Cognitive processing during sleep: the role of signal significance and participant characteristics

Submitted by

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Declaration

I, Michelle Ball, declare that the PhD titled "Cognitive processing during sleep: the role of signal significance and participant characteristics" is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: Date:

Published papers (full length and refereed), reports and grants directly relevant to this thesis:

Ball M and Bruck D (2004) The salience of fire alarm signals for sleeping individuals. *Proceedings of the Third International Symposium on Behaviour in Fire*, Belfast, 1-3 October. London: Interscience Communications.pp 303-314.

This is Experiment 1.

Ball M and Bruck D (2004) The effect of alcohol upon response to different fire alarm signals *Proceedings of the Third International Symposium on Human Behaviour in Fire*, Belfast, 1-3 October. London: Interscience Communications. pp 291-302.

This is Experiment 2 (Note that n=12 in the paper, but 14 in the thesis because additional data that was not available at the time of publication has been included. The additional data has not altered the direction of results).

Bruck D, Reid S, Kouzma J and **Ball M** (2004) The effectiveness of different alarms in waking sleeping children. *Proceedings of the Third International Symposium on Human Behaviour in Fire*, Belfast, 1-3 October. London: Interscience Communications. pp 279-290.

This is Experiment 3.

Bruck D (2002-2005) Reducing fire deaths: a new approach to fire alarms. <u>Australian Research Council Linkage (APAI) Grant</u> $67,635 from ARC, $37,516 from industry partner (Onesteel).

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Watts, Hampton T, Bruck D and **Ball M** (2007) Examination of risk factors and mental health status in an accidental fire death population. Proceedings of the *7th Asia-Oceania Fire Science and Technology Conference*, Hong Kong, September (in press)

Thomas I & **Ball M** (2007) Waking effectiveness of alarms (auditory, visual and tactile) for the alcohol impaired. *Report for the US Fire Protection Research Foundation.* Can be accessed at http://www.nfpa.org/assets/files//PDF/Research/alcohol&alarmsreport.pdf

Bruck D, Thomas I and **Ball M** (2005/2006) Waking effectiveness of alarms (auditory, visual and tactile) for the alcohol impaired. *Grant from the US National Fire Protection Foundation*, $96,000.

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Bruck, D and **Ball M** (2005) Sleep and Fire: Who is at Risk and Can the Risk be Reduced? in *Fire Safety Science - Proceedings of the Eighth International Symposium.* Ed(s). Daniel Gottuk and Brian Lattimer. International Association for Fire Safety Science, London, UK. 37-51.

Hasofer, AM, Thomas IR, Bruck D & **Ball M** (2005) Statistical modelling of the effect of alcohol and sound intensity on response to fire alarms. *Proceedings of the 8th International Symposium of the International Association for Fire Safety Science*, Beijing, Sept 2005. pp 507-518.

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Note: Compact Disc of sounds in sleeve in back cover

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Abstract

Fire fatality statistics show that being asleep in a residential home is a serious risk factor for death in a fire. These statistics also show that this risk is increased according to individual factors such as being very young, or being under the influence of alcohol. Research has shown that sleeping children do not reliably respond to a smoke alarm signal (Bruck, 2001). No previous research has investigated the effect of alcohol on the ability to respond from sleep to a smoke alarm. The current project consists of a series of five studies that investigate the response from sleep of vulnerable populations such as children and young adults under the influence of alcohol to a smoke alarm signal. The purpose of the five studies included:

1. The development and testing of a new signal to be compared to existing manufactured beeping signals in the further studies;
2. Investigating the effect of alcohol on the ability of young adults to respond from deep sleep to three different auditory signals (high-pitched Australian Standard Alarm (ASA), a female voice alarm, and a mid-pitched signal in the temporal-three (T-3) pattern) under three alcohol conditions (sober, .05 blood alcohol concentration (BAC) and .08 BAC);
3. Testing several alarms with sleeping children including a message recorded by their mother using the child's name and stating there was a fire, a female voice alarm, and the T-3. This was then compared to existing data for the ASA from Bruck & Bliss (2000);
4. Investigating the response of sleeping young adults to a male voice alarm and a high-pitched T-3 in two alcohol conditions (sober and .08 BAC);
5. Ivestigating the response of sleeping young adults to naturalistic fire cues including a naturalistic house fire sound, a flickering light, and a combination of the two in two alcohol conditions (sober and .08 BAC).

