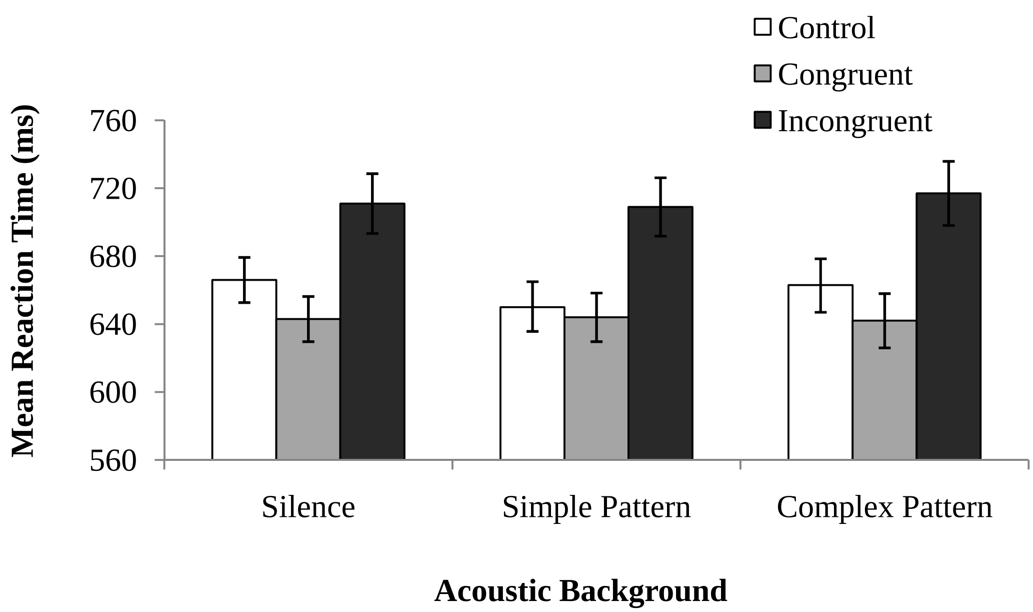
Omnibus Analysis

For all participants, mean reaction times (RTs) for correct responses and the percentage of incorrect responses (errors) were analyzed using separate 3 x 3 within-subject ANOVAs. Trial Type (neutral, congruent and incongruent) and Acoustic Background (silence, simple and complex) constituted within-subject factors. The Least Significant Difference method was used to examine all multiple comparisons. In the majority of our analyses for both Experiments 1 and 2, the variance of our data violated the sphericity assumption of the repeated-measures ANOVA. Therefore, for all analyses I applied the Greenhouse-Geisser method to adjust our degrees of freedom to correct the significance test. For each participant, reaction times more than 2.5 standard deviations above and below the mean in each of the nine cells of the within-subject design were considered outliers and excluded from all statistical analyses. This procedure eliminated less than 1.5% of all observations.

Reaction times. The 3 x 3 within-subjects repeated-measures ANOVA of RTs revealed only a significant main effect of Trial Type, $F(1.286, 51.457) = 48.163$, $p < .001$. Averaged across auditory patterns, participants responded 69 ms faster on congruent trials than on incongruent trials, and 17 ms faster on congruent trials than on neutral trials ($p < .001$ for both comparisons). Furthermore, participants responded 53 ms slower on incongruent trials than on neutral trials ($p < .001$). Neither the main effect of

Acoustic Background, $F < 1$, nor the interaction between Trial Type and Acoustic Background, $F(3.498, 139.931) = 1.038$, $p = .384$, was significant. Mean RTs corresponding to neutral, congruent and incongruent trials for each of the three auditory patterns are displayed in Figure 1.

Figure 1. Mean RT as a function of Trial Type and Acoustic Background in Experiment 1. Error bars represent standard errors.



Error rates. Analysis of error rates revealed a similar pattern of performance to that of the reaction time data. The main effect of Trial Type was significant, $F(1.838, 73.512) = 3.880$, $p < .03$, but neither the main effect of Acoustic Background, $F < 1$, nor the interaction of Trial Type and Acoustic Background, $F < 1$, revealed significant differences. Averaged across the three levels of Acoustic Background, participants responded significantly more accurately on congruent than on incongruent trials ($p < .03$), and on neutral than on incongruent trials ($p < .04$). However, no significant difference in error rates was found between congruent and neutral trials ($p = .618$).

