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Exploring the properties of alarms signals that make them attention-capturing: The role of interstimulus intervals

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Foreword

I want to thank Robin Liljenberg for helping me with the data collection. I also want to thank John Marsh for his help in this study. I also want to thank Robert Ljung for his help, and fast responds to my emails.

Abstract

Alarm signals such as sirens are crucial in alerting users of impending dangers. Therefore, it is important that the siren is designed so it can capture user's attention. In a previous study (Hansson, 2017) background alarm sirens composed of changing-state sounds with an embedded temporal deviant, produced greater disruption of serial short-term memory than a signal without a temporal deviant. However, to give rise to disruption the siren needed to change from fast to slow, since a change from slow to fast was impotent in its effect on task performance. This was further addressed in Hansson (2018) where it was shown that acoustic change appeared to be a necessary prerequisite for obtaining the fast-to-slow temporal deviant effect: When steady-state sounds were used fast-to-slow and or slow-to-fast temporal deviants were equally disruptive of serial recall. However, in order to create a steady-state siren, inter-stimulus intervals were incorporated into the siren to prevent the continuous uninterrupted presentation of a single tone. Since inter-stimulus intervals were not used in Hansson (2017) it could be the presence of these that eliminated the potency of the fast-to-slow over the slow-to-fast temporal deviation effect in Hansson (2018). Therefore, the current study was undertaken to investigate whether the embedding inter-stimulus intervals within a changing-state siren would restore the potency of the fast-to-slow temporal deviation over the slow-to-fast temporal deviation in capturing attention. The additional disruption for fast-to-slow temporal deviants over slow-to-fast temporal deviants (that did not produce disruption relative to control) returned in the current study when inter-stimulus intervals were included within the siren. The results support the notion that the additional disruption produced by fast-to-slow, over slow-to-fast temporal deviants depend on the changing-state properties of the siren. Implications of this result for the design and operation of sirens within ecologically valid settings are discussed.

Keywords: Alarm sirens; Steady-state; Changing-state; Temporal deviant; Orienting response.

Innehållsförteckning

Figurförteckning

Introduction

Alarm systems are embedded in most technological things in our modern world. Regardless of whether they are embedded in cell-phones or powerplants, alarm sirens are designed to serve the purpose of capturing a user's attention. In hospitals or air traffic control users can experience 20-30 alarms simultaneous trying to alert of dangers and trying to capture their attention (Momtahan, Hétu & Tansley, 1993). When numerous alarms sound at the same time, there is a higher probability that users will turn off the alarm siren (Edworthy & Meredith, 1994). Edworthy and Meredith (1994) argue that it's hard for humans to remember numerous alarm sirens, even if participants have previous practice at learning and remembering the same alarm signals. To minimize the numbers of potential alarm systems, a good alarm siren that have the propensity to capture attention is essential. Users often mistake the seriousness of an alarm with the situation the alarm is supposed to convey. If the alarm sirens is designed in a similar way for example a continuous signal, then the acoustic similarities by the different alarms can make users confuse them by another. As a consequence, for example, an aircraft's crew may ignore a critical alarm while instead searching for a minor alarm, because the signal is similar (Edworthy, Loxley & Dennis, 1991; Wolfman, Miller & Volanth, 1996).

In order to design alarm signals that are able to conceive correct urgency, variations of The Pulse Burst Theory can be used. Patterson (1982) suggested that alarm signals that are built up by signals and 200ms pauses could be used to build better alarm signals. Instead of having one signal, each alarm is built with bursts of signals, and urgent signals should give bursts with a shorter interval. Due to the increased urgency that bursts of signals with shorter duration convey, users should know if an alarm is more urgent than another alarm. Further, an alarm siren should be perceived as urgent, for users to react to dangers. Perceived urgency has been shown to be affected by repetitions, changes in harmonic series, amplitude, and delayed harmonics (Edworthy, Loxley & Dennis, 1991; Wolfman, Miller & Volanth, 1996).

Research has demonstrated that task-irrelevant background sounds impact negatively upon human cognitive performance (Miles, Jones, & Madden, 1991; Wood & Cowan, 1995; Hughes, Vachon, Jones, 2007). For example, Cherry (1953) showed with the so-called cocktail effect that even low intensity sounds could grab attention, especially if the sound stream contained the participant's own name. The presence of to-be-ignored sounds impair human cognitive performance in a variety of tasks. This is the so-called "irrelevant sound effect" (Miles, Jones, & Madden, 1991; Beaman, 2004; Knez & Hygge, 2002: Röer, Bell, & Buchner, 2013). Some to-be-ignored sounds convey urgency (Noyes, Hellier & Edworthy, 2006). The perceived urgency of a sound is affected by its acoustic parameters such as its frequency, speed, pitch range and amplitude (Edworthy, Loxley & Dennis, 1991; Hellier, Edworthy, Weedon, Walters, & Adams, 2002).

