Oglethorpe Journal of Undergraduate Research

Volume 7 | Issue 1 Article 3

2017

Selective Tactile Attention Under Auditory Perceptual Load

Stephanie C. Bowar
Oglethorpe University, stephanie.clare94@gmail.com

Recommended Citation
Bowar, Stephanie C. (2017) "Selective Tactile Attention Under Auditory Perceptual Load," *Oglethorpe Journal of Undergraduate Research*: Vol. 7 : Iss. 1 , Article 3.
Available at: https://digitalcommons.kennesaw.edu/ojur/vol7/iss1/3

Overlapping sensory stimuli are a constant in everyday life and can at times be overwhelming. As a result, it is necessary to pay attention to certain relevant stimuli while ignoring others. In order to focus on a particular stimulus, it must be detectable through the ‘noise’ of irrelevant stimuli. The detection of these stimuli has historically been the focus of signal detection theory research (e.g. Perez, Donoso, & Medina, 2010; Moray & O’Brien, 1967). Signal detection theory aims to provide insight regarding when a stimulus will be salient enough to detect, and when that salience becomes low enough that the stimulus is lost in the noise.

While signal detection theory focuses on the basic detection of stimuli, the actual selection of a stimulus to the exclusion of others is called selective attention. Selective attention can be defined as the mind’s ability to focus selectively on one stimulus to the exclusion of simultaneous, irrelevant stimuli (Reisberg, 2013). Research into this selection process has been ongoing for many years, resulting in several debates. One of these is the debate as to whether attentional resources are separate for each sensory modality, or whether all attention is drawn from the same central source. Daniel Kahneman (1973) suggested the latter, proposing a supramodal view of attention. In other words, Kahneman theorized that all attentional resources are drawn from one limited-capacity pool shared by all modalities. Therefore, selective attention is a matter of resource allocation to tasks. Multiple tasks can be performed at once as long as the attention required does not exceed overall attentional capacities; otherwise, task performance suffers.

A competing view was proposed by Christopher Wickens (1980), who suggested a modality-specific model of attention. This model assumes that attentional resources are entirely separate for each modality. If attentional resources across modalities are entirely separate from one another, then taxing attention in one modality should not have any bearing on attention in another modality. In other words, load in one modality, such as vision, cannot modulate attention in a different modality, such as audition. Load in one modality may modulate attention within that modality; for instance, a demanding visual task may affect attention towards other visual cues. However, no cross-modal effects should be seen.

Kahneman’s supramodal view of attention later gave rise to the Perceptual Load Theory of Attention (Lavie, 1995). Perceptual load theory is an elaboration on Kahneman’s theory, rather than an entirely separate theory, and has a more specific hypothesis than Kahneman’s original theory. While Kahneman’s theory discusses resource allocation, it does not necessarily discuss stimulus selection and the ramifications of selection. Perceptual load theory discusses selection explicitly, and states that the extent to which irrelevant stimuli (distractors) are processed depends on the attentional demand (perceptual load) of the relevant (attentionally selected) task. When perceptual load is low, enough attentional resources remain to process concurrent distractors. Therefore, low perceptual load allows for greater distraction away from the target stimulus or task. However, when perceptual load is high, most or all attentional capacity is consumed, and distractor processing decreases or is eliminated entirely. High perceptual load allows for little to no distraction from the target stimulus or task. Within the context of perceptual load theory, Kahneman's theory also implies that perceptual load theory applies cross-modally, meaning load in one sensory modality can affect attention in a separate modality. If attentional resources are central, taxing attention in any modality will leave fewer attentional resources available to process other stimuli, regardless of sensory modality. Therefore, high perceptual load in one modality can result in decreased distractor processing in a different modality.

The literature body surrounding perceptual load theory is complicated by a number of other ongoing debates. In perceptual load theory research, some researchers (e.g. Lavie, 2005; Dittrich & Stahl, 2012; Vermeulen, Corneille, & Niedenthal, 2008) have made a distinction between 'cognitive' or 'working memory' load and 'perceptual' load, claiming that while high perceptual load decreases distractor interference, high cognitive or working memory load increases distractor interference. Other researchers, however, have treated perceptual load and working memory load identically. The latter researchers have used a working memory task as a perceptual load manipulation, and have still found results consistent with perceptual load theory (Klemen, Büchel, & Rose, 2009; SanMiguel, Corral, & Escera, 2008). This debate, as well as general discrepancy in operational definitions among perceptual load theory researchers, makes the literature body on perceptual load theory complicated. Furthermore, studies which have attempted to distinguish between 'cognitive' and 'perceptual' load may need to be interpreted with caution when discussing the literature body surrounding perceptual load theory, due to these inconsistencies in findings. Because of this debate in the literature, the current study avoided any operationalizations of perceptual load that have, in the past, been considered 'cognitive' or 'working memory' load.

Aside from these difficulties, literature on auditory attention in particular has been complicated by the integration of verbal cues as a manipulation of perceptual load in some studies (e.g. Gherri & Eimer, 2011; Francis, 2010). These cues invoke a linguistic system that relies on different underlying mechanisms rather than the simple perception of tones or animal sounds, making these operational definitions incomparable to similar studies in vision. Therefore, it becomes impossible to draw conclusive results from these studies about how perceptual load theory does or does not apply to the auditory modality. Due to this, results from studies using verbal auditory perceptual load may not accurately depict how perceptual load theory may behave in the auditory modality. For this reason, the current study focused on nonverbal auditory perceptual load.

In light of the many complications that surround the literature on perceptual load theory, the current study narrowed its focus to the debate regarding common vs. modality-specific attentional resources, particularly in the auditory modality. While perceptual load theory has received much empirical support, most of this research has been within visual paradigms (e.g. Cartwright-Finch & Lavie, 2007; Simons & Chabris, 1999; Lavie, 2010). However, there has also been research into whether perceptual load theory applies to the auditory modality, with conflicting results across various studies.

Some studies have supported perceptual load theory's application to the auditory modality. One such study (Fairnie, Moore, & Remington, 2016) focused on perceptual load theory in a strictly auditory paradigm, examining the effects of auditory load on the perception of auditory distractors. Fairnie et al. designed an auditory search task intended to be an auditory equivalent to a visual search task previously used by Macdonald and Lavie (2008). In this auditory task, 20 participants (12 male, ages 17-34), were presented with various animal sounds, and perceptual load was manipulated based on the number of different animal sounds present (one, two, four, or six), with greater numbers being higher perceptual load. Participants were then tasked with pressing a key to identify each time they heard either a dog's bark or a lion's roar. During this task, the sound of a car driving past was presented on 50% of trials in addition to the animal sounds. Following their detection response for the main task, participants were asked to identify whether the car sound was present. They were instructed to do this as quickly as they could, using a key press. Fairnie et al. found that under conditions of high auditory perceptual load, detection of a secondary auditory stimulus was reduced. Since this study used a within-modality paradigm, it does not carry any implications regarding common vs. modality-specific attentional resources. However, it demonstrates the application of perceptual load theory in a purely auditory paradigm.