Analysis of Stroop Facilitation, Interference and Overall Effect

Stroop facilitation was measured by examining the difference in RTs and error rates between neutral and congruent trials (see MacLeod, 1991). Stroop interference was determined by examining the difference in RTs and error rates between incongruent and neutral trials. For the magnitude of the overall Stroop effect, RTs and error rates for incongruent trials were contrasted with those for congruent trials (e.g., Schmidt & Besner, 2008). For a discussion on issues related to assessing magnitudes of Stroop facilitation, of interference, and of overall effect, see Lindsay and Jacoby (1994).

Reaction times. In regard to response time, separate one-way repeated measures ANOVAs with Acoustic Background as the within-subjects variable were performed. Stroop interference, facilitation, and overall effect were examined. There was neither a significant difference in Stroop facilitation between auditory patterns, $F(1.858, 74.336) = 2.180$, $p = .124$, nor was there a significant difference in Stroop interference between auditory patterns, $F < 1$. Furthermore, there was no significant effect of Acoustic Background on overall Stroop effect, $F < 1$. Table 1 displays the magnitudes of Stroop facilitation, interference and overall effect for each pattern in terms of RTs.

Table 1.

RT Magnitudes of Stroop Facilitation, Interference and Overall Effect with Standard Errors (in parentheses) as a function of Acoustic Background in Experiment 1.

Analysis	Pattern	RT Magnitude (SE)
	Silence	23.2 (6.52)
Facilitation	Simple	6.00 (6.07)
	Complex	21.1 (6.72)
	Silence	45.1 (11.6)
Interference	Simple	59.0 (10.2)
	Complex	54.1 (10.9)
	Silence	68.3 (10.6)
Overall Effect	Simple	65.0 (10.2)
	Complex	75.1 (10.4)

Error rates. Analysis of the error rates was analogous to the analysis of the RT data. The results revealed no significant effects between auditory patterns in terms of facilitation (F(1.939, 77.573) = 1.211, p = .303), interference (F(1.958, 78.336) = 1.017, p = .365), or overall Stroop effect ($F < 1$).

Habituation Analysis

In order to determine if participants habituated to the background sound, median RTs were calculated for the first and second halves of each experimental block. Thus, performance on the first 36 trials was contrasted with performance on the final 36 trials of each Acoustic Background. A 3 x 3 x 2 within-subjects repeated-measures ANOVA of median RTs was performed with Trial Type, Acoustic Background and Cycle treated as within-subject factors. As expected, there was a main effect of Trial Type, F(1.401, 56.035) = 42.971, $p > .001$. The comparisons revealed the same pattern as the omnibus analysis ($p < .001$ for all comparisons). There was also a main effect of Cycle, $F(1, 40) = 4.120$, $p < .05$. Participants responded significantly faster on the second half of trials in comparison to the first half ($p < .05$). However, there was no main effect of Acoustic Background, and the analysis revealed no significant two-way or three-way interactions.

Discussion

As research into the effects of irrelevant sound exposure during the performance of the Stroop task has yielded inconsistent results, the original research hypothesis was bidirectional in nature. Both attention and capacity-resource theories posited that extraneous sound may produce an attentional-narrowing effect. To complicate matters however, the precise manner in which this focusing of attention might impact performance was unclear. Additionally, the complex pattern, having more variation than the simple pattern, was postulated to recruit more attentional resources and induce more stress than the simple pattern or silence (see Driskell & Salas, 1996).

According to the attention theory (Easterbrook, 1959), if an irrelevant auditory stimulus acting as a stressor induces a narrowing of attention, participants should become more focused on the most relevant task feature. Similarly, according to Houston’s (1969) interaction of inhibition model, the magnitude of the Stroop should decrease in the presence of sound because the inhibition of the extraneous sound should enhance performance on tasks requiring inhibition of irrelevant visual information. Thus, according to both the attention theory and the interaction of inhibition model, the magnitude of the Stroop effect was hypothesized to be lower in the presence of an irrelevant auditory background than quiet due to better focusing of attention on the font colour. The results of Experiment 1 provide no empirical support for these theories because the magnitude of the difference between incongruent and congruent trials was not significantly less in the presence of the either the complex pattern (77 ms) or the simple pattern (65 ms) in comparison to silence (76 ms). This is further supported by an additional analysis revealing no significant difference in RTs between auditory background (combining both the complex pattern and the simple pattern) and silence ($F < 1$).