Alarm sirens capture human attention by their unexpected onset. To study this effect, observations and measurements of the orienting response (OR) can be used. An OR is an automatic reflex that consists of different physiological and psychological changes (Näätänen, 1992; Sanmiguel & Escera, 2010). If exposed to abrupt sounds, or a deviation from homogeneous background sounds, attention is captured involuntary. OR consists of head movements in the direction of the sounds, pupil dilation, increased peripheral blood flow, slowed heart rate and so on (Potter et al., 2015; Sokolov, 1963). The orienting response to deviant sounds has been vigorously tested in the "auditory oddball paradigm" wherein a rare, deviant sound is presented within the context of a repeated standard sound. This produces an orienting response that can be measured with electroencephalography (EEG) through a triumvirate of components (P3a, MNN and RON). Within the task, the orienting response can also be measured by pupillometry: the onset of a deviant produces pupil dilation (Schröger & Wolf, 1998a; Schröger & Wolf, 1998b).

The strength of disruption an acoustic signal produces depends on the character of the sound. A steady state tone that is continually repeated (1 1 1 1), is less disruptive than a changing state sound that containing different tones and other stimulus (1 2 3 4; Beaman & Jones, 1997; Röer, Bell & Buchner, 2013; Hughes et-al, 2005). However, changing-state sounds such as these are thought to produce disruption by an interference-by-process, not via attentional capture or attentional orienting. The automatic processing of the serial order of changes within the sound stream interferes with the deliberate serial rehearsal process required for maintaining visually-presented items in a sequence.

Sounds that disrupt human performance and provoke strong orienting responses are called deviants or deviant sounds (Vachon, Hughes & Jones, 2012; Parmentier & Hebro, 2013). Deviant sounds refer to sounds that violate the predicted pattern of stimulation – such as those that are higher in pitch, intensity or speed that preceding sounds. Deviants have been shown to give rise disruption of focal task performance and strong ORs. In contrast to changing-state sounds, deviant sounds are those that are unexpected given the context provided by the preceding part of the sound stimulation, such as 1 in the following sequence: 2 2 1 1 2 2. Furthermore, deviant-sound streams has shown to be more disruptive to human performance in serial recall than changing-state sounds (Vachon, Hughes & Jones, 2012; Parmentier &

Hebro, 2013; Hughes, Vachon & Jones, 2005). Two theories have been suggested as to why deviant and changing state sequences disrupt task performance. First is Wood & Cowan, (1995) uni (single) mechanism theory. This states that attentional capture happens for each change (A B C D E) within a changing-state sequence. Each time the auditory signal changes, an attentional switch occurs (Wood & Cowan, 1995). Deviant and changing-state mechanism is, on the unitary theory, underpinned by the same mechanism. The opposing theory is the duplex, mechanism account (Hughes, 2014). In this theory attentional grabbing does not happen for each of the changes in the sequence. Instead, the disruption that changing-state sound confers on serial short-term memory is attributable to interference-by-process. The disruption of short term memory is attributed to two similar processes. The first is applied automatically and preattentively to the sound and process the order of acoustic changes within then sound. The second is the deliberate process of serially rehearsing the visually-presented to-be-recalled items via subvocal/inner speech.

Considering changing-state sounds and deviant sounds disruptive inducing nature, an alarm siren composed of these characteristics should be good at capturing attention. This was my hypothesis for my first study Hansson (2017), and it was investigated further in my second study Hansson, (2018). Below is a short summary of the result of my previous two studies.

In Hansson (2017) I tested if a changing-state siren, with an embedded deviant had the propensity to capture attention.

As mentioned above, sound streams that contain irrelevant or embedded deviant sounds are more disruptive of visual-verbal serial short-term memory than those without deviant events. Therefore, in Hansson (2017) my hypothesis was that an alarm siren composed of changing state sounds with an embedded temporal deviant should be effective at capturing attention. Because if deviant sounds are disruptive to human performance then it is plausible that a deviant sound embedded in an alarm system would make the alarm more effective at capturing attention (Hansson, 2017). A siren-type of sound with a temporal deviant or without a temporal deviant -as represented by a change in speed, were compared in relation to how effective they were at disrupting human serial recall performance (Hansson, 2017).