Unlike Fairnie et al. (2016), much of the research into perceptual load theory in the auditory modality has examined the cross-modal effect of visual perceptual load on the perception of auditory distractors. For example, Macdonald and Lavie (2011) conducted two similar experiments to examine whether an auditory equivalent to inattentional blindness could be achieved through visual perceptual load—namely, "inattentional deafness." Where inattentional blindness is the failure to notice visual stimuli due to concurrent perceptual load, "inattentional deafness" is the auditory equivalent: a failure to notice auditory stimuli due to concurrent perceptual load. Fifty-six participants (thirty-one male, mean age 22) were given either a complex (high load) visual task, involving subtle line length discrimination, or a simple (low load) visual task, involving basic color discrimination, to repeat over a number of trials. Participants were presented with crosses made up of two lines. One line was always blue and one always green, and one line was always slightly longer than the other. Each line was equally likely to be blue or green, as well as long or short. During each trial, white noise was played as they completed the task. However, in select trials, a pure tone was played in place of the white noise as the participant completed the task. In conditions of high visual perceptual load, participants failed to notice the shift in auditory cue. In contrast, participants noticed it a majority of the time under conditions of low visual perceptual load. This cross-modal effect of visual perceptual load on auditory processing suggests the successful application of perceptual load theory to the auditory modality. These results also support Kahneman's supramodal theory of attention. If attentional load in the visual modality can affect attention in the auditory modality, it suggests that attention in the visual modality is consuming a large amount of central attentional resources. This leaves fewer resources available to process irrelevant auditory distractors, explaining the decrease in auditory distractor processing under high perceptual load.

Inattentional deafness induced by visual load has also been demonstrated by other studies. For example, Raveh and Lavie (2014) varied the perceptual load of a visual search task while measuring 18 participants' (ten women, mean age 25.9 years) detection of an auditory tone presented amidst white noise. Similarity of the target and nontarget letters in the search task was used as a manipulation of perceptual load. Under high perceptual load, target and nontarget letters were similar, resulting in a more difficult task. Under low perceptual load, nontarget letters were small Os, resulting in an easier task. Across four variations of this experiment, they varied the point at which participants reported on the auditory stimulus (either after reporting on the search task, or immediately upon presentation), whether or not they expected it, and whether the auditory cue was presented amidst noise or on its own. Overall, participants were less likely to detect the auditory stimulus in high perceptual load conditions than in low perceptual visual load conditions. These results imply support for both Kahneman and perceptual load theory, indicating that attention in the auditory modality can be cross-modally affected by perceptual load in the visual modality.

Similar results were found by Molloy, Griffiths, Chait, and Lavie (2015), who examined the effect of visual perceptual load on both the detection of, and neural response to, auditory distractors. Fourteen participants (four female, mean age 28.7 years) performed multiple trials of a visual search task and were asked afterwards whether or not they detected a pure auditory tone played during the trial. The perceptual load manipulation was a replication of Raveh and Lavie's (2014) perceptual load manipulation, in which the similarity of the target and nontarget letters in the visual search task was varied. Similar target and nontarget letters constituted the high perceptual load condition, while in the low perceptual load condition, nontarget letters were small Os. During the visual search task, neural reactions in specific areas of the brain to auditory tones were measured throughout trials using magnetoencephalography, a functional neuroimaging technique. Both participants' detection accuracy and neural reactions decreased as perceptual load increased. This indicates that participants were overall less aware of and responsive to irrelevant auditory stimuli under high visual perceptual load. These results again support Kahneman's supramodal view of attention, suggesting that perceptual load theory can apply in a cross-modal context. They also further support perceptual load theory's application to the auditory modality.

This effect of visual load on neural responses to auditory distractors was also found by Parks, Hilimire, and Corballis (2009). With 17 participants (eight women, mean age 19.9 years), Parks et al. used a visual search task of either high or low perceptual load and measured its effect on the postauricular reflex. The postauricular reflex (PAR) is a contraction of the postauricular muscle, located near the ear, which reacts to auditory stimuli. Under low perceptual load, participants were instructed to identify the target based on a single feature (color). Under high load, participants identified the target based on the conjunction of two features: color and spatial orientation. The auditory cues presented took the form of bursts of white noise presented during the visual discrimination task. Participants' PAR response was decreased under conditions of higher visual perceptual load. According to Parks et al. and their use of the PAR as a measurement of attention to auditory stimuli, decreased PAR response indicates decreased attention to these auditory stimuli. Decreased attention to these stimuli suggests that irrelevant auditory stimuli were processed less under high visual perceptual load. This supports Kahneman's view of attention, which would predict that due to the high attentional demand of the visual task, processing of auditory cues suffered. This also suggests that perceptual load theory, which predicts decreased awareness of irrelevant cues under high load, applies cross-modally in addition to the auditory modality.

In addition to demonstrating perceptual load theory's application to audition, these studies provide support for Kahneman's supramodal view of attentional resources. Visual perceptual load seems to modulate auditory selective attention, which implies shared audiovisual resources, in line with Kahneman's theory of a central attentional pool.

Further support for cross-modal effects was provided by Murphy and Dalton (2016), whose research implies shared visuotactile attentional resources. This study used a visual search task of either low or high perceptual load and measured its effect on the perception of vibrotactile distractors in 16 participants (3 male, mean age 21 years). Similar to past research, the visual search task involved identifying target letters (X or N) among distractor letters. In the low perceptual load condition, distractor letters were small Os, while in the high perceptual load condition, distractor letters looked similar to the target letters (H, K, M, V, W, or Z). A single vibration was administered on 50% of trials to either the left or right palm. Vibrations were administered by securing hearing aids against participants' palms with surgical tape and playing audio through the hearing aids. Immediately after the search task response on each trial, participants were asked to report the presence or absence of tactile stimuli during that trial by lifting a foot pedal. Analysis revealed that both tactile detection sensitivity (Cohen's d) and tactile detection accuracy were reduced under conditions of high visual perceptual load. This both suggests the existence of shared visuotactile attention and introduces a paradigm of "inattentional numbness" to the literature on perceptual load theory.

As discussed in the above literature, perceptual load theory and its application to the auditory modality has received support from both behavioral and neurophysiological perspectives, as has Kahneman's supramodal view of attention. However, some research has failed to find effects of perceptual load in the auditory modality.

