Attending at a low intensity increases impulsivity in an auditory SART

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Abstract (196 words)

Why attention lapses during prolonged tasks is debated, specifically whether errors are a consequence of under-arousal or exerted effort. To explore this we investigated whether increased impulsivity is associated with effortful processing by modifying the demand of a task by presenting it at a quiet intensity. Here, we consider whether attending at low but detectable levels affects impulsivity in a population with intact hearing. A modification of the Sustained Attention to Response Task (SART) was used with auditory stimuli at two levels: the participants' personal 'lowest detectable' level and a 'normal speaking' level. At the quiet intensity, we found that more impulsive responses were made compared to listening at a normal speaking level. These errors were not due to a failure in discrimination. The findings suggest an increase in processing time for auditory stimuli at low levels that exceeds the time needed to interrupt a planned habitual motor response. This leads to a more impulsive and erroneous response style. These findings have important implications for understanding the nature of impulsivity in relation to effortful processing. They may explain why a high proportion of individuals with hearing loss are also diagnosed with Attention Deficit Hyperactivity Disorder (ADHD).

Keywords: Auditory attention; Effortful listening; Impulsivity; Sustained attention; SART

1 Introduction

Impulsivity can be measured by failures to inhibit habitual responses. For example in the Sustained Attention to Response Task (SART) (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), participants have to respond speedily to each of a rapidly presented sequence of numerical targets with a simple button press, but to withhold their response to one specified number. Unless people are actively attending to each stimulus, a 'false alarm' response is often made to the stimulus that does not require a button press (Chamberlain & Sahakian, 2007). After people make such errors they typically realise it and this is reflected behaviourally in a slowing down of reaction times to subsequent stimuli (Fellows & Farah, 2005; Manly, Robertson, Galloway, & Hawkins, 1999). Such errors are referred to as 'impulsive'. Despite the name of the task, it has been suggested that the SART may be a better measure of this impulsivity than it is of sustained attention (Carter, Russell, Helton, 2013). It is thought that the repetitive nature of the task establishes a strong tendency for a response to be made unless there is a counteracting signal that prevents its initiation or execution. Impulsive errors are made when the time needed to identify the target is longer than the time allocated to initiate the motor response (Logan & Cowan, 1984; Logan, Schachar, & Tannock, 1997; Molenberghs et al., 2009). It is also suggested that such errors may be a result of a speed accuracy trade off in response strategy (Peebles and Bothell, 2004). In the SART faster response times to go targets are associated with increased impulsive errors (Manly et al. 2000). This outcome may result in a competing response strategy, respond quickly but make more errors, or respond slowly and be more accurate.

Why the counteracting signal fails to stop, and the response is initiated in such tasks is still unclear. One view is that errors arise because the mind drifts due to the boring and undemanding nature of the task, an underload theory (Nachreiner & Hanecke, 1992). However, more recent research suggests a very different explanation. Despite the monotony of continuous performance tasks they tend to be rated as very high on measures of cognitive load (e.g. NASA task load index (Hitchcock, Dember, Warm, Moroney, & See, 1999)). This high workload might be produced by the need to continuously process and identify every target to decide on an appropriate response (Hitchcock, et al., 1999). Therefore, instead of the attentional lapses that lead to impulsive responses being made due to the monotony of the task, the attentional lapses may arise due to an inability to maintain the effortful processing required to deal with the continuous workload, an overload theory. Increasing the task load with a concurrent task has been shown to increase errors made (Head and Helton, 2014).

The possibility that effortful processing may be responsible for attention failures and impulsive responding in these tasks may explain a curious relationship that exists between hearing impairment and difficulties with sustained attention. The cognitive and behavioural problems seen in those with hearing loss overlap considerably with the diagnostic criteria of Attention Deficit Disorder. Indeed, a high proportion of individuals with hearing impairments are also diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) (Williams & Abeles, 2004). In the current context, these difficulties may be a reflection of the effort required to process auditory information, rather than an independent behavioural problem. It may be that degraded auditory processing makes it more difficult, rather than impossible to discriminate words (Shinn-Cunningham & Best, 2008). Those with hearing loss may effectively have greater demands on their attention to enable the successful processing of what are effectively low but detectable levels of auditory input. Given that we know that sustained attention cannot be maintained indefinitely (Robertson, et al., 1997), errors can be expected as sustained attention fails. As a consequence impulsivity, mind-wandering, inattentiveness, not paying attention would all be predicted.