Major findings from the series of studies include that alcohol significantly affected the ability of sleeping young adults to respond to a smoke alarm, even at .05 BAC, and that this effect was worse for males than for females. This effect persisted across all studies were alcohol was used, regardless of signal. The response of sleeping children to the ASA (57%) was significantly poorer than to a voice alarm recorded by their mother (100%), a female voice alarm (94%), and the T-3 (96%). The male voice alarm and high-pitch T-3 were both significantly better than the ASA in waking young adults, but methodological concerns may have affected results for the high-pitched T-3. Finally, light was found to be a poor stimulus in waking people from sleep, and there was no advantage to combining naturalistic stimuli in producing a response. It was concluded that alcohol significantly affects a person's ability to respond to their smoke alarm signal. Pitch and tonal complexity emerged as potentially important parameters that need to be further explored in relation to smoke alarm signal design.

CHAPTER ONE

GENERAL INTRODUCTION AND REVIEW OF LITERATURE

To the lay person notions of cognitive processing during sleep may seem far-fetched or strange. It is generally thought that the sleep state represents a period of complete cognitive quiescence. However it has been known for many years that this is simply not the case. In fact cognitive processing continues throughout the sleeping period which allows us to monitor our external environment for changes that may need our attention. It allows us to filter information from our surroundings to bring forward what is important specifically to us and to ignore what is not. This process permits awakening when necessary, but also promotes sleep maintenance to insignificant extrinsic stimuli. Consider the example of a breast-feeding mother's response to the cries of her newborn baby while her partner sleeps on beside her. The father is able to filter out the cry because he knows that the child does not require attention from him.

Cognitive processing during sleep has received attention in the research field as largely a theoretical concept of interest. However it is possible to use the results of this research for a most practical application, namely in exploring the human response to the smoke alarm signal. It has long been understood that information regarding human behaviour is important to apply to warning signal design, however research in the past has focused upon the behaviour of people who are awake. Yet it is widely accepted that the most vital role of a smoke alarm is to alert individuals to the possibility of a fire *when they are asleep*. Factors surrounding human response in general can contribute as much to the probability of a response to an alarm signal as characteristics of the alarm itself. These factors may come uniquely from within the individual, for example as a consequence of a person's age, or may relate to the way the person interacts with their environment, for example alcohol or substance use. Knowledge regarding individual risk factors for death in a fire can be examined in concert with research that has investigated individual differences in responses to external stimuli in an effort to optimise the success of the smoke alarm signal. Taken together this information has the potential to determine if improvements to the current smoke alarm are possible, or even necessary.

Possible benefits of combining research from engineering and human behaviour could be used to assist in determining optimal parameters for certain characteristics of the alarm signal, such as the most appropriate sound intensity, pitch, speed of signal, etc. These factors may or may not be independent of the risk factors for death.

It is also possible that improvements to the current smoke alarm signal could be made by incorporating knowledge from wider topics within psychology such as human perception. Simply put, perception pertains to the meaning that the human brain subscribes to incoming sensory experience. For example it is how incoming visual information is transformed into a meaningful percept rather than a crude jumble of shapes and colours. Knowledge regarding perception can be applied to smoke alarm signal design as it relates to enhancing the immediate meaningfulness and recognisability of a signal, regardless of whether a person is awake or asleep.

The importance of further incorporating knowledge about human behaviour into smoke alarm signal design is clear. Standards for smoke alarms have been developed in good faith with an emphasis on engineering concerns because information surrounding human interaction with smoke alarms is scarce. More research that explores human response to smoke alarms is vital to allow standards to be improved with the ultimate goal of saving lives.