In contrast to the attention theory, according to the capacity-resource theory (Bargh, 1989; Kahneman, 1973), an irrelevant acoustic background might be expected to promote appropriate focusing of attention on the most salient task feature. In the Stroop task, the most salient feature is the word meaning as it is more automatic or accessible than word colour. In this case Stroop performance should be best during the silent background condition than in either of the sound background conditions. Again, I found no conclusive evidence to support this theory.

With regard to the expected effect of pattern complexity, according to both the changing state hypothesis (e.g., Jones, 1993) and the feature model (e.g., Nairne, 1988), increased complexity of the acoustic background may be associated with an increased Stroop effect. As a more complex auditory pattern holds more changing state information than a simpler pattern, the complex pattern may induce the generation of multiple or more intricate representations or order tags in memory than the simple pattern. Likewise, the feature model would predict that a higher degree of variability within the auditory stimulus may lead to a greater amount of feature adoption. The more modality-independent representations that become created in memory by the auditory stimulus, the more the processing of the relevant task stimulus (the font colour) will be impeded. Again, no significant variations in the magnitude of Stroop effect between any of the three acoustic backgrounds were found. Furthermore, the habituation analysis did not suggest that the influence of Acoustic Background on performance was masked by participants becoming accustomed to the patterns. Although participants performed faster on the second half of trials in each block, this pattern of results was evident in all auditory backgrounds. Thus, Experiment 1 did not generate any conclusive evidence to support any theory that suggests an overall impairment or enhancement in performance of the visual Stroop task in the presence of irrelevant sound.

Experiment 2

No effect of acoustic background either alone or in combination with Trial Type was apparent in Experiment 1. Experiment 2 was performed, in spite of these null results, as a second attempt to identify a possible effect of acoustic background on cognitive processing. Four auditory patterns were used, all of which represented variants of the complex pattern (ABA_ABA_ABA) used in Experiment 1. As in the first experiment, each of the tone sequences was presented continuously while participants performed a block of the visual Stroop task.

The Temporally Varied Pattern was designed to probe the nature of tone repetition rate on Stroop task performance. The original complex pattern from Experiment 1 was modified so as to keep the variation in the temporal aspect of the pattern while incorporating no changes in frequency. The Frequency Varied Pattern was created in order to investigate the specific effect of frequency change on Stroop task performance. Thus, the frequency changes of the original complex pattern were preserved but the Frequency Varied Pattern followed an isochronous sequence (i.e., ABAABAABA). The Segregated Streams Pattern was designed in an attempt to encourage listeners to perceive the background pattern as two separate streams rather than as one integrated stream. It has been known for many years that an auditory pattern that includes rapid changes in frequency may be perceived as two separate sequences or streams (e.g., Bregman, 1990; van Noorden, 1975). Indeed, using a pattern very similar to the complex pattern of Experiment 1, van Noorden showed that a 10 semitone difference between the ‘A’ and ‘B’ tones led listeners to perceive two streams, one comprised only of ‘A’ tones and the other comprised only of ‘B’ tones. The third pattern used in Experiment 2 included a 10 semitone frequency difference between tones A and B in order to examine the effect that two different auditory streams may have on performance of the Stroop task. Finally, a fourth pattern, the Random Pattern, was designed to investigate the effect of an unpredictable auditory sequence on Stroop performance. This pattern was comprised of a randomly ordered sequence of 100 ms of silence, tone A, and tone B.

Method

Participants

Fifty-seven participants were recruited from the University of Manitoba Introduction to Psychology course and received course credit for their involvement. As in Experiment 1 all participants had normal vision and hearing according to self-report.

None of the participants involved in Experiment 1 participated in Experiment 2. One participant was excluded due to misunderstanding of the task directions (above 30% error rate on incongruent trials). A total of 45 females and 11 males were included in the analysis.

Materials

The computer and sound system, along with visual stimuli (words, letter-string and colours) were identical to those used in Experiment 1.

Sounds. All sounds used in these patterns were synthesized in the same manner and using the same software as in Experiment 1. Four different patterns were synthesized for use in Experiment 2.