One study (Murphy, Fraenkel, & Dalton, 2013) tested the effect of auditory load on the perception of auditory distractors. Murphy et al. administered auditory tasks of either low or high perceptual load. Participants were to respond to auditory targets presented in the attended ear while ignoring white noise in the unattended ear. Participants' response was based either on a single feature of the auditory stimulus (low load) or on a conjunction of features (high load). On certain trials, the distractor word "cat" was presented amidst the white noise in the unattended ear, and participants were asked whether or not they heard anything other than the target stimulus and the white noise. Perception of the distractor word was measured based on reaction time to give this response. Participants had an equal reaction time (36 ms or 35 ms) to the distractor word under high or low perceptual load. This implies an inability to apply perceptual load theory to the auditory modality. This is especially puzzling considering Raveh and Lavie's 2014 findings, where the detection of an auditory cue amidst white noise decreased under high perceptual load. However, Murphy et al.'s failure to find the expected results may be due to the use of a verbal cue, rather than a tonal cue, as Raveh and Lavie used. As previously discussed, the use of verbal cues in perceptual load theory research can complicate results, due to verbal cues engaging different cognitive mechanisms than nonverbal cues.

Gomes, Barrett, Duff, Barnhardt, and Ritter (2008) also failed to find expected results. Gomes et al. again tested the effects of auditory load on the detection of auditory distractors. They presented auditory stimuli through two channels, instructing 12 participants (seven female, ages 20-44) to attend to one channel and ignore the other. Through the attended channel, auditory tones were presented to participants quickly (high load) or slowly (low load). Participants were instructed to press a button to identify target tones based on the volume of the tone. Through the unattended channel, similar but irrelevant distractor tones were presented. Gomes et al. measured event-related potentials in response to auditory cues using an electroencephalogram. Participants displayed similar processing of the distractor tones under both low and high perceptual load, further suggesting that perceptual load theory does not apply to the auditory modality. It is possible that due to the similar nature of the attended and unattended tones, this lack of effect may have been due to habituation to the irrelevant channel. If participants habituated to the tones in the unattended channel, their processing of those tones would be unaffected by perceptual load.

In addition to studies that have failed to find auditory effects of perceptual load theory, some studies have failed to find cross-modal effects of perceptual load theory. This may imply support for Wickens' model of attention (1980) rather than Kahneman's. If perceptual load theory does not apply cross-modally, it suggests that attentional resources may be separate for each modality, as Wickens suggested. Therefore, load in one modality would not affect attention in another.

For example, Parks, Hilimire, and Corballis (2011) examined the effects of visual target load on the detection of both irrelevant auditory and visual distractors. Twenty participants (four women, mean age 19.5) in this study engaged in a rapid serial visual presentation (RSVP) task. Participants were instructed to identify targets based only on color (low perceptual load) or based on a combination of color and orientation (high perceptual load). Orientation was defined by whether visual stimuli (crosses) were upside-down. Electroencephalogram (EEG) was recorded as participants completed the task to measure steady-state evoked potentials (SSEPs). SSEPs are evidenced by activity in certain areas of the brain as a reaction to stimulation. Participants were simultaneously presented with irrelevant auditory tonal cues, irrelevant visual cues, or simultaneous, irrelevant auditory and visual cues. Analysis of EEG data revealed that based on brain activity, interference from visual distractors decreased under conditions of high visual perceptual load. However, no effects of visual load on auditory distractors were found. Brain activation did not change in response to auditory distractors under conditions of low vs. high perceptual load. These results stand in contrast to other studies that found that perceptual load theory applies as expected to the auditory modality. Additionally, the observation of within-modal effects in vision, but lack of cross-modal effects between vision and audition, suggests that attentional resources are modality-specific, as Wickens hypothesized. If increased visual load inhibits the processing of visual distractors, but does not inhibit the processing of auditory distractors, this implies that vision and audition have separate attentional resources that do not affect one another. However, none of the studies that did find the expected effects of perceptual load theory measured SSEPs, and it is possible that an indirect measurement of this type of brain activation is not an effective measurement of auditory distractor interference.

Similarly, Sandhu and Dyson (2016) also failed to find cross-modal effects of perceptual load. This study measured the effect of high or low auditory load on the perception of visual distractors, as well as the effect of high or low visual load on the perception of auditory distractors. Forty-eight participants (43 female, ages 17-28) were cued by an easy visual or auditory discrimination task (low load) or a difficult visual or auditory discrimination task (high load). Based on the cue, participants were required to either give a judgment response or give a null response to visual or auditory distractors. When auditory load was used, the perceptual load was manipulated based on the ease or difficulty of detecting a "warble" (a frequency modulation during a concurrent sound), which, when presented, was either loud and easy to detect (low load) or quiet and difficult to detect (high load). When visual load was used, the perceptual load was manipulated based on the ease or difficulty of deciphering whether an image contained an ellipse. When presented, the ellipse was either obviously an ellipse (low load) or easily mistaken for a circle (high load). The judgment response, which involved only distractor stimuli, was based on the congruency between concurrent auditory and visual stimuli (distractors). Sandhu and Dyson failed to find a cross-modal effect of either auditory or visual load on the processing of visual or auditory distractors, respectively. This once again supports Wickens hypothesis about modality-specific resources, while also demonstrating the failure of perceptual load theory to apply to the auditory modality. If visual load does not modulate the perception of auditory distractors, and auditory load does not modulate the perception of visual distractors, this implies that audition and vision use separate attentional resources that do not affect one another.

However, Sandhu and Dyson's methodology was novel both in terms of task and measurement methods. Because their operationalizations were novel, rather than previously established, it may be that they were not taxing attention in a valid way. Furthermore, the tasks performed in Sandhu and Dyson's study were such that perceptual load and distractors were presented sequentially, rather than simultaneously. Visual or auditory load was presented immediately before visual or auditory distractors were presented. This could easily have decreased, or even eliminated, any effect that perceptual load may have had on distractor processing. Perceptual load theory specifically addresses instances where stimuli are presented simultaneously. Within that context, stimulus selection occurs as a result of an inability to process all concurrent stimuli, and some stimuli are ignored. Because Sandhu and Dyson presented distractor stimuli following the presentation of visual or auditory load, rather than concurrently, any effects of stimulus selection would have been decreased or eliminated entirely.

It has been established in the literature that non-auditory load can modulate audition according to perceptual load theory (Macdonald & Lavie, 2011; Raveh & Lavie, 2014; Molloy et al., 2015; Parks et al., 2009), although some researchers have failed to find this effect (Parks et al., 2011; Sandhu & Dyson, 2016). It has also been found that perceptual load theory can apply to the auditory modality when audition is used as the load manipulation (Fairnie et al., 2016), and that the perception of tactile distractors can be affected by perceptual load (Murphy & Dalton, 2016). Furthermore, there is ongoing debate about whether attentional resources are drawn from a central pool (Kahneman, 1973) and perceptual load theory predict, or whether resources are modality-specific (Wickens, 1980). If resources are modality-specific, cross-modal effects of perceptual load theory should not be found. However, if attentional resources are supramodal, perceptual load theory should produce cross-modal effects.