Two sirens were used and they operated on different speeds of fast or slow. In the temporal deviant trials the siren could go from slow-to-fast or fast-to-slow. As can be seen in figure 1, an alarm siren with an embedded temporal deviant going fast-slow appear to be more disruptive, than an alarm siren going slow to fast.

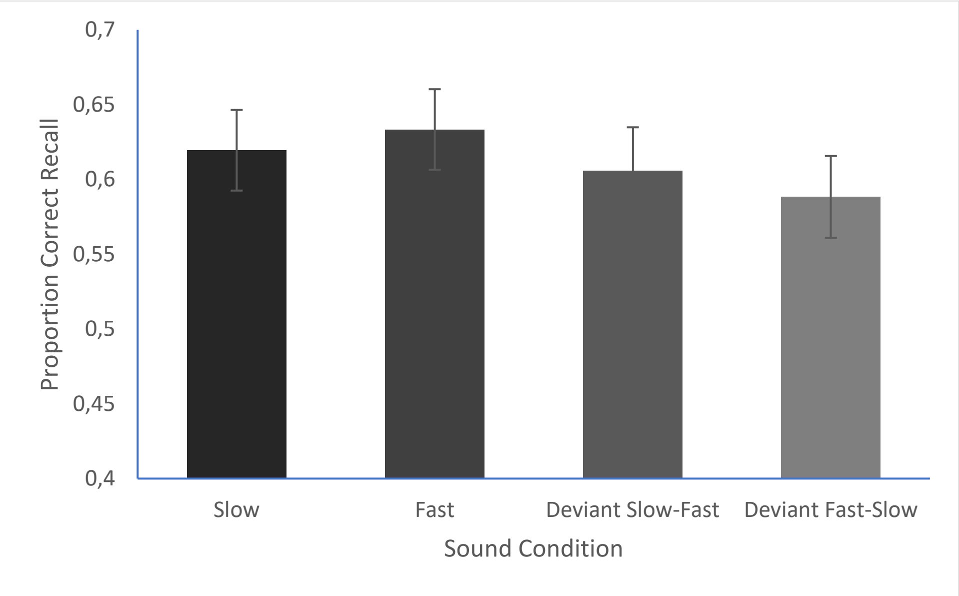

Figure 1. Shows proportion correct recall in the four sound conditions (Hansson, 2017). The error bars refer to the standard errors of the mean.

In Hansson, (2018) I tested whether a temporal deviant embedded in a steady-state sequence had the propensity to capture attention, and furthermore if there is a greater disruption from a siren going fast-to-slow, then one going slow-to-fast.

Numerous studies have shown that changing-state sound disrupts performance more than steady-state sounds and this is could be due to an interference by process, and not attentional capture (Hughes et al., 2007). Steady-state, repeating sounds (1 1 1 1 1) typically fail to disrupt performance (Campbell, Beaman & Berry, 2002; Jones & Macken 1993) unless they contain a temporal deviant :1 1 1 2 1 1 1 (whereby the 2 represent a change in voice). As above mentioned, in Hansson, (2017), I showed that alarm sirens composed of changing-state sounds with an embedded temporal deviant whereby the siren went from fast to slow produced more disruption than fast and slow sirens without a deviant and sequences conveying a slow-fast deviant. In Hansson, (2018), I studied the acoustic parameters involved in capturing attention. I studied whether a temporal deviant embedded in steady-state sequences had the propensity to capture attention. And furthermore, if a siren that changing from fast to slow was more disruptive than a siren changing from slow to fast. My hypothesis was that if the temporal deviant is related to the changing-state nature of the siren that I should get a different result in Hansson, (2018), compared to Hansson (2017). In Hansson (2018) the same procedure was applied, but a steady-state signal was used, instead of a changing-state sequence. The manipulation of speed in Hansson (2018), was within the context of a steady-state sequence, while in Hansson, (2017) it was in a changing-state sequence. To enable the signal to be perceived as an alarm siren and not a continues tone, ISIs were inserted. The length of the ISIs were manipulated to change the speed of the siren.

The results showed that the presence of a temporal deviant decreased serial recall performance. Speed did not appear to differentially disrupt performance. And contrary to Hansson (2017), the presence of a temporal deviant had a similar effect regardless of whether it was embedded within a fast or slow "base sequence".