The Temporally Varied Pattern, represented graphically as ’AAA_AAA_AAA’, included a single tone at a pitch of C4, at a frequency of 261.626 Hz. The ISI between tones within each triplet was 75 ms and the ISI between the last tone of one triplet and the first tone of the next was set to 175 ms. The Frequency Varied Pattern, represented graphically as ’ABAABAABA’, included two different tones, ‘A’ at a pitch of C4, and ‘B’ at a pitch 5 semitones higher at F4 (a frequency of 349.228 Hz). The Segregated Streams Pattern, represented graphically as ’ABA_ABA_ABA’, included two different tones, ‘A’ at a pitch of C4, and ‘B’ at a pitch 10 semitones higher at Bb4 (a frequency of 466.164 Hz) with the ISI of 175 ms between each triplet. Finally, the Random Pattern consisted of a random ordering of a tone with pitch C4 (261.626 Hz), a tone with pitch F4 (349.228 Hz), and a silent period 100 ms in duration.

Procedure

Participants completed four separate blocks of trials, each accompanied by a different auditory background. The order in which these blocks were completed was counterbalanced across participants. Again, each block consisted of 72 experimental trials with 24 neutral, 24 congruent and 24 incongruent trials presented in random order.

Immediately following completion of the experimental session, participants were asked if they listened to music while studying for academic tests or examinations.

Results

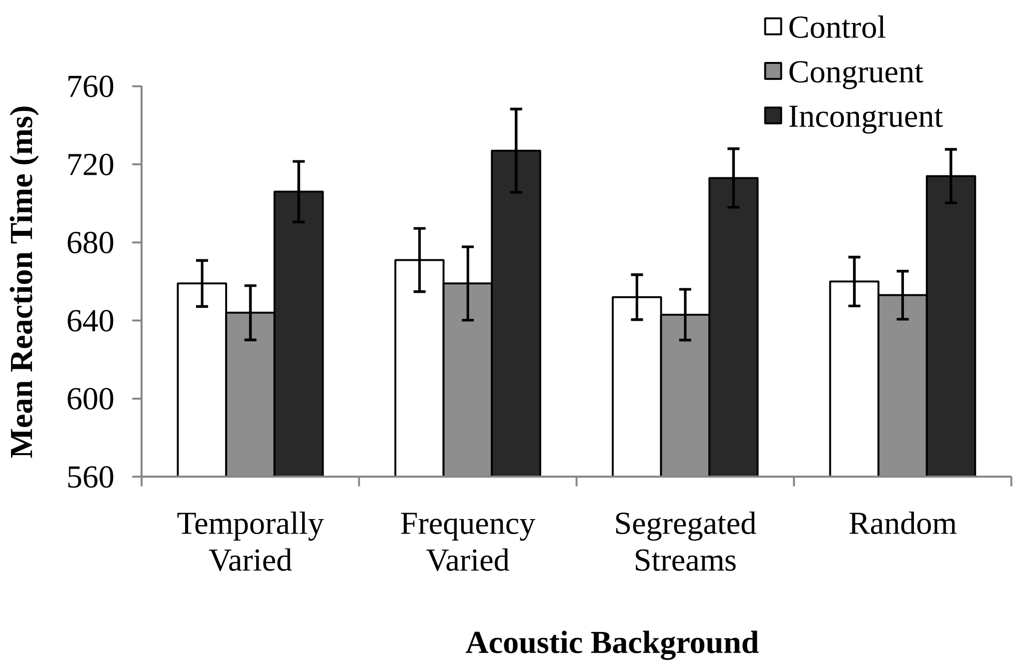
Omnibus Analysis

Mean RTs for correct responses only and percentage errors were analyzed using 3 x 4 within-subject ANOVAs. Trial Type (neutral, congruent and incongruent) and Acoustic Background (Temporally Varied Pattern, Frequency Varied Pattern, Segregated Streams Pattern and Random Pattern) constituted the within-subject factors. For each participant, RTs more than 2.5 standard deviations above and below the mean in each of the 12 cells of the within-subject design were considered outliers and excluded from statistical analyses. This procedure eliminated less than 2% of all observations.

Response Times. The RT analysis revealed a significant main effect of Trial Type, $F(1.563, 85.965) = 91.484$, $p < .001$. Overall, participants responded 65 ms faster on congruent trials than on incongruent trials ($p < .001$), and approximately 11 ms more quickly on congruent trials than on neutral trials ($p < .01$). Additionally, responses on neutral trials were 55 ms faster than on incongruent trials ($p < .001$). Neither the main effect of Acoustic Background, $F < 1$, nor the interaction between Trial type and

Acoustic Background, *F* < 1, was significant. Mean RT for each combination of Trial Type and Acoustic Background are displayed in Figure 2.