Smoke Alarms

Brief History

In 2001 senior fire safety engineer with the United States National Institute of Standards and Technology (NIST) Richard Bukowski authored a most informative document regarding the history of smoke alarm use in the USA. The following paragraphs give an abridged account that is drawn from his more thorough paper.

Prior to the 1970's smoke alarms were very rarely used in residential properties. Before this time heat detectors were available to warn occupants of fire, but they were rarely used because effective systems required multiple alarms that could be prohibitively expensive. Then in 1971 Hurricane Agnes occurred in the USA and the Department of Housing and Urban Development purchased 17,000 mobile homes as part of the federal disaster relief effort. It was requested that the National Bureau of Standards (NBS; later to be known as NIST) implement fire safety systems in these homes of the highest standard up to the current knowledge. Based upon this, NBS instigated a requirement that single-station smoke alarms be placed outside the bedrooms of each unit. An enormous surprise emerged from fire statistics for these dwellings. Although the statistically expected number of fires occurred within the one to three year time period these homes were occupied, there were *no* fire deaths, and very few injuries. From these findings it was surmised that smoke alarms were effective in alerting occupants to the presence of fire before it trapped them. As a direct result of these findings, the US manufactured (mobile) housing industry adopted the first smoke alarm regulation. In 1975 the Mobile Home Manufacturing Association decreed that one smoke alarm was to be located outside the bedrooms in every manufactured home produced.

As a direct result of the above regulation NBS commenced investigation into the operation of smoke alarms and several problems with existing units were revealed. This lead to the call for effective product approval standards to be developed to ensure that they worked effectively and reliably. The residential smoke alarm industry was eager to work in close cooperation with NBS, and rapid development and improvement of smoke alarms occurred. Much of the work subsequent to this lead to standards being developed that made recommendations regarding the optimum number of smoke alarms needed, and their positioning.

In the early to mid 1970's full scale testing of smoke alarm performance was conducted through the Indiana Dunes Tests which were undertaken using commercially available smoke alarms that were installed in homes due to be demolished. On each occasion real furnishings were burned, and different conditions were put in place, eg. open versus closed doors. Instruments were used to monitored conditions in each experiment to judge how long it would take for unassisted escape to be no longer viable. In total, 76 separate experiments were conducted over a period of two years, in three different homes. Data obtained indicated that for optimum performance to be achieved, a smoke alarm needed to be located on every floor of the home.

The results of the Indiana Dunes Tests had far reaching and immediate impact in many areas. Laws began to be adopted across various jurisdictions that required the provision of smoke alarms on every level in new residential housing. Some jurisdictions went so far as to require installation of smoke alarms in existing residences. Montgomery County, Maryland, was the first to enact such an ordinance which became effective in 1978. Subsequent to this it was reported that the residential fire death rate began to decline.

Following the success of Montgomery County, most state or provincial building codes in the U.S. and Canada rapidly instigated mandatory smoke alarms. Compliance with these regulations was found to be unusually high, typically above 95%. There has been a decline in U.S. fire deaths by 50% between 1975 and 1998 that has been accredited largely to the smoke alarm (Bukowski, 2001).

However caution must be taken when interpreting Bukowski's claim. It would be erroneous to assume that the improvement in fire fatality statistics was solely due to improvements in smoke alarm technology or the compliance with smoke alarm regulations. At the same time many gains have been made throughout the building industry that have resulted in improvements in design surrounding fire protection including the use of materials that afford high levels of protection. The decline in fire related deaths is likely to be the result of improvements across the board that are inclusive of compulsory smoke alarms, rather than exclusively because of them.