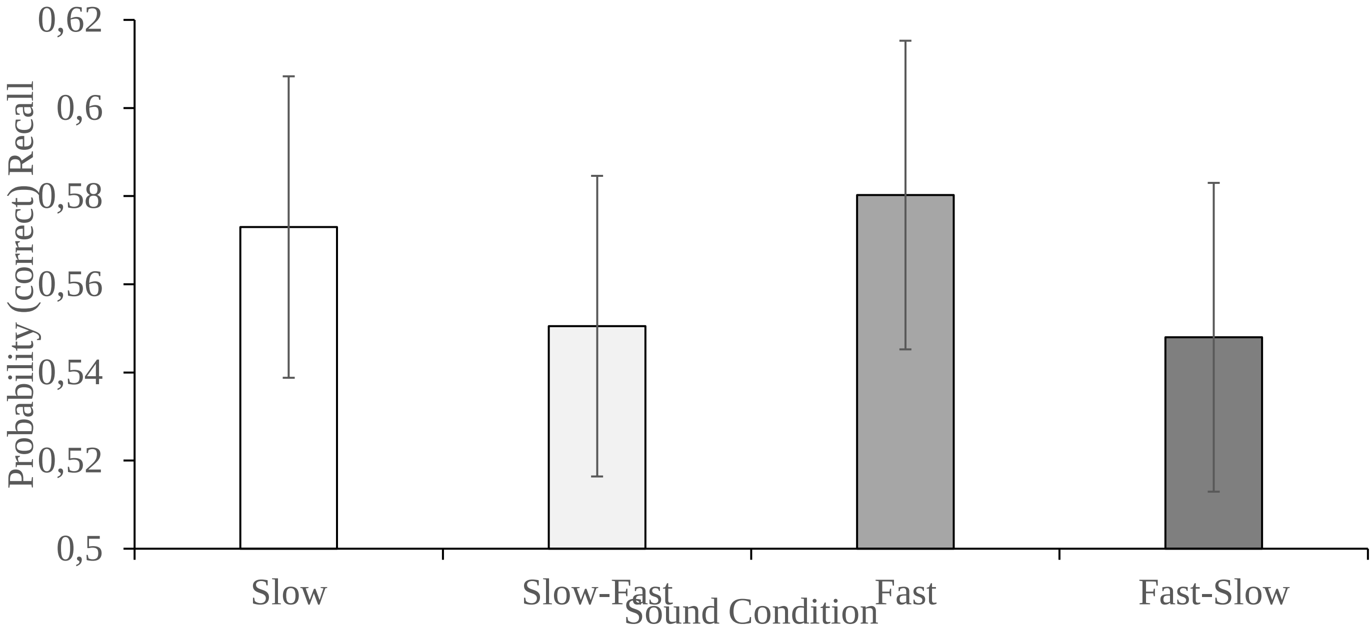

Figure 2. Probability correct recall, in the four conditions. The error bars refer to the standard errors of the mean.

Hypothesis

In the current study the ISI from Hansson (2018) is incorporated into the changing (alternating) tones used in Hansson (2017). This was to done to investigate if the fast to slow temporal deviant effect observed in Hansson (2017) returns. If it returns, then this would indicate that it is necessary for a siren to acoustically change over time to capture attention. If, however, the fast-to-slow temporal deviant effect is not replicated, then it is likely that the sounds must occur without temporal gaps between them in order to produce the effect.

Method

Participants

50 participants were recruited for the study. All reported normal hearing and normal or corrected-to-normal vision. Recruitment was by TimeCenter and random drop-ins. In return for participating in the study, participants were rewarded with two cinema tickets.

Apparatus and Materials

The experiment was executed on a PC running an E-Prime 2.0 program (Psychology Software Tools) that controlled stimulus presentation. To be remembered items consisted of the random presentation of eight digits from the set, 1-8 digits on a computer screen. No digit could be presented twice in a given list. Each digit was shown for 350 ms with a 400 ms ISI. Participants wore headphones throughout the study and the to-be-ignored alarm siren sounds were presented over headphones at approximately 65dB(A). The alarm-siren did consist of two different sounds at 400 and 300hz. The tones were edited to last 800ms for the slow and 200ms for the fast one. The sirens either contained a temporal deviant or did not. Deviants were represented as a temporal change, either going from fast-to-slow or from slow-to-fast. The speed of the tones was manipulated by the length of the tone, rather than the length of the ISI with tones either presented for 200ms with 200ms ISI in the fast condition, or 600ms with 200ms ISI in the slow condition. The four types of sound stimuli are as follows:

a) Fast – tones presented at 200ms each with 200ms ISIs throughout the trial.
b) Slow – tones presented at 600ms each with 200ms ISIs throughout the trial.
c) Fast-slow temporal deviation – tones started at 200ms each with 200 ms ISIs between as a "standard" then between the presentation of the fourth and fifth visual item, deviated to 600ms each, remaining at the slow speed for the rest of the trial and the subsequent trials until the next deviation.
d) Slow-fast temporal deviation – tones started at 600ms each with 200ms ISIs as a "standard" then between presentations of the fourth and fifth visual item, deviated to 200ms each, remaining at the fast speed for the rest of the trial and the subsequent trials until the next deviation.

Experimental Design

A 4 [2 (Sound Speed) x 2 (Temporal Deviant)] design was used whereby sound speed (fast *vs.* slow) and presence of a temporal deviant (temporal deviant *vs*. no temporal deviant) was manipulated within-participants.

The study was conducted in a classroom in the University of Gävle. Participants wore headphones and were presented with to-be-ignored sound across these. The participants were then presented with steady state sounds with, or without a temporal deviant. The deviant was temporal in nature such that the sequence either changed from fast to slow, or from slow to fast. Participants performed 90 trials. The previous signal acted as standard until the next signal occurred. Temporal deviant trials were presented randomly within the 90 overall trials with the constraint of ensuring that there were at least four non-temporal deviation trials between each deviation. There were seven of each temporal deviation trial throughout the study. Serial recall performance was the dependent variable. Participants were required to remember the correct order of the eight randomly presented digits on each of the 90 trials'.

Procedure

The participants were tested in groups wherein they were instructed to sit in front of a laptop computer screen while wearing headphones. Digits sustained a visual angle of about 2.6^{o} (participants sat at approximately 50 cm distance from the screen). They were instructed to ignore sounds coming from their headphones. They also received written instructions on their computer screens about the test. Following presentation of the last to-be-remembered item in a sequence, the digits were re-presented at random positions within a circular array. Beneath the array there were eight horizontally arranged response boxes corresponding to each position in the to-be-remembered list. Participants were required to reproduce the to-be-remembered list in forward serial order by selecting the digits using the mouse-driven pointer. Once a digit was selected, it disappeared for 50 ms before reappearing and a copy of the digit appeared in the response window corresponding to the current recall position. Because items remained in the circular array once selected, repetitions of the same item were possible, as with written recall.

Before each trial started there was a 5.6 second introduction of the sounds throughout which six sets of dashes were presented (--), then an arrow (→) to signal the onset of the first visually-presented digits. The dashes had the same visual timings as the digits so that participants could become accustomed to the "standard" sound for the trial did not occur under different conditions than the presentation of the to-be-remembered information.

Participants were given four practice trials (the sound corresponding with the speed of the first standard speed encountered in the study). Participants initiated the test themselves and it took approximately 40-50 minutes to complete. The test could be aborted if participants so desired.

Results

A strict serial recall scoring system was used whereby participants were required to put a digit in its correct original serial position to score a point. Figure 1 shows the mean serial recall performance in the four conditions collapsed across serial position. Speed appears to not disrupt performance. Temporal deviant sound appears to decrease correct recall performance. The presence of a siren going fast to slow shows a larger decrease in serial recall performance than a siren going slow to fast.