Figure 2. Mean RT as a function of Trial Type and Acoustic Background in Experiment 2. Error bars represent standard errors.



Error rates. As in Experiment 1, analysis of accuracy data revealed a similar pattern of performance to that of the reaction time data. The main effect of Trial Type was significant, $F(1.865, 102.598) = 9.085$, $p < .001$. However, neither the main effect of Acoustic Background, $F < 1$, nor the interaction of Trial Type and Acoustic Background, $F < 1$, revealed a significant difference. Pooling the four levels of Acoustic Background, participants responded significantly more accurately on congruent than on incongruent trials ($p < .001$), and on neutral than on incongruent trials ($p < .003$). No significant difference in error rates was found between congruent and neutral trials ($p = .347$).

Analysis of Stroop Facilitation, Interference and Overall Effect

For both RT and accuracy data, separate one-way repeated measures ANOVAs were performed to assess any differences in regards to Stroop facilitation, interference, and overall effect between sequences.

Reaction times. For the RT data, there was no significant difference in the magnitudes of Stroop facilitation between patterns, measured as the difference in response time between congruent and neutral trials. Similarly, no significant difference was found in the amount of Stroop interference between Acoustic Backgrounds, measured as the difference in response time between incongruent and neutral trials. Finally, no significant difference in overall Stroop effect, measured as the difference in response time between incongruent and congruent trials, were found between any of the auditory sequences, ($F < 1$ for all). Table 2 displays the magnitudes of Stroop facilitation, interference and overall effect for each pattern in terms of RTs.

Table 2.

RT Magnitudes of Stroop Facilitation, Interference and Overall Effect with Standard Errors (in parentheses) as a function of Acoustic Background in Experiment 2.

Analysis	Pattern	RT Magnitude (SE)
	Temporally Varied	15.0 (6.60)
Facilitation	Frequency Varied	12.4 (7.60)
	Segregated Streams	8.48 (6.90)
	Random	6.73 (6.18)
	Temporally Varied	47.0 (8.95)
Interference	Frequency Varied	56.0 (11.0)
	Segregated Streams	61.3 (8.78)
	Random	55.0 (7.35)
	Temporally Varied	62.0 (7.19)
Overall Effect	Frequency Varied	68.4 (7.38)
	Segregated Streams	69.8 (8.60)
	Random	61.7 (7.56)

Error rates. Analogous to the results of RT data analysis, no significant differences attributable to Acoustic Background were found in facilitation, interference, or magnitude of the overall Stroop effect ($F < 1$ for all).

Habituation Analysis

In order to determine if participants habituated to the background sound in Experiment 2, a 3 x 3 x 2 within-subjects repeated-measures ANOVA of median RTs was performed with Trial Type, Acoustic Background and Cycle treated as within-subject factors. The pattern of results was the same as in Experiment 1. There was a main effect of Trial Type, $F(1.813, 99.732) = 84.217$, $p > .001$. Multiple comparisons revealed the same pattern as the omnibus analysis ($p < .001$ for all comparisons). There was a main effect of Cycle, $F(1, 55) = 8.984$, $p < .005$. Again, participants responded significantly faster on the second half of trials in comparison to the first half ($p < .05$). The analysis revealed neither a main effect of Acoustic Background nor any two-way or three-way interactions.

Order Analysis

Importantly, the experiment incorporated 24 distinct sequences for appropriate counterbalancing of Acoustic Background. To examine the possibility of order effects, the above ANOVAs were conducted on the first 48 participants so that each of the 24 sequences was represented exactly twice in these analyses. Again, in terms of both RT and error rates, no significant differences in the magnitudes of Stroop facilitation, interference or overall effect were found between patterns.