Although much more extensive research will be required to entirely resolve the debate regarding common vs. modality-specific attentional resources, important insight can be provided into this debate with a novel cross-modal examination. The incorporation of audition into this examination can also provide new insight into the conflicting literature regarding perceptual load theory's application to the auditory modality in general. Because audition is more commonly used as a distractor in the literature, rather than as the load manipulation, the use of auditory load may be useful in providing new information. Cross-modal audiotactile effects also have yet to be explored. If auditory load were found to affect tactile attention, this would further support Kahneman's theory by demonstrating shared audiotactile attentional resources.

The current study aimed to examine the effect of auditory perceptual load on perception of tactile distractors. Using an adaption of Fairnie et al. (2016), auditory perceptual load was manipulated by presenting an auditory search task to participants over multiple trials. Concurrently, vibrotactile stimulation was presented to participants on 50% of trials, who were then asked to identify the presence or absence of the vibration following each trial.

It was hypothesized, according to Kahneman (1973) and perceptual load theory, that perception of tactile distractors would decrease as auditory perceptual load increased. Increased auditory perceptual load would result in a drain on central attentional resources, leaving fewer resources available to process tactile stimuli. Decreased distractor processing under high perceptual load, as compared to low perceptual load, would reinforce perceptual load theory's application to the auditory modality. It would also provide support for Kahneman's theory of supramodal attentional resources: as the attentional demand for the auditory task grows, fewer resources are available to process tactile distractors.

Methods

Participants

Eighty total participants were included in the analysis. Of these participants, 58 were female and 22 were male. The mean participant age was 20.46 with a standard deviation of 4.38. Among these participants, 10% identified as Hispanic or Latino; 7.5% identified as Asian or Pacific Islander; 47.5% identified as Caucasian; 31.3% identified as Black or African American; and 3.8% identified as mixed or biracial. In analyses involving the audiotactile task, five of the total 80 participants were eliminated due to failure to perceive the tactile stimulus; therefore, only 75 participants were included in analyses related to the audiotactile measure.

Participants were a convenience sample recruited from a university student population. All participants were right-hand dominant and had self-reported normal or corrected-to-normal hearing. Each participant was run individually in a quiet room. As compensation for their participation, participants were allowed to choose between $10 or two points of extra credit towards all current Psychology classes in which they were enrolled at the university.

Design

The current study used a one-way repeated measures design with three levels. The independent variable was perceptual load level, with levels being no perceptual load, low perceptual load, and high perceptual load. The first level (no perceptual load) served as a control condition, during which participants received no auditory stimulation. In the low and high load conditions, auditory load was manipulated through an auditory search task, adapted from Fairnie et al. (2016). The dependent variable was the number of trials on which participants failed to detect a vibrotactile stimulus presented during the auditory task.

Materials

Two consent forms were administered to each participant. Participants were also asked to fill out a demographics form asking them to report their gender, age, year in school, and ethnicity, as well as which hand they write with.

The auditory search task took the form of ten-second audio clips, during which various animal sounds were presented simultaneously. One animal sound was the target sound of the search task, while the other animal sounds were nontarget sounds. The target sound was a dog’s bark. This followed Fairnie et al., who also used a dog’s bark as a target sound. Nontarget animal sounds included those of a pig, a sea lion, a dolphin, an elephant, and a jaguar. Animal recordings were obtained from www.freesoundeffects.com. The clips used included “dogbark2”, “pigfarm”, “sealion2”, “dolphin1”, “elephant9”, and “jag”. To administer the auditory task, ten-second clips were arranged on REAPER Digital Audio Workstation v5.21 and were played from a Dell Inspiron 14 5000 series laptop using iTunes. Audio was played through Audio-Technica

QuietPoint ATH-ANC7b Active Noise-Cancelling Headphones. Based on Fairnie et al. (2016), all sounds were played at an average volume of 80 decibals.

In the low auditory load condition, the search task included a set size of two animal sounds: the target sound (dog's bark) and one nontarget sound (jaguar). The jaguar sound was ongoing throughout the ten seconds of the clip. The target sound was presented only once during each clip, lasted for one second, and included three dog barks. The target sound occurred at either the three-second, six-second, or nine-second mark, and the point at which it occurred was randomized across trials. This was an attempt to circumvent any expectation of, or habituation to, the stimulus.

In the high auditory load condition, the search task included a set size of all six animal sounds: the target sound (dog's bark) and five nontarget sounds (pig, sea lion, dolphin, elephant, jaguar). Nontarget sounds were ongoing and overlapping throughout the ten seconds of the clip. Nontarget animal sounds were presented in three different possible arrangements of the sounds to avoid habituation to the auditory stimulus. Habituation to auditory stimuli was a risk demonstrated by Bell, Röer, Dentale, and Buchner (2012). The target sound, again, was presented only once, randomized across trials, and was the same target sound as in the low auditory load condition. For both low and high conditions, participants were instructed to press a key on a dummy keyboard with their right hand each time the target sound was detected during the search task.

On 50% of all trials in the auditory task, a vibrotactile stimulus was administered against the palm of the participant's left hand during the trial. Presentation on 50% of trials, rather than 100%, was intended to avoid any potential habituation to the vibration. Trials during which the vibration was present were positive trials, while trials without a vibration present were negative trials. Participants were instructed to raise their left hand immediately each time a vibration was detected. The vibration was administered at either the two-second, five-second, or seven-second mark of each positive trial, randomized across all positive trials. This was a further attempt to avoid expectation of the vibration. These presentation times were also offset from the presentation times of the dog's bark, in an effort to eliminate error due to participants having to respond simultaneously to multiple cues.

Additionally, participants were blindfolded with a sleeping mask for all trials, as the sight of the part of the body receiving stimulation can result in exaggerated perception of the stimulation (Wesslein, Spence, & Frings, 2015). Vibratory stimuli were administered by the experimenter with a TheraTapper machine. The experimenter used a switch to administer each vibration at the correct time. Vibrations were delivered through a handheld pulser attached to the machine, which was secured against the palm of participants' left hand using surgical tape, following Murphy and Dalton (2016).

Several measures were included in the study to potentially control for possible contributing factors that may have affected performance in the audiotactile task. These measures examined both personality and cognitive ability.

Big Five Inventory (BFI; John, Donahue, & Kentle, 1991). The BFI measures personality of individuals according to five traits: extraversion, agreeableness, conscientiousness, neuroticism, and openness. Reliability for these subcategories ranges from α = .73 to α = .80, with a mean of α = .78. The overall mean reliability of the scale was found to be α = .82 (Benet-Martínez & John, 1998). The BFI has a test-retest reliability of α = .80 (Gosling, Rentfrow, & Swann, 2003).

Wechsler Adult Intelligence Scale – Revised (WAIS-R; Wechsler, 2008). From the WAIS-R, the Digit Span Task (DST) subtest was used to measure working memory. The DST required participants to listen to lists of numbers, with each subsequent list including one more number than the previous list did. When prompted, participants were to repeat the numbers back to the experimenter, either in the same order as presented or in reverse order. They were given a numerical score based on their performance. The WAIS-R manual reports test-retest reliability for the DST ranging from α = .70 to α = .89.

Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). The Block Design Task, a subtest of the WASI, was used to measure general cognitive ability. This task involved the presentation of various block patterns to participants, who were then asked to use their own blocks to create the same pattern. They were subsequently scored on the correctness of their designs and the time taken to complete them. The Block Design Task has an internal consistency between .92 and .94 for the primary age group included in analysis, with a test-retest reliability of .92, as reported by the WASI manual.

Perceived Multitasking Ability (Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013). This three-item questionnaire asked participants to rank their multitasking abilities relative to both other college students and other adults in general (see Appendix A). Finally, following the administration of the above tasks, a demographics form was administered to each participant, asking them to report their sex, age, year in school, ethnicity, and which hand they write with (see Appendix B).

Procedure

After obtaining consent, consent forms were separated from other participant information, and participant demographics and data were de-identified using identification numbers. Participants were asked to orally confirm that their right hand is their dominant hand. Participants were then given a blindfold to wear and a TheraTapper pulser was secured to their left palm. They were then informed that they would undergo 60 ten-second trials with five-second pauses between each trial. On some trials, they would hear an assortment of animal sounds. They were instructed that anytime they heard the bark of a dog among these animal sounds, they were to press the space bar on the keyboard in front of them with their right hand. Participants were also advised that because not all trials would include any animal sounds, they should expect some periods of silence during their session, but this did not indicate the end of the session. Participants were further informed that during each trial, they may or may not feel a vibration against their left hand. Anytime they felt a vibration, they were to briefly raise their left hand to indicate that they felt it. It was emphasized that identification of the dog's bark was their primary task.

Each participant underwent 20 trials per condition (control, low load, high load), equaling 60 total conditions. Vibrations were presented on an average of ten trials per condition, always equaling 30 total positive trials and 30 total negative trials. Participants' responses to the vibrations were recorded over all 60 trials, including correct hits (vibration detected on positive trial), misses (vibration not detected on positive trial), and false alarms (vibration incorrectly detected on negative trial).

Following the completion of all 60 trials, participants completed the WASI Block Design Task, followed by the WAIS-R Digit Span Task. Next, participants filled out a Multitasking Questionnaire and a 44-item BFI. Finally, each participant completed a demographics form.

Each session lasted between 30 and 45 minutes. As compensation for participation, participants received either $10 or two points of extra credit towards any currently enrolled Psychology classes at Oglethorpe University.

Results

Descriptive statistics were run on all measures to test for outliers (see Table 1). No outliers were identified (see Table 2, Table 3). For all analyses, two items from the multitasking ability measure (*Rank your multitasking ability relative to that of other college students on a scale of 0 – 100*; *Rank your multitasking ability relative to that of other adults in general on a scale of 0 – 100*) were combined into a composite score representing general perceived multitasking ability. The inventory's third item was not included in this composite score, as it used a different scale than the previous two items. For the sake of parsimony, the inventory's third item (*How much difficulty do you have performing multiple tasks simultaneously relative to other college students?*) was eliminated from analyses due to redundancy. Additionally, reliability information for the BFI administered is reported in Table 2.

Pearson Correlations

Pearson correlations were conducted and are reported in Table 2. Agreeableness on the BFI was significantly negatively correlated with false positives under low load conditions. This indicated that more agreeable individuals were less likely to incorrectly detect vibrations under low conditions than less agreeable individuals. Additional significant correlations were found regarding false positives in the vibration detection task. False positives under the control condition were significantly correlated with false positives under both the low and high auditory load conditions. This indicates an increased likelihood that individuals who incorrectly detect vibrations under control conditions will also incorrectly detect vibrations under both low and high auditory load.

Missed tactile stimuli under low auditory load were significantly positively correlated with missed tactile stimuli under high auditory load, indicating that as individuals failed to detect vibrations under low auditory load, they were also less likely to detect them under high auditory load. Similar significant correlations were found regarding the control condition; as individuals were less likely to detect vibrations in the control condition, they were also less likely to detect them under low and high auditory stimulation.

Furthermore, performance in both the Block Design Task and Digit Span Test significantly negatively correlated with both misses under low load and misses under high load. This indicated that individuals who tended to do well in the Block Design Task and Digit Span Test were less likely to miss vibrations under both low and high auditory load. Block Design performance was also positively correlated with Digit Span Test performance, indicating that individuals who performed well on one were likely to perform well on the other.

Analyses of Covariance

To investigate the impact of auditory perceptual load on perception of tactile stimuli, correlations were examined for potential relationships between variables, specifically regarding dependent variables. Block Design Task and Digit Span Test scores were each significantly negatively correlated with misses. Additionally, perceived multitasking ability was significantly negatively correlated with false positives under low load, as was agreeableness in the BFI. Variables that correlated significantly with dependent variables were then tested as significant covariates. Multiple models were tested, and non-significant covariates were consequently dropped, following procedures outlined by Tabachnick & Fidell (2001). The elimination of non-significant covariates did not change the overall patterns of significance. They were therefore eliminated for the sake of parsimony, and the final analyses are included below. These analyses included Block Design Task as a covariate, as it was the only significant covariate identified.

Three one-way repeated measures ANCOVAs were conducted. The independent variable in these analyses was auditory load, which consisted of three levels: no load (control), low load, and high load. The first dependent variable analyzed was the number of missed tactile stimuli under each condition. Block Design Task scores were included as a covariate, as Block Design Task scores were found to be a significant covariate of missed vibrations. There was a significant main effect of auditory load on perception of tactile stimuli, $F(2,146) = 7.36$, $p = .001$, $p\eta^2 = .09$. Tukey post-hoc tests revealed that while misses between low and high auditory load conditions were not significantly different ($p > .05$), people were significantly ($p < .05$) more likely to miss tactile stimuli in the low or high auditory load conditions than in the control condition (see Figure 1).

In order to further examine the data, a similar ANCOVA was conducted to investigate differences in false positives across conditions, with the same independent variable and covariate as the previous ANCOVA. In this analysis, false positives, or the incorrect detection of tactile stimuli when no such stimuli were presented, were analyzed as the dependent variable. However, these differences between conditions were not significant, $F(2,146) = .73$, $p = .48$, $p\eta^2 = .01$.

Finally, a repeated measures ANCOVA was run to analyze the differences across conditions in the number of total correct hits, with penalties incurred for false positives during trials. The number of false positives given by participants under each condition were subtracted from the number of total correct hits in respective conditions, and the resulting differences between conditions were examined. Block Design was again considered as a covariate. These differences between conditions were also not significant, $F(1,73) = 3.55$, $p = .06$, $p\eta^2 = .05$.