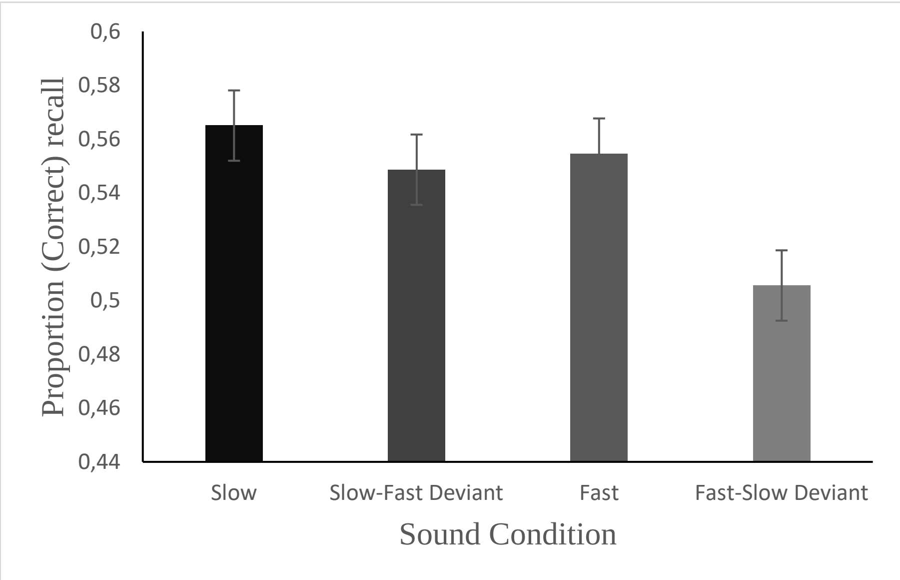

Figure 3. Shows proportion correct recall in the four sound conditions. The error bars refer to the standard errors of the mean.

A 2 (Sound Speed: Fast vs Slow) × 2 (Temporal Deviant: Deviant Present vs. Deviant Absent) repeated measures Analysis of Variance (ANOVA) revealed a main effect for sound speed, Sound speed, $F(1, 49) = 13{,}346$, $MSE = 0{,}053$, p=0,001, $\eta 2p = 0{,}214$

Further, there was a main effect for temporal deviant, Deviant $F(1, 49) = 10{,}838$, $MSE = 0{,}036$, $p = 002$, $\eta 2p = 0{,}181$

There was also a near-significant interaction Sound Speed and temporal Deviant $F(1, 49) = 3{,}374$, $MSE = 0{,}013$, $p = 0{,}072$, $\eta 2p = 0{,}064$

Follow-up planned pairwise comparisons show that there is no significant difference between fast and slow when there is no temporal deviant p = .221 95% CI [-.006, .027], but there is a significant difference when a temporal deviant was presented, with a temporal deviant presented in the context of a siren that starts fast (thus changing from fast to slow) producing more disruption than the presence of a temporal deviant in the context of a siren that starts slow (thereafter changing from slow to fast), p< .005 95% CI [.013, .073].

Also, while there was no significant difference between no temporal deviant and temporal deviant conditions when the speed of the sequence was slow p = .160 95 % CI [-.007, .039], there was a significant difference between no temporal deviant and temporal deviant when the speed of the sequence was fast p < .001 95 % CI [.022, .076], indicating that a temporal deviant that reflected a change in siren speed from fast-to-slow produced greater disruption than a temporal deviant that resulted in a change of siren speed from slow-to-fast(Robert and Russo, 1999).

Discussion

In emergency service and other socially important functions, a good alarm system is critical to saving lives. Therefore, it is important to research how alarm sirens can be better designed to capture user's attention. In the current study the ISI from Hansson, (2018) was incorporated into the changing-state-siren used in Hansson, (2017). This to investigate if the fast-to-slow temporal deviant effect seen in Hansson, (2017), should return. If it returned, then it would indicate that it is necessary for a siren to acoustically change over time to capture attention. And if it should not have returned then it was likely that the sound must occur without temporal gaps between them to produce the effect. The result showed that sound speed doesn’t appears to disrupt performance, which was also the same in my previous two studies Hansson, (2017-2018). Temporal deviant sound appears to decrease correct recall performance, which it also did in Hansson, (2017), and Hansson, (2018). This effect has also been seen in other studies containing a temporal deviant (Parmentier & Hebrero, 2013; Hughes, Vachon, & Jones, 2007; Röer, Bell & Buchner, 2013; Hughes et-al, 2005). Furthermore, the fast to slow effect returned. When a siren going fast to slow was present, a larger decrease in serial recall performance occurred than when a siren was going slow to fast.

This supports my first hypothesis that its necessary for a siren to acoustically change over time to obtain this effect. Below follows a short recap of my other two studies and their results.