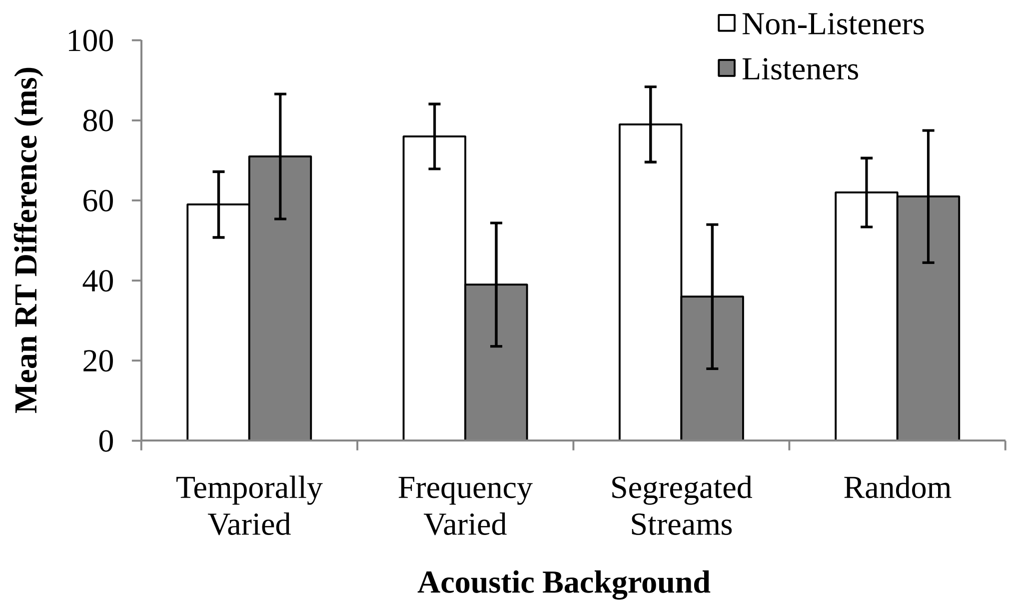
Post Hoc Investigation of Individual Differences

To examine additional variables that may play a role in performance of the Stroop task during exposure to auditory stimuli, participants were asked if he or she listened to music while completing coursework or studying for academic examinations. Participants responded along a continuum of “never”, “rarely/sometimes”, “often/almost always”, and “always”. Based on their responses, participants were divided into two Study Preference categories. ‘Music listeners’ were defined as those who usually or always listen to music while studying, whereas ‘non-listeners’ were characterized as those who rarely or never listen to music while studying. One participant indicated that she routinely left the television on while studying. She was categorized as a music listener as she was evidently able to study in the presence of irrelevant auditory stimuli.

Analysis of Stroop facilitation, interference and overall effect by Study Preference

Reaction Times. In order to investigate possible differences in Stroop task performance between music listeners and non-listeners, separate 4 x 2 mixed-design ANOVAs were conducted. Magnitudes of Stroop facilitation, interference and overall effect in each Acoustic Background were treated as within-subjects factors and Study Preference was treated as the between-subjects factor. As in the previous analysis, there were no main effects of magnitude of the Stroop facilitation, interference or overall effect between Auditory Backgrounds ($F < 1$ for all). Although there were no significant interactions between either facilitation or interference and Study Preference ($F < 1$ for both), there was a significant interaction between overall Stroop effect and Study Preference, $F(2.897, 156.439) = 2.788$, $p < .05$. Pairwise comparisons revealed differences between music listeners and non-listeners on two of the four auditory backgrounds, the Frequency Varied Pattern, ($p < .05$), and the Segregated Streams Pattern, ($p < .05$). No significant differences were found between music listeners and non-listeners during exposure to the Temporally Varied Pattern or the Random Pattern. Mean RTs for the magnitude of the Stroop effect of both music listeners and non-listeners are displayed in Figure 3.

Figure 3. Mean RT Differences between Incongruent and Congruent Trials as a function of Acoustic Background and Study Preference in Experiment 2. Error bars represent standard errors.



Error rates. In terms of accuracy, no significant interactions were found between Stroop facilitation ($F < 1$), interference ($F < 1$), or overall effect ($F = 1.050$, $p = .359$) and Study Preference.

Discussion

As in Experiment 1, although I successfully replicated the Stroop effect in terms of both reaction time and accuracy differences between incongruent and congruent trials, no significant effect of acoustic background in the magnitude of the Stroop effect was observed. These results, then, provide no evidence to support theories that postulate substantial effects of background sound on visual selective attention (e.g., capacity-resource theory, Bargh, 1989; Kahneman, 1973; attention theory, Easterbrook, 1959; interaction of inhibition, Houston, 1969).