In Australia the national building code has required that all new homes built after 1st January 1997 to be fitted with mains powered smoke alarms. Further legislation has been implemented by individual states that have extended this requirement to include compulsory alarms in existing residences, regardless of their age. For example in Victoria it has been compulsory since February 1999 for self-contained smoke alarms to be installed in all residential buildings. Similar legislation was adopted in New South Wales from May 2006, in Queensland from July 2007, and legislation is in place in South Australia, but not yet implemented.

Current Standards

Standards are documents which set down minimum requirements for the manufacture and appropriate use of goods that are developed for the protection of the interests and safety of consumers across the world. Individual standards are usually developed by committees comprised of experts from within the particular field of expertise. Standards organisations exist at both international and national levels. National standards are generally developed to follow the international standards with minor changes that reflect local policies or issues.

International standards exist which cover minimum requirements for several aspects of fire detection and warning devices. The most appropriate international standard that applies to the current study is ISO 8201 titled "Acoustics – Audible emergency evacuation signal" (International Organisation for Standardisation, 1987). Although it does not apply specifically or solely to smoke alarms it has been applied to dictate characteristics of the auditory signal emitted. Briefly, ISO 8201 includes the following important requirements:

- Temporal pattern – a three pulse temporal pattern is described. This pattern is known as the Temporal Three (T-3) and is comprised of a repeating four second cycle of three beeps and a pause. This is represented in Figure 1.1.

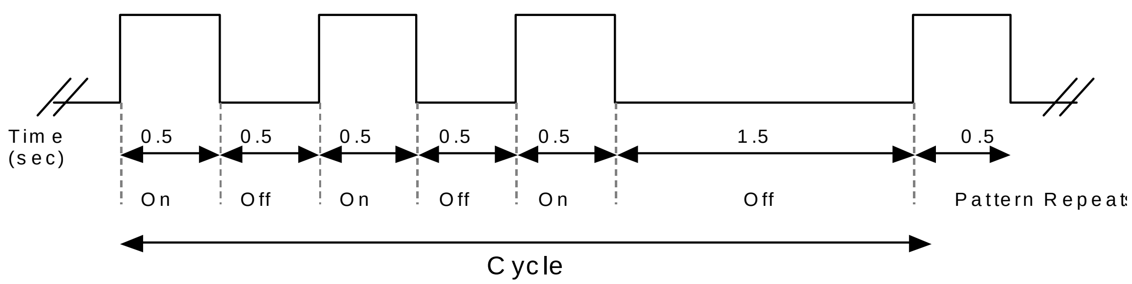


Figure 1.1. Temporal-Three Signal Pattern

- Recognition – The character of the T-3 signal must be clearly distinguished from other signals

- Sound pressure level – The A-weighted sound pressure level must clearly exceed the level of background noise in any given area, and must be received at not less than 65 dBA. **If the device is intended to arouse sleeping occupants, then the minimum sound pressure level is raised to 75dBA to be received at the bed-head with all doors closed**.
- Duration – The standard demands that the signal be repeated for a period of time not less than 180 seconds.
- Supplementary instructions – A key word or phrase may be included during the "off" phase of the T-3 signal. Examples given include FIRE! and GET OUT.
- Visual or tactile signals – These may supplement the auditory signal using the same temporal pattern of stimulus delivery.

ISO 8201 also includes possibilities for a frequency shift in the signal under requirements for the temporal pattern. However, no minimum or maximum pitch levels are included.

The US National Fire Protection Association (NFPA) includes requirements for the use of smoke alarms in sleeping areas (NFPA 72, 58, 7.4.4.1). The sound intensity is required to emit a signal that fulfils the greater of the following criteria:

- 15dBA above the average ambient sound level
- 5dBA above the maximum sound level having a duration of about 60 seconds, or
- 75dBA as a minimum measured at the pillow.

The T-3 has been adopted in the US and Australia as the required smoke alarm signal in accordance with ISO 8201. In Canada central alarms in public buildings are required to sound the T-3 signal, but smoke alarms are required to sound a signal that is significantly different to the T-3 (Proulx & Laroche, 2003).