Task irrelevant sounds impact negatively upon human cognitive performance, as earlier research has shown (Miles, Jones, & Madden, 1991; Wood & Cowan, 1995). Moreover, different sounds, steady-state, changing-state sounds impact human performance differently. Changing-state-sounds have in research shown to give a stronger disruptive effect than steady-state-sounds (Röer, Bell & Buchner, 2013; Hughes et al, 2005). Alarm sirens that are composed of changing-state-sounds should be good in alarm sirens, since they disrupt ongoing task performance more than do steady-state sounds. Furthermore, temporal deviant sounds have, in serial recall tests, been shown to further disrupt human performance. Therefore, using a changing-state-sirens with an embedded deviant should be optimal at capturing attention, and the result of Hansson (2017) and the present study confirms this. Moreover, an alarm siren with a change of speed from fast-to-slow, yielded less correct recall in Hansson, (2017), than an alarm siren changing from slow to fast, which suggests that the previous is better at capturing attention. To further investigate this effect, another study was conducted (Hansson, 2018). In Hansson, (2018) the same experiment was repeated, but with a steady-state-siren, instead of a changing-state one. ISIs was added to the siren so that it was not a continuous signal. Temporal deviants were represented as a temporal change, either going from fast-to-slow or from slow-to-fast. The results showed that the fast-to-slow effect didn't return, when a steady-state-siren with ISI was used. The addition of ISI could have made the fast-to-slow effect to not appear in Hansson (2018). Therefore, the current study was undertaken to incorporate the ISI from Hansson (2018) in the changing-state siren of Hansson (2017). This was to see if the fast to slow temporal deviant effect returned. If it returned, then it would appear necessary for a siren to acoustically change over time for the change in speed to lead to attentional capture. If, however, the fast-to-slow temporal deviant effect was not replicated, then it is likely that the sounds must occur without temporal gaps between them in order to produce the effect.

As above mentioned the fast-to-slow temporal deviation effect did return in the current study. This shows that it was not the addition of ISI in Hansson, (2018) that made the fast-to-slow effect absent, nor was it the absence of ISI in Hansson (2017) the cause of the fast-to-slow effect. Instead it seems that a changing-state sequence is required to get this effect. This result could help in the design of alarm sirens. In some environments it can be 20-30 alarms, therefore, it is important that each alarm is able to conceive urgency and capture attention. Furthermore, the alarm signals can sound similar to each other. This renders it difficult for users do discern what alarm urgency the alarm conceiving. Therefore, it's important that the alarm sirens are designed to conceive urgency and capture user's attention. Failing to do that could lead to accident's (Momtahan, Hétu & Tansley, 1993; Edworthy & Meredith, 1994; Edworthy, Loxley & Dennis, 1991; Wolfman, Miller & Volanth, 1996). Because fast-to-slow and slow-to-fast temporal deviants produced comparable attentional capture when used with a steady-state-siren in Hansson, (2018), it might be considered that it would be better overall to use a steady-state alarm siren, because both changes of speed lead to a disruption. In the changing-state experiments only fast-to-slow lead to a disruption. However, a changing-state speech warning after the steady-state siren fast-slow, slow-fast could fortify the attention capturing effect of the alarm siren. This because changing-state speech has in research (Hughes & Jones, 2003) been seen to break through selective attention and impair performance on focal tasks. The spoken warning could contain words that have been shown to induce greater levels of arousal in subjects. Such as deadly, danger etc. These kinds of word have, in research, been shown to induce more arousal than words like warning and caution. Or an instruction containing these words could also be presented, for example "danger, move away from the street", or "danger pedestrians ahead", depending on the situation (Hellier, Edworthy, Weedon, Walters, & Adams, 2002).

My previous two studies, Hansson, (2017, 2018), and the current one has been conducted in a classroom and therefore has not been tested in a more realistic environment. Therefore, to further study the fast-to-slow or slow-to-fast temporal deviation effects a realistic experiment is required. This would enable one to see whether the fast-to-slow, slow-to-fast, temporal deviation effect returns in an environment where the acoustic parameters can't be controlled. For example, a steady-state-siren with an embedded temporal deviant, and with or without a changing-state speech warning could be used in a driving simulation to test if the alarm is able to alert drivers of impending danger. Another experiment could be to fit a steady-state-siren with an embedded temporal deviant to an emergency vehicle, and study pedestrian behaviour. It is hoped that the contribution of the current study in identifying attentional capturing properties of alarms, can inform alarm design and testing.

References

Beaman, C. P., & Jones, D. M. (1997). Role of serial order in the irrelevant speech effect: Tests of the changing-state hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*(2), 459-471. doi:10.1037//0278-7393.23.2.459

Campbell, T., Beaman, C. P., & Berry, D. C. (2002). Auditory memory and the irrelevant sound effect: Further evidence for changing-state disruption. *Memory, 10*(3), 199-214. doi:10.1080/09658210143000335

Cherry, E.C. (1953). Some experiments on the recognition of speech, with one and with two ears, *Journal of the Acoustical Society of America*, *25*, 975-979

Beaman, C. P. (2004). The irrelevant sound phenomenon revisited: What role for working memory capacity? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(5), 1106-1118. doi:10.1037/0278-7393.30.5.1106

Edworthy, J., Loxley, S., & Dennis, I. (1991). Improving Auditory Warning Design: Relationship between Warning Sound Parameters and Perceived Urgency. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 33*(2), 205-231. doi:10.1177/001872089103300206

Edworthy, J., & Meredith, C. (1994). *Cognitive psychology and the design of alarm sounds. Medical Engineering & Physics, 16*(6), 445-449. doi:10.1016/1350-4533(94)90067-1

Hansson. (2017). Alarm signals, can steady and deviant sounds be used to capture human attention, *DIVA, Högskolan i Gävle*.