Intriguingly however, when individual differences in Study Preference were taken into account, a novel and exciting result emerged. Specifically, during exposure to the Frequency Varied Pattern and the Segregated Streams Pattern, participants who study regularly in the presence of background music showed significantly less of a Stroop effect than those who seldom study in the presence of background music. Analysis of the reaction time data revealed significant differences between the two groups in terms of magnitude of the overall Stroop effect during the Frequency Varied Pattern and the Segregated Streams Pattern but not during the Temporally Varied Pattern or the Random Pattern.

General Discussion

Prior studies that have investigated the effects of background auditory stimuli on cognitive performance have obtained seemingly equivocal results (e.g., Cassidy & Campbell, 2007; Chajut & Algom, 2003; Hartley & Adams, 1974; Houston & Jones, 1967; Houston, 1969; Jones & Broadbent, 1979; Ogden et al., 1979; Smith & Broadbent, 1980). The results of the current study corroborate neither evidence suggesting an overall improvement (Chajut & Algom, 2003; Houston & Jones, 1967; Houston, 1969) nor evidence suggesting an overall impairment in visual attentional selectivity in the presence of sound (Cassidy & Campbell, 2007; Hartley & Adams, 1974; Ogden et al., 1979). Although systematic differences in methodology and task specifications may contribute to the conflicting results of these studies, important confounding effects may arise through particular characteristics of study participants.

In the present experiments, a Stroop effect was observed regardless of auditory background. Regardless of whether silence, a simple pattern or more complex patterns differing in temporal and frequency characteristics were presented during the Stroop task, significant differences in reaction times were found between neutral, congruent and incongruent trial types. These results serve to illustrate the power of the Stroop effect to overcome the general effects of extraneous sound. The most intriguing findings of this study do not stem from general effects of any auditory sequence, but rather the interaction of particular patterns with an individual difference characteristic in the population sample.

Upon comparison of participants who routinely listen to music while studying and those who seldom, if ever, purposely study with music, music listeners showed decreases in the magnitude of the overall Stroop effect, measured as the difference between the times taken to respond to congruent and incongruent trials. Importantly, this pattern of results was not observed across all four of the auditory sequences. Only sequences that involved predictable, repetitive, changes in frequency were found to exert significant effects on Stroop performance. Thus, it appears as though both individual characteristics and structural components of auditory sequences may moderate the effect of background sound on Stroop performance.

The results of Experiment 2 support the notion that Study Preference may influence cognitive performance in the presence of sound; however, this conclusion must be qualified. The experiments were not designed to focus on any particular individual difference. Study Preference only became of interest after running exploratory analyses on the two groups. Not only were the music listeners and non-listeners not matched on potentially important demographic or personality characteristics, but the groups vastly differed in size. The non-listening group consisted of 44 members whereas the music listening group was comprised of only 12. Although Study Preference may contribute to the observed differences in the Stroop effect across auditory sequences, I cannot claim the existence of a strict causal relationship between Study Preference and the magnitude of the Stroop effect.

That said, evidence serves to suggest that Study Preference may influence cognitive performance in the presence of background auditory stimulation. Etaugh and Ptasnik (1982) found that individuals who seldom study with background music performed best on a reading comprehension task in silence. Conversely, those who regularly study in the presence of background music were found to perform best in the presence of music. Unfortunately, although Stroop performance was tested in silence in Experiment 1, I did not test the effects of silence on Stroop performance in Experiment 2. I therefore could not contrast the potential differences between music listeners and non-music listeners on Stroop performance in silence.

If individual characteristics of participants are responsible for pattern-specific differences in Stroop performance, not only must the importance of Study Preference be considered, but it may also be important to determine whether the likelihood of studying with music is itself related to any underlying personality constructs. With this in mind, I will briefly revisit the concept of arousal.

Sound has long been thought to have an arousing effect on individuals (Chajut & Algom, 2003; Fox & Embrey, 1972; Uhrbrock, 1961). However, as explained in the introduction, effects of increasing arousal levels on Stroop performance remain unclear. Whereas Kahneman (1973) and Bargh (1989) would predict an increased Stroop effect due to a focusing of attentional resources on the most accessible, automatic aspect of the task, Easterbrook (1959) would predict a decrease in the magnitude of the Stroop effect. My research does not provide direct empirical evidence to support either theory. Rather, I found that the influence of specific characteristics of auditory sequences depends on whether or not participants have experience with regularly studying in the presence of background music.