The local standard in Australia at the time of writing was AS 3786 – 1993 (Standards Australia, 1993) titled "Smoke alarms". This is a comprehensive document covering all aspects of the manufacture and installation of smoke alarms, and only relevant information will be included here. The most pertinent information is on page 14, section 3.5 "Sound Pressure Level". The intensity required is an output of not less than 85dBA when measured at a distance of three metres. No mention is made of special requirements for when the alarms is to be used to alert sleeping individuals, but this information is included in other related Australian Standards. In standard AS 1670.1-2004 titled "Fire detection, warning, control and intercom systems – System design, installation and commissioning. Part 1: Fire" (Standards Australia, 2004) requirements exactly reflect ISO 8201 as outlined above for sound pressure level and frequency, however this standard applies to fire systems in buildings such as hotels rather than residential homes. A 2004 amendment introduced the T-3 as the required smoke alarm signal in Australia.

Smoke alarm audibility

When considering the effectiveness or otherwise of residential smoke alarms it is important to note that characteristics of the physical environment assert a critical influence over the audibility of alarm signals. There exists an endless possibility for differences between residential environments where smoke alarms are needed. Influential characteristics include the composition of the room (eg. concrete, wood, plaster, etc.) and its furnishings, and the dimensions of the room itself. Sounds have been found to be somewhat amplified in rooms containing mostly hard surfaces, such as a kitchen or bathroom, but somewhat attenuated in rooms with predominantly soft furnishings, thick carpets, and heavy curtains, such as a bedroom (Halliwell & Sultan, 1986b). Furthermore, sound is accentuated in a small room, and somewhat attenuated in a large room. More obviously, it will also be attenuated if required to travel from one room to the next, and further attenuated if it needs to travel through impediments such as closed doors (Halliwell & Sultan, 1986a; Lee, 2005). The impediment will be reduced if heating or cooling ducts are present because they provide an alternative path allowing the sound to flank around walls or doors through the vents. However the presence of an operating single room air conditioner will decrease audibility because they are known to generate a sound level of around 55dBA, and the smoke alarm sound level would need to be louder than this to be effective in waking a sleeping person (Lee, 2005). Importantly, the sound absorption that occurs due to furnishings and impediments such as walls and doors increases as the frequency, or pitch, of the signal increases (Halliwell & Sultan, 1986a).

Fire fatality statistics

A reduction in fire deaths has followed legislation that has improved fire safety measures including the mandatory installation of smoke alarms. Yet much remains to be done in ensuring that the mandated systems are operating at an optimal level. A persistent fact is that many needless deaths occur as a result of fire every year. Of course smoke alarms are not present or in working order in some cases, and in others their operation is moot. For example if a person accidentally sets their clothing alight while cooking, the success or failure of their smoke alarm to operate will make little difference to the outcome. However fire deaths do occur in cases where smoke alarms are present and working, and where their operation has the potential to make a difference. Are these people dying because they have failed to heed the warning of their smoke alarm? Or is it possible that for some reason they have not received the warning intended for them? The first step in answering these questions is to examine fire fatality statistics to seek patterns that might indicate particular areas of concern.

In usual circumstances, unimpaired adults aged below 64 years respond well to smoke alarm signals that are installed and operated within prescribed standards. Yet examination of fire fatality statistics from around the developed world reveal that being asleep in a residential home is a serious risk factor for death in a fire (Barillo & Goode, 1996; Brennan, 1998; Karter, 1986; Runyan, Bangdiwala, Linzer, et al., 1992). In an Australian study, Brennan (1998) reported that 66.7% of victims were asleep at the time of the fire. It was also noted that 86% of victims who died in a house fire between the hours of 8pm and 8am were reported to be sleeping. Thirty-one percent of those who died during daytime hours (8am to 8pm) were also asleep. Of sleeping decedents, it was determined that around 75% had not moved from their original location which implies that they were overcome without enough time to formulate an effective response, or without making any response at all (Brennan 1998). Other studies note that fatal fires are most likely to occur during the sleeping hours (approximately 11pm to 7am) (Barillo & Goode, 1996; Runyan, Bangdiwala, Linzer, et al., 1992).