Whilst in a hearing impaired population developmental history makes it difficult to investigate whether attentional difficulties are a consequence of effortful processing, effortful listening can be simulated in a population with intact hearing. This can be achieved by using a modified version of the SART, whereby low intensity auditory stimuli are used instead of stimuli in the visual modality. An auditory SART variant of the traditionally visual task has been successfully adapted for use in another study (Seli, Cheyne, Barton, & Smilek, 2012). Moreover, the auditory SART has been shown to delay the motor response, which may in part mitigate the speed accuracy trade off aspect of the SART (Seli et al., 2013; Head and Helton, 2013). In the current study, an auditory SART is used to investigate the effect of effortful processing on impulsivity by changing the demand of the task, i.e. stimuli played at low or normal intensities.

Here, each of the participants performed the auditory SART under two conditions: at their lowest accurate detectable threshold level and at an intensity associated with normal speech levels. In this way the attentional effort needed to support auditory processing is compared whilst the monotonous aspect of the task is held consistent. We predicted that participants would make more errors (i.e. respond when they should withhold their response) under the low intensity condition, compared to the normal intensity condition. Critically, we predicted that these errors would not be a consequence of a failure in detection and that this would be reflected in increased reaction times after an error has been made (Fellows & Farah, 2005; Manly, et al., 1999).

2 Method

2.1. Ethics statement

This study was approved by the School of Psychology Research Ethics Committee at the University of Lincoln. Informed written consent was received by all participants that took part in this study. All experimental procedures complied with the British Psychological

Society Code of Ethics and Conduct and with the World Medical Association Helsinki Declaration as revised in October 2008.

2.2. Participants

Thirty participants aged between 18 and 47 (24 female, 6 male, mean age ± SD = 23 ± 7 years) took part in the study. Initial inclusion criteria included not having any known existing hearing impairments or self-reported attention deficits. In addition, participants undertook a hearing test prior to the experiment. The Hughson-Westlake procedure (Carhart & Jerger, 1959), an established modification of the Hughson-Westlake limits technique (Hughson & Westlake, 1944), was used to detect whether any of the participants had any unknown hearing difficulties. If participants had problems in the hearing test that were greater than mild hearing loss (above 25dB hearing level) they were excluded post hoc. No exclusions had to be made on this basis, average hearing level ranged from 5-20dB.

2.3. Design

The experiment used a repeated measures design with two conditions. Participants undertook a modified version of the SART (Robertson, et al., 1997); the task was adapted to present auditory instead of visual stimuli. Participants listened to a random sequence of auditory presented spoken numbers (i.e. numbers one to nine) presented at regular intervals. Participants were required to withhold response to one specified number (NO GO trial) and initiate a response to all other numbers (GO trials). Participants completed the task at two dB levels: 'normal speech level' and 'low intensity level'. The normal intensity was set at that of conversational speech, defined as 60dB SPL (Pearsons, Bennett, & Fidell, 1977). The low intensity condition was set to each individual participant's lowest detection level. Set at a level at which all targets could still be heard and repeated back correctly (see below for details). The order of conditions was counterbalanced between participants.

2.4. Determining the Lowest Detection Thresholds

Before the experiments were conducted, lowest detection thresholds were measured for each participant using an Oscilla SM930 screening memory audiometer. A single handheld thumb press response button was used. Tones were presented through passive noise reducing headphones (TDH39 headphones SILENTA noise reducing headset). An audiogram including the threshold of their lowest audible frequency in hertz (Hz) and intensity in decibels (dB) was established. This identified their optimum level of hearing with sustained attention and without distraction. The same closed-cup headphones that were used for the hearing test were also used for stimuli presentation in the experiment (see below). Participants were seated in a sound proof booth and tested independently. The ambient sound levels within the booth complied with the specifications according to British Standards/European Norm (BS EN) ISO 8253-1:1998 which allow thresholds as low as 0 dB HL to be established.