Individuals differ in both their baseline cortical arousal levels (Eysenck, 1967) and their tendencies to seek out stressful, arousing situations (Zuckerman et al., 1964). Furnham, Trew, and Sneade (1999) probed the relationship between the concurrent effects of music on cognitive performance and personality characteristics. Although their results were not statistically significant, a trend emerged revealing that reading performance of introverts was impaired by presentation of background music. In contrast, music enhanced the performance of extraverts on the same task. The authors posited that music increased arousal levels of all participants, but exerted contrasting effects on extraverts and introverts. Arousal levels of extraverts were pushed closer to optimal levels, whereas arousal levels of introverts were pushed to exceed optimal levels (Eysenck, 1967).

Furnham and colleagues' (1999) results are supported by a recent study that found that, in comparison to extraverts, introverts perform significantly worse on the Stroop

Neuropsychological Screening Test (Golden & Freshwater, 1994) in the presence of high arousal-negative affect music and everyday noise (Cassidy & MacDonald, 2007). Additionally, Furnham and Allass (1999) found an inverse relationship between music complexity and cognitive performance of introverts and extraverts. For introverts, performance on recall and observation tasks worsened as a function of increasing musical complexity. In contrast, cognitive performance of extraverts was enhanced as complexity increased. With this in mind, do extraverts and introverts differ in terms of music listening habits?

Extraverts tend to prefer to work and study in more social and arousing conditions whereas introverts prefer more secluded areas, away from external distraction (Campbell & Hawley, 1982). In accordance, studies have found that extraverts perform better on recall tasks in the presence of distractions in comparison to introverts (Daoussis & McKelvie, 1986; Morgenstern, Hodgson, & Law, 1974). Not surprisingly, the literature suggests that extraverted participants are more likely to purposely involve background music while studying than introverts (Daoussis & McKelvie, 1986; Furnham & Bradley, 1997).

The results of Experiment 2 indicate that Study Preference interacts uniquely with different auditory sequences to influence Stroop task performance. Distinct structural components of the sound sequences appear to modify the relationship between music listening and Stroop performance. In comparison to non-listeners, music listeners showed a diminished magnitude of the overall Stroop effect during the Frequency Varied Pattern and the Segregated Streams Pattern, but not during the Temporally Varied Pattern and the Random Pattern. Unlike the Temporally Varied Pattern, both the Frequency Varied

Pattern and the Segregated Streams Pattern constitute auditory sequences that vary in frequency from one tone burst to the next. Yet, the Random Pattern also incorporated changes in tone frequency. The distinction may lie in the fact that frequency change in the Random Pattern was random in nature, with the pattern of frequency alternation between the two tones being unpredictable. In contrast, the Frequency Varied Pattern and the Segregated Streams Pattern involved predictable, repetitive, frequency changes. As music generally involves repetitive and predictable chord progressions and vocal melodies (Harwood, 1976; Snyder, 2000), it is not entirely surprising that participants who routinely listen to music while studying performed better than those who do not on the Stroop task during exposure to the Frequency Varied Pattern and the Segregated Streams Pattern.

Although Experiment 2 revealed some intriguing results, it was not without limitations. The Segregated Streams Pattern consisted of auditory bursts differing by 10 semitones; however, it is possible that, for one reason or another, the intended segregation of perceptual streams did not occur. Subsequent studies should perhaps make the two streams more distinct by perhaps increasing inter-tonal frequency difference or decreasing the ISI. Furthermore, in order to investigate the possibility that a Random Pattern with increased variation could induce a significant effect on Stroop performance, future studies should increase the number different tones and note and silence durations. Finally, personality characteristics such as introversion and extraversion should assessed directly by employing a scale such as the Neuroticism-Extraversion-Openness Five Factor Inventory (Costa & McCrae, 1992) in follow-up studies in order to identify the contribution of personality traits on cognitive performance in the presence of background sound.

Overall, our conclusions indicate that individual differences may interact with background sound to influence cognitive task performance. Particularly, Study Preference appears to contribute to pattern-specific differences in magnitude of the overall Stroop effect. However, one must be cautious in interpreting these results. Personality characteristics such as extraversion and introversion may underlie music listening tendencies, yet were not measured in the current study. Intricate interactions may exist between individual differences, the nature of the auditory stimulus, and cognitive tasks (Cassidy & MacDonald, 2007). Therefore, multiple factors must be considered when interpreting findings from studies of background sound and cognitive task performance.

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