Discussion

The current study hypothesized that, under conditions of increasing auditory perceptual load, individuals would be progressively more likely to miss tactile stimuli in the form of vibrations administered against their palm. The above analyses reveal partial support for this hypothesis. In line with predictions, participants were more likely to miss tactile stimuli under both low and high auditory perceptual load than they were in the control condition. However, it was also predicted that participants would be significantly more likely to miss these vibrations under high load than low load. This effect was not found, as participants missed vibrations similarly under both low and high auditory perceptual load.

Partial support for the current study's hypothesis is consistent with Kahneman's (1973) theory of a common pool of attentional resources. This study suggests that perceptual load in one modality, namely the auditory modality, can affect attention in another modality, namely the tactile modality. Per Kahneman's theory, taxing attention in one modality leaves fewer attentional resources available to process other stimuli, regardless of modality. Therefore, a decrease in perception of vibrotactile stimuli under auditory load suggests common attentional resources for all sensory modalities.

This is inconsistent with Wickens (1980), who theorized that each sensory modality had separate attentional resources. Kahneman's theory that attentional resources are common for all sensory modalities, or supramodal, implies that a drain on attention in any modality limits the attention available to process stimuli anywhere else, be it in the same sensory modality or separate sensory modalities. By contrast, Wickens' theory of modality-specific attentional resources would imply that taxing the attention of one sensory modality is incapable of affecting attention in another modality, as the attentional resources for these modalities are independent of one another. Were Wickens' theory supported, taxing participants' auditory attention in the current study would not have affected their ability to perceive tactile stimuli. Therefore, the current study's results are inconsistent with Wickens' theory, instead suggesting support for Kahneman.

These findings are also partially consistent with Fairnie et al. (2016), which used the same kind of auditory load manipulation to demonstrate perceptual load theory's application to the auditory modality. However, they are not fully consistent with Fairnie et al., as differences were found only between the control and load conditions, but not between different levels of auditory load. This may be related to the study using only a partial replication of Fairnie et al.'s original load manipulation. In Fairnie et al.'s study, both the load manipulation and the critical stimulus involved were within the auditory modality. Therefore, greater focus was needed in order to discriminate between those stimuli, as they were, by nature, more similar to one another than stimuli in separate modalities. As a result, attention was inherently taxed more greatly in a purely within-modal design. In the current study, however, the load manipulation was within the auditory modality, while the critical stimulus was tactile. Although auditory load was still found to have a mediating effect on tactile attention, less overall stimulation was presented to the auditory modality than was in Fairnie et al.'s original study. Because of this, it is possible that auditory attention was not taxed as much as intended in the current study, producing a smaller effect than anticipated.

Despite this, the current study's findings show that auditory load can modulate attention in another modality. This may prove an important contribution to the existing literature, as there are few studies which examine perceptual load theory in a cross-modal paradigm. The existing literature also contains conflicting data regarding perceptual load theory's application to audition in general, and the current study may provide further insight on the topic. In this regard, the current study is consistent with several previous researchers (Macdonald & Lavie, 2011; Raveh & Lavie, 2014; Molloy et al., 2015; Parks et al., 2009) who found that non-auditory load can modulate auditory attention, thereby demonstrating that perceptual load theory can apply to audition in general. It is inconsistent with researchers who have neither found evidence to suggest that non-auditory load can modulate auditory attention (Parks et al., 2011; Sandhu & Dyson, 2016), nor that auditory load can modulate attention in other modalities (Sandhu & Dyson, 2016). Finally, the current study's findings are also consistent with Murphy and Dalton (2016) in that a degree of inattentiveness was demonstrated towards the tactile modality under the influence of attentional load.

In addition to these interpretations, however, there were limitations inherent in the design that may have affected the outcome. The first was an apparent ceiling effect in the auditory task used to manipulate auditory perceptual load. Although significant differences were found between the control and load conditions, individuals performed consistently highly across all conditions. Even in the highest load condition, individuals tended to miss an average of only one or two vibrations total out of the 30 vibrations administered. It can be concluded from this that while the auditory task seemed to tax attention slightly more than the control condition, it did not tax attention nearly as much as intended. In addition to previous discussion of this issue, which focused on the current study only partially replicating Fairnie et al. (2016) as a whole, this also may have been due to an imperfect replication of the original task in Fairnie et al., as the study did not provide enough detail to replicate it identically. Therefore, certain aspects of the current study's administration of the task may have affected how challenging it was. For example, Fairnie et al. did not disclose the number of trials undergone by participants. It is possible that the current study performed too many trials by comparison, resulting in participants' habituation to the auditory load.

The current study also did not measure individuals' performance on the auditory task itself, due to budgetary and software restrictions within the study's implementation. While performance on the auditory task itself was not central to this study's hypothesis, an examination of auditory task performance may have provided further insight regarding tactile detection performance. Without measuring performance on the auditory task given, it is difficult to say with certainty how much attentional load it really provided.

Given both the past research and the current study, further research is required to continue exploring cross-modal examinations of selective attention. While the current study suggests support for Kahneman's theory of supramodal attentional resources, further measures of cross-modal load and selective attention may provide further insight as to whether this holds true. These may further explore attention or load in the tactile modality. They also may incorporate olfactory or gustatory attention, neither of which have yet been studied in the context of Kahneman's theory or perceptual load theory. Future research should also continue exploring selective attention in the auditory modality with regard to perceptual load theory. Because it is consistent with previous research that suggests perceptual load theory applies to the auditory modality (Fairnie et al., 2016), the current study indicates that auditory perceptual load can affect selective attention. However, further research should strive to extend this effect within studies, as well as examine whether auditory attention can be affected by load in other sensory modalities. This may help to further resolve past conflicts in the literature over whether perceptual load theory can correctly predict outcomes in situations involving audition.

In addition, given the limited ways in which tactile attention has been measured thus far, further research should continue to focus on novel means by which to measure selective tactile attention. This will allow for greater ease in extending perceptual load theory research to the tactile modality. We see evidence for the necessity of this research in, for instance, the integration of haptic feedback as a safety measure in certain automobiles. In these instances, vibrations may be sent through steering wheels to alert drivers to potential danger while driving. This necessitates a clearer understanding of how both visual and auditory load while driving affect perception of tactile stimuli.

In conclusion, the current study aimed to address conflicts in the literature regarding perceptual load theory's application to the auditory modality, as well as its application to cross-modal settings in general, as implied by Kahneman's (1973) research. After using an adapted replication of previous models, results suggest that perceptual load theory applies both to the auditory modality and applies cross-modally. Further investigation is required to find whether this effect can be extended.