Hansson. (2018). When the Siren Sounds: In Search of Acoustic Properties that make an Alarm Signal Effective at Capturing Attention, *DIVA, Högskolan i Gävle*.

Hellier, E., Edworthy, J., Weedon, B., Walters, K., & Adams, A. (2002). The perceived urgency of speech warnings: Semantics versus acoustics. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 44*(1), 1-17. doi:10.1518/0018720024494810

Hughes, R., & Jones, D. (2003). Indispensable benefits and unavoidable costs of unattended sound for cognitive functioning, *Noise And Health, 6*(21), 63-76,

Hughes, R. W., Vachon, F., & Jones, D. M. (2005). Auditory Attentional Capture During Serial Recall: Violations at Encoding of an Algorithm-Based Neural Model? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*(4), 736-749. doi:10.1037/0278-7393.31.4.736

Hughes, R. W., Vachon, F., & Jones, D. M. (2007). Disruption of short-term memory by changing and deviant sounds: Support for a duplex-mechanism account of auditory distraction. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(6), 1050-1061. doi:10.1037/0278-7393.33.6.1050

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(2), 369-381. doi:10.1037//0278-7393.19.2.369

Knez, I., & Hygge, S. (2002). Irrelevant speech and indoor lighting: effects on cognitive performance and self-reported affect. *Applied Cognitive Psychology, 16*(6), 709-718. doi:10.1002/acp.829

Mcintyre, J. W. (1985). Ergonomics: Anesthetists' use of auditory alarms in the operating room. *International Journal of Clinical Monitoring and Computing, 2*(1), 47-55. doi:10.1007/bf02915873

Miles, C., Jones, D. M., & Madden, C. A. (1991). Locus of the irrelevant speech effect in short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*(3), 578-584

Momtahan, K., Hétu, R., & Tansley, B. (1993). *Audibility and identification of auditory alarms in the operating room and intensive care unit. Ergonomics, 36*(10), 1159-1176. doi:10.1080/00140139308967986

Noyes, J. M., Hellier, E., & Edworthy, J. (2006). Speech warnings: a review. *Theoretical Issues in Ergonomics Science, 7*(6), 551-571. doi:10.1080/14639220600731123

Näätänen, R. (1992). Attention and brain function. Hillsdale (N.J.): L. Erlbaum.

Parmentier, F. B., & Hebrero, M. (2013). Cognitive control of involuntary distraction by deviant sounds. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(5), 1635-1641. doi:10.1037/a0032421

Patterson, R., D. (1982). Guidelines for auditory warning systems on civil aircraft, *Civil aviation authority, London, paper 82018*

Roberts, M., & Russo, R. (2014). *A student's guide to analysis of variance*. London: Routledge.

Röer, J. P., Bell, R., & Buchner, A. (2013). Evidence for habituation of the irrelevant-sound effect on serial recall. *Memory & Cognition, 42*(4), 609-621. doi:10.3758/s13421-013-0381-y

Sanmiguel, I., Linden, D., & Escera, C. (2010). Attention capture by novel sounds: Distraction versus facilitation. *European Journal of Cognitive Psychology, 22*(4), 481-515. doi:10.1080/09541440902930994

Sokolov, E., N. (1963). Perception and the conditioned reflex, Pergamon Press, Oxford.

Vachon, F., Hughes, R. W., & Jones, D. M. (2012). Broken expectations: Violation of expectancies, not novelty, captures auditory attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*(1), 164-177. doi:10.1037/a0025054

Wolfman, G. J., Miller, D. L., & Volanth, A. J. (1996). An Application of Auditory Alarm Research in the Design of Warning Sounds for an Integrated Tower Air Traffic Control Computer System. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 40*(19), 1002-1006. doi:10.1177/154193129604001910

Wood, N. L., & Cowan, N. (1995). The cocktail party phenomenon revisited: Attention and memory in the classic selective listening procedure of Cherry (1953). *Journal of*

Experimental Psychology: General, *124*(3), 243-262. doi:10.1037/0096-3445.124.3.243