In addition to ruling out any possible hearing difficulty, the audiogram provided a starting point to further specify an appropriate level for the low intensity condition. Because the dB range of speech is more complex than pure tones, the audibility of the number stimuli were defined further. For this task, it was not only important that participants could detect a sound but identify what it was. To establish the level of the stimuli for the 'low intensity' condition, participants were played a sequence of numbers from one to nine in a random order. The presentation of each list was also presented in a stepwise manner. Participants were asked to repeat the numbers to ensure that they could discriminate the number stimuli. If participants were unable to repeat all of the nine numbers the intensity of the stimuli was increased by 5dB SPL. If participants could accurately identify the numbers the level was tested 5dB SPL quieter. This continued until participants were no longer able to identify all nine numbers. The intensity above was then tested again with the numbers in a random sequence. Lowest detection threshold was defined as the lowest level at which the participant could accurately identify the numbers. The level used was checked twice. Using number stimuli for the task meant that participant could verbally demonstrate correct identification of the stimuli by repeating the value of the number. This clarified that participants could hear and identify the meaning of all of the targets, presented at an individually specified intensity before they started the full test.

2.5. Procedure

Participants sat in front of a desk with a 17 inch computer monitor, showing only a black fixation cross presented centrally in the screen. They were provided with a standard keyboard and were required to press a single button on all specified 'GO trials'. Participants were instructed to rest their finger on the response key.

At the beginning of the task a start screen was presented, with a reminder of the correct key to press. Participants were asked to respond to all GO trials as soon as they heard them and not press the button when they heard the NO-GO trial. The participant initiated the experiment by pressing the response button when they were ready to begin. This was followed by a two second interval with no sound to ensure that the first number of the trial would not be missed. The stimuli were presented in a random sequence. Auditory stimuli consisted of the numbers one to nine presented simultaneously to both ears spoken in a human voice. All numbers were articulated with the same female human voice, read as neutrally as possible.

Each number was presented randomly and lasted for 605ms, with an inter-stimulus interval (ISI) of 895ms. Participants were able to respond at any time within the presentation of the stimulus and the ISI, a response window of 1500ms. Reaction time was measure from the onset of the stimulus. Each of the two conditions lasted for 13 minutes and consisted of 522 trials. Within each condition there were 58 'NO-GO' trials (one specified number), making up 11% of trials. There were 464 'GO' trials (the eight remaining number stimuli) making up 89% of trials. 'NO-GO' trials corresponded to a single number, which were randomly specified for each participant. Participants were asked to inhibit their response for this number by not pressing the button. Following the 'GO' targets, participants were required to press the response button and were asked to do so as soon as they identified the target. The same NO-GO target was used for both intensity conditions, to ensure the experience of the 'low' and 'normal' intensity conditions were the same for the individual. The target number was counterbalanced between participants to make sure any differences between conditions were due to the intensity level and not the sound of a specific target number. No feedback was given if an error was made. Participants undertook the second condition after a short break of which the duration was defined by the participant. Participants were debriefed at the end of the study.

3 Results

It was predicted that more errors would be made in the low intensity level compared to the normal intensity (60dB) condition. In support of this a repeated measures ANOVA comparing intensity (normal and low) and error type (commission and omission) showed significant main effects. All significance is assumed at the 0.05 level, two-tailed. Significantly more errors were made in the low intensity condition (17.87±13.24) compared to the normal speech condition (6.43±4.38) ($F(1,29) = 14.95$, $p = 0.001$ η^{2} = 0.34, 95% CI [2.69,8.74]).

To determine whether the errors were a consequence of either a failure to withhold response to a NO-GO target (i.e. commission error/false alarm) or as a failure to press on a GO target (i.e. omission error/miss), the proportion of commission and omission errors observed were compared across both intensity conditions. Significantly more commission errors were made across both tasks (15.57±11.63) compared to omission errors (8.73±10.66) ($F(1,29) = 12.71$, $p = 0.001$, $\eta^2 = 0.31$, 95% CI [1.46, 5.38]). This is the case even though there is proportionately less opportunity to make commission errors (11%) compared to omission errors (79%). This shows that proportionately more commission errors were also made to NO-GO targets (29.94%±22.37) compared to omission errors to GO targets (1.67%±2.04).