Clearly, it is not always simply being asleep that increases a person's chances of dying. International studies have examined the risk factors for death in a fire and consistently found that age is an important factor, with very young children and the elderly being the groups most at risk (Australasian Fire Authorities Council, 2005; Barillo & Goode, 1996; Brennan, 1998; Karter, 1986; Marshall, Runyan, Bandiwala, et al., 1998; Runyan, Bangdiwala, Linzer, et al., 1992; Sekizawa, 1991). The reasons for the increased vulnerability of people in these age groups are largely intuitive. It is obvious that the very young and the very old are likely to have less capacity to respond to a fire emergency due to factors that may include reduced physical and cognitive resources. In fact it has been shown that the presence of an adult who is neither affected by physical or cognitive impairment nor under the influence of psychoactive substances increases the chance of survival for people in these age groups (Marshall et al., 1998). A recent study has also highlighted the importance of mental illness as a risk factor for death in a fire (Watts-Hampton et al., 2007).

If the above is true, then accidental fire deaths that occur in those aged between 18 to 64 years should be viewed as preventable. Yet people within this age group continue to fall victim to fires. Careful examination of data for such people has consistently implicated alcohol as a factor that significantly elevates an otherwise unimpaired person's risk for death in a fire. In fact presence of alcohol in the system has been found to elevate this risk factor to the extent that it matches the risk factor for the most vulnerable age groups (TriDataCorporation, 1999). Furthermore, alcohol intoxication has also contributed to the number of deaths that occur in children and the elderly. For example Marshall and colleagues (1998) reported that surviving carers were affected by alcohol in 15% of juvenile deaths. Most importantly, alcohol intoxication has been found to greatly increase the probability of death from fire across *all* age groups to the extent that it has emerged as the *single most significant risk factor* (Runyan et al., 1992).

International studies reporting examination of fire fatality statistics that have identified alcohol as a significant risk factor for death in a fire include:

1. Berl & Halpin (1978) examined data for deaths occurring as a result of 'rapid' fire (death within six hours of the fire incident) in the state of Maryland, USA for the period 1972 to 1977. They found that 50% of victims aged over 20 years showed a blood alcohol content (BAC) of above .10, classifying them as legally intoxicated. Further examination showed that approximately 70% of persons in the age group 30 to 60 years were legally intoxicated at the time of their death. This is interesting because fire fatality statistics actually decline for people in that age group, meaning that alcohol ingestion greatly increases the risk factor for death.

2. Paetta & Cole (1990) conducted a study examining coronial data for deaths resulting from fire in North Carolina, USA, during 1985. They reported that 56% of decedents tested for the presence of alcohol were legally intoxicated (.10 blood alcohol content [BAC] at that time).
3. Barillo & Goode (1997) conducted a study of fire deaths in New Jersey, USA, covering the seven year period from 1985 to 1991. They reported that alcohol was detected in the system of 29.5% of fire victims.
4. Squires & Busuttil (1997) conducted a study of the association between alcohol and fire fatalities in Scotland, UK, for the period 1980 to 1990. Their data showed that alcohol was present in the systems of 62% of fire victims.
5. Marshall, Runyan, Bangdiwala, et al., (1998) examined data collected by the medical examiner of North Carolina, USA, for fire deaths from 1988 to 1999. Of the cases where tests for alcohol were conducted, 53% showed a BAC exceeding .10.
6. McGwin, Chapman, Rousculp, Robison & Fine (2000) examined data of fire fatality victims in the state of Alabama, USA, for the period 1992 – 1997. They reported that over half of all victims tested positive for alcohol.
7. Sjögren, Eriksson & Ahm (2000) investigated data for all unnatural deaths in Sweden from1992 to 1996. Their results showed that 41% of all fire deaths were associated with alcohol use.
8. A recent Australian study which examined coronial data in the state of Victoria for the period from February 1998 to June 2005 observed that 71.2% of victims who had received a definite or probable diagnosis of mental illness at some time in their lives showed a BAC of .05 or greater. Thirty-five percent of victims without a diagnosis also displayed BAC at or over .05 (Watts-Hampton, Bruck & Ball, 2007).