References

Bell, R., Röer, J. P., Dentale, S., & Buchner, A. (2012). Habituation of the irrelevant sound effect: Evidence for an attentional theory of short-term memory disruption. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(6), 1542–1557. http://doi.org/10.1037/a0028459

Benet-Martínez, V., & John, O. P. (1998). Los Cinco Grandes across cultures and ethnic groups: Multitrait-multimethod analyses of the Big Five in Spanish and English. *Journal of Personality and Social Psychology*, *75*(3), 729–750. https://doi.org/10.1037/0022-3514.75.3.729

Cartwright-Finch, U., & Lavie, N. (2007). The role of perceptual load in inattentional blindness. *Cognition*, *102*(3), 321–340. http://doi.org/10.1016/j.cognition.2006.01.002

Dittrich, K., & Stahl, C. (2012). Selective impairment of auditory selective attention under concurrent cognitive load. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(3), 618–627. http://doi.org/10.1037/a0024978

Fairnie, J., Moore, B. C. J., & Remington, A. (2016). Missing a trick: Auditory load modulates conscious awareness in audition. *Journal of Experimental Psychology: Human Perception and Performance*. http://doi.org/10.1037/xhp0000204

Francis, A. L. (2010). Improved segregation of simultaneous talkers differentially affects perceptual and cognitive capacity demands for recognizing speech in competing speech. *Attention, Perception, & Psychophysics*, *72*(2), 501–516. http://doi.org/10.3758/APP.72.2.501

Gherri, E., & Eimer, M. (2011). Active listening impairs visual perception and selectivity: An ERP study of auditory dual-task costs on visual attention. *Journal of Cognitive Neuroscience*, *23*(4), 832–844. http://doi.org/10.1162/jocn.2010.21468

Gomes, H., Barrett, S., Duff, M., Barnhardt, J., & Ritter, W. (2008). The effects of interstimulus interval on event-related indices of attention: An auditory selective attention test of perceptual load theory. *Clinical Neurophysiology*, *119*(3), 542–555. http://doi.org/10.1016/j.clinph.2007.11.014

Gosling, S. D., Rentfrow, P. J., & Swann, W. J. (2003). A very brief measure of the Big-Five personality domains. Journal Of Research In Personality, 37(6), 504-528. doi:10.1016/S0092-6566(03)00046-1

John, O. P., Donahue, E. M., & Kentle, R. L. (1991). The Big Five Inventory--Versions 4a and 54. Berkeley, CA: University of California,Berkeley, Institute of Personality and Social Research.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice-Hall Inc.

Klemen, J., Büchel, C., & Rose, M. (2009). Perceptual load interacts with stimulus processing across sensory modalities. *European Journal of Neuroscience*, *29*(12), 2426–2434. http://doi.org/10.1111/j.1460-9568.2009.06774.x

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(3), 451–468. http://doi.org/10.1037/0096-1523.21.3.451

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences*, *9*(2), 75–82. http://doi.org/10.1016/j.tics.2004.12.004

Lavie, N. (2010). Attention, Distraction, and Cognitive Control Under Load. *Current Directions in Psychological Science*, *19*(3), 143–148. http://doi.org/10.1177/0963721410370295

Macdonald, J. S. P., & Lavie, N. (2008). Load induced blindness. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(5), 1078–1091. http://doi.org/10.1037/0096-1523.34.5.1078

Macdonald, J. S. P., & Lavie, N. (2011). Visual perceptual load induces inattentional deafness. *Attention, Perception, & Psychophysics, 73*(6), 1780–1789. http://doi.org/10.3758/s13414-011-0144-4

Molloy, K., Griffiths, T. D., Chait, M., & Lavie, N. (2015). Inattentional deafness: Visual load leads to time-specific suppression of auditory evoked responses. *The Journal of Neuroscience, 35*(49), 16046–16054. http://doi.org/10.1523/JNEUROSCI.2931-15.2015

Moray, N., & O'brien, T. (1967). Signal-Detection theory applied to selective listening. *Journal of the Acoustical Society of America*, *42*(4), 765–772. http://doi.org/10.1121/1.1910648

Murphy, S., & Dalton, P. (2016). Out of touch? Visual load induces inattentional numbness. *Journal of Experimental Psychology: Human Perception and Performance, 42*(6), 761–765. http://doi.org/10.1037/xhp0000218

Murphy, S., Fraenkel, N., & Dalton, P. (2013). Perceptual load does not modulate auditory distractor processing. *Cognition*, *129*(2), 345–355. http://doi.org/10.1016/j.cognition.2013.07.014

Parks, N. A., Hilimire, M. R., & Corballis, P. M. (2009). Visual perceptual load modulates an auditory microreflex. *Psychophysiology, 46*(3), 498–501. http://doi.org/10.1111/j.1469-8986.2009.00801.x

Parks, N. A., Hilimire, M. R., & Corballis, P. M. (2011). Steady-state signatures of visual perceptual load, multimodal distractor filtering, and neural competition. *Journal of Cognitive Neuroscience*, *23*(5), 1113–1124. http://doi.org/10.1162/jocn.2010.21460

Perez, C. A., Donoso, J. R., & Medina, L. E. (2010). A critical experimental study of the classical tactile threshold theory. *BMC Neuroscience*, *11*. http://doi.org/10.1186/1471-2202-11-76

Raveh, D., & Lavie, N. (2015). Load-induced inattentional deafness. *Attention, Perception, & Psychophysics*, *77*(2), 483–492. http://doi.org/10.3758/s13414-014-0776-2

Reisberg, D. (2013). *Cognition: Exploring the science of the mind* (5th ed.). New York, NY: W. W. Norton & Company, Inc.

Sanbonmatsu, D. M., Strayer, D. L., Medeiros-Ward, N., & Watson, J. M. (2013). Who multi-tasks and why? Multi-tasking ability, perceived multi-tasking ability, impulsivity, and sensation seeking. *PLOS ONE*, *8*(1), e54402. https://doi.org/10.1371/journal.pone.0054402

Sandhu, R., & Dyson, B. J. (2016). Cross-modal perceptual load: The impact of modality and individual differences. *Experimental Brain Research*, *234*(5), 1279–1291. http://doi.org/10.1007/s00221-015-4517-0

SanMiguel, I., Corral, M.-J., & Escera, C. (2008). When loading working memory reduces distraction: Behavioral and electrophysiological evidence from an auditory-visual distraction paradigm. *Journal of Cognitive Neuroscience*, *20*(7), 1131–1145. http://doi.org/10.1162/jocn.2008.20078

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception*, *28*(9), 1059–1074. http://doi.org/10.1068/p2952

Tabachnick, B.G. & Fidell, L.S. (2001). Using Multivariate Statistics (4th ed.). Needham Heights, MA: Allyn & Bacon.

Vermeulen, N., Corneille, O., & Niedenthal, P. M. (2008). Sensory load incurs conceptual processing costs. *Cognition*, *109*(2), 287–294. http://doi.org/10.1016/j.cognition.2008.09.004

Wechsler, D. (1999). Wechsler Abbreviated Scale of Intelligence. The Psychological Corporation: Harcourt Brace & Company. New York, NY.