As expected, participants made significantly more commission errors in the low intensity condition (9.83±8.69) compared to the normal speech condition (5.73±4.25) ($t(29) = -3.12$, $p = 0.004$ $\eta^2 = 0.25$, 95% CI [1.41, 6.79]; Figure 1A), indicating a more impulsive reaction at low intensity when their response should have been withheld. In addition, significantly more omission errors were made in the low intensity condition (8.03±10.32) compared to the normal intensity condition (0.70±1.12) ($t(29) = -3.98$, $p < 0.001$ $\eta^2 = 0.35$, 95% CI [3.57, 11.10]; Figure 1B).

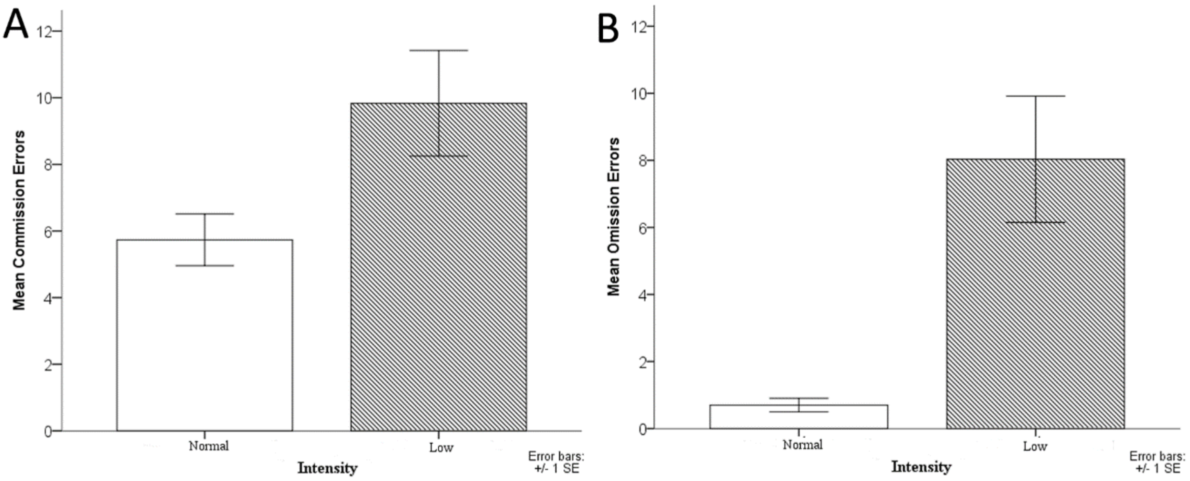

Figure 1A. Mean commission errors made during the SART at normal intensity (60dB) and lowest detection threshold

Figure 1B: Mean omission errors made during the SART at normal intensity (60dB) and lowest detection threshold

One obvious potential explanation for the higher errors (incorrect button responses to the NO-GO targets) in the low intensity condition might be that participants simply could not correctly discriminate the target, despite the initial standardisation of accuracy. To confirm that this was not the case, reaction times were averaged from the four responses before, and the four after commission errors. This method is used in the visual task variants, and typically show that SART reaction times typically slow down after an error has been made (Fellows & Farah, 2005; Manly, et al., 1999). It is suggested that the post error slowing indicates awareness of errors made (Manly et al. 2000). Average reaction time was calculated based on the correct responses to GO trials (excluding those around the error). A (3x2) repeated measures ANOVA compared reaction time to correct responses (before, after, average) around an error in the normal and low volume conditions.

Analysis showed that mean reaction times were slower over the whole task in the low intensity condition (712ms±73) compared to the normal intensity condition (611ms±76)

(F(1,26) = 77.85, p = 0.001 η^2 =0.75, 95% CI [78.81, 123.46]; Figure 2). This shows that it takes longer to process and respond to the same sounds when presented at a low, but detectable intensity than at normal intensity.