Although sex differences were not investigated in all of the studies reported above, there is some evidence that males who die in a fire are more likely to have alcohol in their systems than females. Berl & Halpin (1978) reported that the overall death rate for males outnumbers females by 50%. They claimed that this was mainly due to the effects of alcohol, with males accounting for 66% of all intoxicated cases. Squires and Busuttil (1997) reported that 68.4% of males tested were found to have consumed alcohol compared to 54.3% of females. Further examination revealed that 63.3% of males and 48% of females tested had a BAC in excess of .08. Watts-Hampton (2006) reported that 63% of victims who displayed a BAC in excess of .10 were males. Finally, Sjögren and colleagues (2000) reported that unnatural deaths associated with alcohol were more than twice as likely in males, which included but does not specifically pertain solely to death in a fire.

Another important interaction with alcohol relating to elevated risk for death in a fire is cigarette smoking. This is likely due to the increased opportunity for ignition that occurs with a burning cigarette. In their review of English language studies spanning the years from 1947 to 1986, Howland & Hingson (1987) stated that eight of nine coronial studies cited indicated that alcohol was more likely to be found in the systems of victims of fire that was ignited by cigarettes. Other studies have similarly reported alcohol and cigarettes to be a lethal combination to the extent that the majority of smoking related fire fatalities show some direct connection with alcohol consumption (Paetta & Cole, 1990; Ballard, Koepsell, & Rivara, 1992; Watts-Hampton et al., 2007).

It is well established that a combination of risk factors is more lethal than any single risk factor on its own (Brennan, 1998). For example Watts-Hampton and colleagues (2007) observed that those who had received a diagnosis of a mental illness at some time in their life or who had displayed evidence of an undiagnosed mental illness were significantly more likely to die younger and to be undertaking risky behaviours such as drinking alcohol, taking drugs, or smoking cigarettes (Watts-Hampton et al., 2007).

The important risk factors described above include characteristics that are endogenous to the individual, such as their age, sex or mental health status. They also include factors that are exogenous to the person, but rather pertain to the activity being undertaken by them at the time of the fire. Dangerous activities outlined above include sleeping, drinking alcohol, and smoking. A combination of risk factors multiplies the chance of dying in a fire, so an elderly male who has a diagnosis of a mental illness who drinks alcohol and smokes cigarettes is at very high risk indeed.

Smoke alarms and sleep

The purpose of smoke alarms is to warn occupants of a fire with sufficient time for them to formulate an effective response. The safest and most effective response to a fire is often (but not always) evacuation, and so the most fundamental requirement is that they provide warning before tenability limits are exceeded.

When people are unimpaired and awake and in reasonable proximity to the fire, they will usually perceive smoke long before their detector triggers the alarm. Moreover, when people are intimate with ignition, as is the case in around 50% of fires, the operation of their smoke alarm becomes a superfluous issue. Where smoke alarms have a vitally important role to play is when people are sleeping, however their effectiveness for this is called into question because being asleep has also emerged as an important risk factor for death in a fire. Coronial reports of 114 fire fatalities in Australia noted that 81% of the fatal fires were at night and in those, 86% of victims were sleeping (Brennan, 1998). Therefore an important question for researchers is whether it may be possible to improve upon the current smoke alarm signal so that its effectiveness in waking sleeping individuals is improved.