Wechsler, D. A. (2008). Wechsler Adult Intelligence Scale (4th ed.). San Antonio, TX: Psychological Corporation.

Wesslein, A.-K., Spence, C., & Frings, C. (2015). Vision of embodied rubber hands enhances tactile distractor processing. *Experimental Brain Research*, *233*(2), 477–486. http://doi.org/10.1007/s00221-014-4129-0

Wickens, C. (1980). The structure of attentional resources. In R.S. Nickerson (Ed.), *Attention and Performance VIII* (pp. 239-275). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Table 1.
Means and Standard Deviations.

	Mean	**Standard Deviation**
1. Low-load misses	1.07	1.68
2. High-load misses	1.32	1.82
3. Control condition misses	.43	.99
4. Low-load false positives	.17	.45
5. High-load false positives	.21	.53
6. Control condition false positives	.11	.35
7. Block design scaled score	9.76	2.57
8. Digit span task score	11.56	1.95
9. Multitasking ability	56.28	18.08
10. Extraversion	3.30	.93
11. Agreeableness	3.83	.67
12. Conscientiousness	3.58	.58
13. Neuroticism	3.16	.85
14. Openness	3.68	.60
15. Age	20.46	4.38

Note. Reported scores for Block Design are scaled scores. Scaled scores have a *M* = 10 and *SD* = 3. Reported numbers of misses are out of 30 possible trials. Reported numbers of false positives are out of 60 possible trials.

Table 2.
Correlations between Missed Vibrations and Working Memory Tasks.

	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**
1. Low-load misses	—								
2. High-load misses	**.65****	—							
3. Control condition misses	**.24***	**.28***	—						
4. Low-load false positives	.02	.05	.08	—					
5. High-load false positives	-.08	-.03	-.05	**.24***	—				
6. Control condition false positives	.01	.07	.02	**.31****	**.39****	—			
7. Block design scaled score	**-.33****	-.19	-.00	.05	.05	-.18	—		
8. Digit span task score	**-.32****	**-.30****	-.22	-.08	-.06	**-.30***	**.27***	—	
9. Multitasking ability	-.13	.02	.00	**-.34****	.07	-.05	.09	**.27***	—

Note. *$p \leq .05$, **$p < .001$

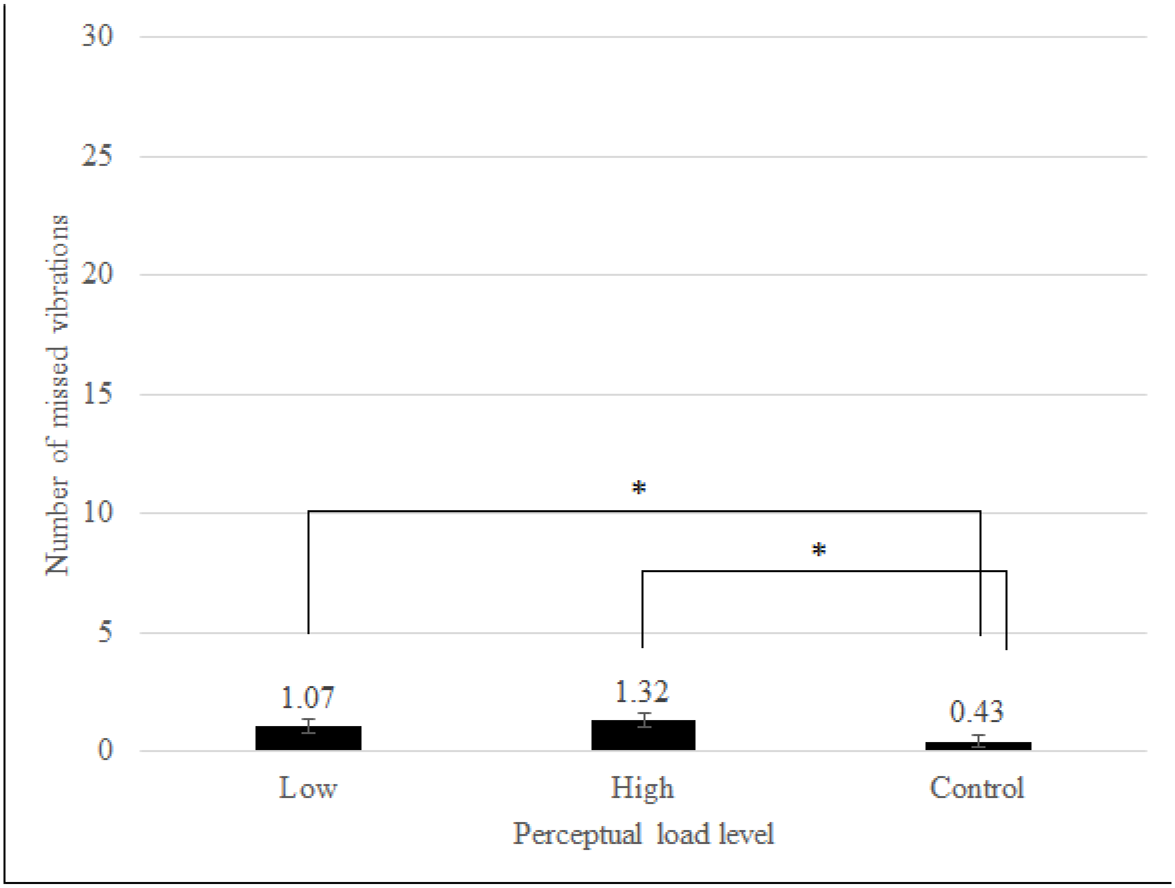

Figure 1. Means of missed vibrations across conditions.
Note. *$p \leq .05$

Appendix A

Multitasking Questionnaire

1. Rank your multitasking ability relative to that of **other college students** on a scale of
   0 – 100: _____________
   Example: 0 indicates, *I'm at the very bottom*. 50 indicates, *I'm exactly average*. 100 indicates, *I'm at the very top*.

2. Rank your multitasking ability relative to that of **other adults in general** on a scale of
   0 – 100: _____________
   Example: 0 indicates, *I'm at the very bottom*. 50 indicates, *I'm exactly average*. 100 indicates, *I'm at the very top*.

3. How much difficulty do you have performing multiple tasks simultaneously relative to **other college students**?

1 2 3 4
5

Much less *Average*
Much more
difficulty
difficulty than
than average
average

Appendix B

Demographics Questionnaire

Sex:
Male [ ]
Female [ ]
Other/Prefer not to disclose [ ]

Your age in years: _________

Which hand do you write with? ___________________

Year in school:
Freshman [ ]
Sophomore [ ]
Junior [ ]
Senior [ ]

Ethnicity:
[ ] Hispanic or Latino
[ ] Asian or Pacific Islander
[ ] Caucasian
[ ] Black or African American
[ ] Mixed or Biracial
[ ] Other