The repeated measures ANOVA also showed a significant difference across the three levels: response times before, after and the average reaction time excluding those around a commission error (F(2,52) = 18.39, p < 0.001 η^2 =0.41; Figure 2). As predicted, post hoc with Bonferroni correction shows that reaction times were significantly faster before an error of commission/false alarm (634ms±90), compared to reaction times after an error (688ms±104, p < 0.001, 95% CI [26.32, 81.07]; Figure 2). Reaction times were also significantly faster before an error (634ms±90) compared to the average reaction time of the task (663ms±84, p = 0.001, 95% CI [10.27, 46.79]). Compared to the average reaction time (663ms±84), reaction time was also significantly slower after an error (688ms±104), (663m ±84, p = 0.17, 95% CI [3.73, 46.59]). There was no significant interaction between the two volume conditions and time around the error (F(2,52) = 1.05, p = 0.357, η^2 =0.04).

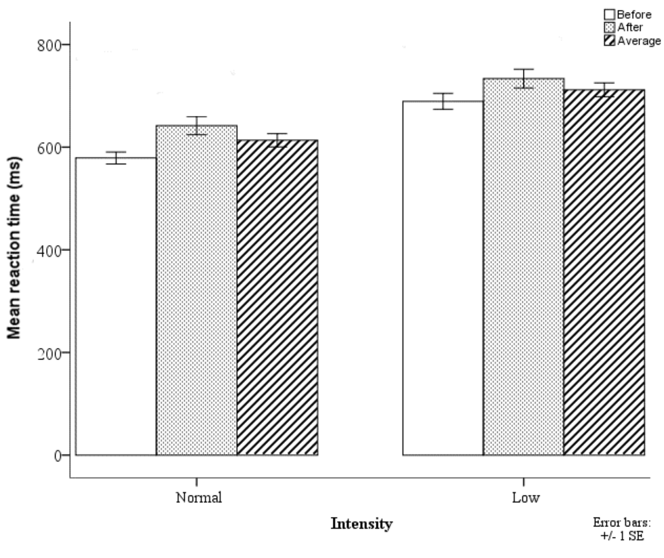

Figure 2: Reaction times to GO trials before and after an error of commission at normal and lowest detection threshold.

Pearsons correlations were used to further interpret the relationship between speed of response and errors made. Faster reaction times in the normal volume condition were correlated with a greater number of commission errors, (r = -48, N = 30, *p* =0.007, two-tailed), but not omission errors (r = -.08, N = 30, *p* =0.67, two-tailed). In the low volume condition however, there was no correlation between reaction time and commission errors (r = -.30, N = 30, *p* =0.10, two-tailed), or omission errors (r = -.03, N = 30, *p* =0.89, two-tailed), suggesting that the increased errors at low volume may be better explained by task demand rather than response strategy related to the speed of response.

A 2 (task: low and normal intensity) by 3 (periods of watch) ANOVA was used to analyse percentage errors over the course of the task. There was no effect of commission errors over time on the task ($F(2,58) = 2.33$, $p = 0.11$ $\eta^2 = 0.07$), but time on the task did have an affect on performance in relation to omission errors ($F(2,58) = 4.65$, $p = 0.01$, $\eta^2 = 0.13$, Figure 3). More omission errors were made in the final period of watch on the task (1.19±) compared to the second (0.77 p= 0.02). The interaction effect shows the decline in performance was greatest at low volume ($F(2,58) = 2.58$, $p = 0.03$, $\eta^2 = 0.12$, Figure 3).

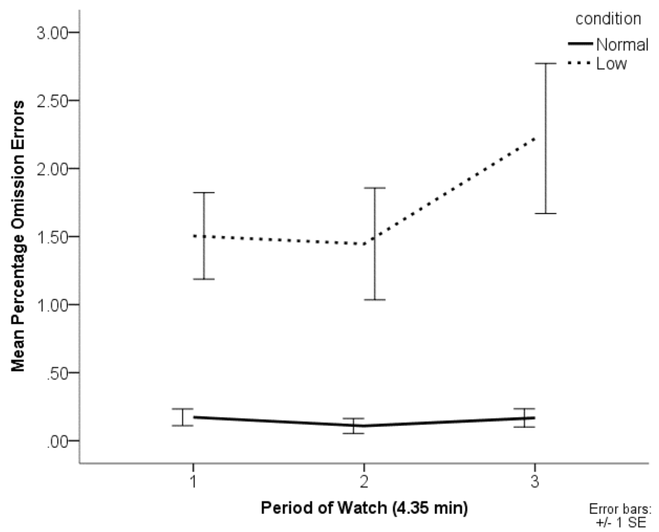

Fig 3

Mean percentage omission errors in the normal and low volume conditions made over time on the task based on three periods of watch (4.35 min).

4 Discussion

This experiment was designed to investigate the role of sustained attention in the control of impulsivity when processing low intensity but discriminable auditory stimuli, and to identify whether impulsive errors in such tasks can be better explained by effortful processing (Grier, et al., 2003; Hitchcock, et al., 1999, Head and Helton, 2014) or under-arousal (Nachreiner & Hanecke, 1992). By increasing the task demand, by making the audibility of the stimulus more difficult, the role of effortful processing when making impulsive errors could be explored. Our findings showed that when a participant completed the auditory SART task at a low but detectable intensity they made more impulsive errors on the task compared to when stimuli were presented at a normal speaking level (60dB). This suggests that at low intensity, attention is needed for successful performance and that this is not sustained over the 13 minutes of the task. When the task demand was greater in the low intensity condition more errors were made. When performance was assessed as a function of time on the task the low intensity condition showed more pronounced changes in omission errors than the normal intensity condition. These results suggest that effortful processing may not only affect the erroneous impulsive responses but also the omission errors. The decrement over time observed in this measure, supports the assumption that omission errors may be the better indicator of inattention in this task, whilst the commission errors are a better measure of impulsivity (Carter, Russell, Helton, 2013). The results are supportive of the view that errors in continuous performance tasks are a consequence of high rather than low cognitive demand (Grier, et al., 2003; Hitchcock, et al., 1999; Head and Helton, 2014).

An obvious explanation for the higher errors in the low intensity condition might be that participants were unable to physically hear the target accurately and so incorrectly pressed the response button to the NO-GO target. However, this was not the case. Detectability was established for each participant prior to testing, and confirmed by verbal recall identifying each of the stimuli. In addition, reaction time analyses from the testing session suggests that participants were aware of when they had made a mistake, i.e. they heard the target but responded incorrectly. Specifically, their reaction times were significantly slower in both the low and normal intensity conditions after an error of commission/false alarm than before the error. Following the standard interpretation, this slowing in reaction time following an error indicates an awareness of a mistake (Fellows & Farah, 2005; Manly, et al., 1999). In comparison to the overall average, reaction times before the error was faster than the average, and after an error reaction time became even slower than the average. This may be suggestive that a more conservative response style is being adopted compared to that typically used in the task.

Therefore, even though more errors were made in the low intensity condition, these results cannot simply be accounted for by a failure of perception. Instead, the results appear to suggest that the impulsive responses arise from a mismatch in the time at which a habitual response is initiated and the time needed to fully process auditory stimuli. This occurs more frequently at low intensity. In line with previous research the impulsive errors observed are understood in terms of a failure to inhibit pre-potent responses (Chamberlain & Sahakian, 2007; Logan & Cowan, 1984; Logan, et al., 1997; Molenberghs, et al., 2009). In the SART, it appears that errors are made when processing is slower than the time allocated to initiate a response. It is not that targets have not been identified, but rather that the time required is longer than that needed to interrupt the pre-potent motor plan. The current results can be understood as participants discriminating the auditory target but failing to do so in sufficient time to inhibit a response, i.e. the target is processed too slowly. After an error is made, participants often exclaim ‘oops’ realising they have fallen into the trap of the regular response pattern. These findings indicate that this happens more frequently in the low intensity condition. In the low intensity condition it appears that the time needed for perceptual processing of the auditory target is lengthened. This interpretation would be consistent with the fact that the mean reaction time is slower over the whole task in the low intensity condition compared to the normal intensity condition. It appears to take longer to process and respond to the same sounds when presented at a low, but detectable intensity than at normal intensity. This may lead to the interrupt signal being sent after the habitual response has already being initiated (Logan & Cowan, 1984; Logan, et al., 1997; Molenberghs, et al., 2009). An alternative interpretation for the increased errors at low volume may be related to the speed accuracy trade off criterion adopted in such tasks (Peebles & Bothell, 2004). However, in the low volume condition there was no correlation with faster responses and error rate, suggesting that the increased errors at low volume may be better explained by task demand rather than response strategy related to the speed of response.

Errors made at low intensity were not made because of some inherently slower processing relative to the initiation of the interrupt signal. Participants were able to accurately identify the targets when the intensity level is initially set and they are able to respond correctly on the task most of the time. The changing variable here could be the availability of attention during the task. In one view, effortful tasks lead to a decline in attentional resources leaving less capacity for subsequent information processing demands (Grier, et al., 2003). Something similar may be happening in the low intensity condition of the current task. More attention is exerted because stimuli require more processing to fully identify them at a low intensity. As the task proceeds the availability of processing resources declines leading to identification becoming slower and the inhibition of response being compromised.

There is also evidence of a reduced hit rate in this task with higher omissions at low intensity than at normal intensity, although it should be noted that this difference corresponded to less than 2% of trials in the low volume condition. Again, while superficial factors such as the intensity being too low might explain failures in response, it seems unlikely, given that performance was still high. Previous studies where the stimuli presented are well above perceptual threshold also show omission errors (Manly, et al., 1999; Robertson, et al., 1997; Seli, et al., 2012), which is suggestive that they are more likely to be failures of attention rather than perception. Indeed, the omission errors in this case appear to be the metric most similar to the errors of omission in vigilance paradigms (Cheyne, Solman, Carriere, & Smilek, 2009). Carter, Russell, Helton, (2013) also found that omission errors increased alongside impulsive commission errors over time in a SART. This finding is not unexpected and has also been observed in other studies using the paradigm e.g., (Johnson et al., 2007).

Early research on attention deficit and impulsivity in those with hearing loss tended to consider these problems to be the result of developmental deficits (Altshuler, Deming, Vollenweider, Rainer, & Tendler, 1976). These included speculation about auditory deprivation, impairments in the development of spoken language, family attitudes and parenting styles that are negative towards deafness, as well as greater isolation in the environment. It was concluded that the high impulsivity in deaf children was likely to represent functional reorganization in attention (Parasnis, Samar, & Berent, 2003). The current findings suggest there may be a simpler explanation of impulsivity when processing low intensity auditory information. Specifically, the problems with attention are not necessarily dependent on a long term deficit, but can occur when attending to low level stimuli for a relatively short period, and to stimuli that could still be accurately identified.

In summary, when performing a task that required sustained attention to enable successful auditory discrimination, impulsive erroneous responses increase compared to when listening to stimuli at a normal speaking intensity. This suggests that the optimal level of attention observed when participants could identify targets correctly before the start of the task was not present throughout the 13 minutes of the task. Given the general slower reaction times at low intensity, it is suggested that the mechanism by which lack of attention has its effect may be in the speed of processing (Logan & Cowan, 1984; Logan, et al., 1997; Molenberghs, et al., 2009). In the case of low intensity stimuli when attention is reduced, the time needed to identify the sound may exceed the time needed to interrupt the execution of the habitual motor plan; leading to the more frequent false alarms or errors of commission observed. These findings support the suggestion that errors made on monotonous continuous performance tasks are a consequence of effort rather than under-arousal (Grier, et al., 2003; Hitchcock, et al., 1999, Head & Helton, 2014) as more errors occur when the demand of the task is increased further. This finding in a population with normal hearing when completing a task at a low but still detectable level suggests an explanation of the impulsive responding that has been reported among those with hearing difficulties (Shinn-Cunningham & Best, 2008).

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