Contrary to popular belief, the human brain remains in a very active state during sleep (Bonnet, 1982), and being asleep is by no means equal to an absence of conscious experience (Broughton, 1982). During sleep not only is our brain busy monitoring internal, autonomic processes such as blood pressure and body temperature, but it is also monitoring the immediate external environment for stimuli that may need our attention. This is of course why it is possible that sounds such as auditory alarms or hearing another person calling their name can rouse a sleeping person. Our life experience easily leads us to acknowledge the truth in this, and it has also been borne out by previous research which has shown that participants can produce a behavioural response to auditory stimuli during sleep, even without necessarily awakening (Badia, Harsh & Balkin, 1986).

During the night human sleep shows a cyclical descending and ascending pattern of cortical arousal, with each cycle being around 90 minutes in duration (Zillmer & Spiers, 2001). During each cycle we pass through progressively deeper stages of sleep from stage 1 (lightest stage) to stage 4 (deepest stage), and then sequentially back through the lighter stages, culminating in a period of rapid eye movement sleep (REM). Stages 1 to 4 are referred to as non-REM (NREM) sleep, and stages 3 and 4 are referred to as delta sleep as EEG patterns are dominated by low frequency high amplitude delta waves. Stages 1, 2 & REM are the lighter stages in depth of sleep, with REM sleep equivalent in depth to stage 2, and stages 3 and 4 are the periods of deep sleep. Throughout the night we cycle through these periods of roughly 90 minutes, spend differing amounts of time in each stage within each cycle. At the beginning of the night we are likely to cycle quite quickly through the lighter stages 1 and 2 and spend more time in the deeper stages of 3 and 4, followed by only a very brief period of REM. Later in the night the cycle will be dominated by lighter sleep, including longer periods of REM sleep.

The amount of time spent in the different sleep stages is known to vary according to age. It has been established that beyond infancy the amount of deep sleep experienced throughout the night decreases with increasing age. Approximately 50% of the sleep experienced by infants is REM sleep, and a smaller proportion of their slow wave sleep is spent in stage 3 than older children. In contrast people who have reached late middle age experience very little stage 4 sleep and a reduced amount of REM sleep, and time spent in stage 2 sleep is increased (Zillmer & Spiers, 2001). A significant relationship has been reported between age and general energy levels in EEG with a decline in energy levels being found to decline with increasing age (Aström & Trojaborg, 1992).

In keeping with the increased amount of deep sleep experienced by the young, it has been found that both the frequency of awakenings, and the intensity of a stimulus required to induce awakening, is related to age, with more frequent awakenings in response to lower stimulus intensity as age increases (Busby, Mercier & Pivak, 1994). It has further been found that six to seventeen year old children will not reliably awaken to an alarm signal (Bruck, 1999; Bruck & Bliss, 2000).

Responses to extrinsic stimuli are elicited more readily during the subjectively lighter stages of sleep, with equivalent waking thresholds found for stage 2 and REM (Rechtschaffen, Hauri & Zeitlin, 1966; Watson & Rechtschaffen, 1969), compared to the subjectively deeper stages (Rechtschaffen et al., 1966). In fact it can take considerable effort to arouse someone from stage 4 sleep (Zillmer & Spiers, 2001). This is illustrated when we consider that auditory arousal thresholds (AATs) normally progressively decline across the night (Bonnet, 1986; Watson & Rechtschaffen, 1969), which is commensurate with the declining proportion of time spent in deep sleep as sleep progresses (Klietman, 1963).

The responsiveness of sleeping individuals to auditory stimuli of differing dimensions is usually explored by assessing auditory arousal thresholds (AATs) using an ascending method of limits (Bonnet, 1982). The method of limits requires that an auditory stimulus be commenced at a low sound intensity level and be increased across discrete increments of strength over predetermined periods of time until the participant responds. For example Bonnet describes a typical method of limits study for which sound was commenced for five seconds at the assumed waking threshold, and increased at an intensity 5dBA greater after a period of ten seconds silence. These incremental increases in sound intensity were continued in the same temporal pattern of stimulus delivery and silence until the participant responded. This methodology allows an assessment of the threshold at which any given sound will cause a response (the AAT), which is thought to be sensitive to discriminating between the performance of different auditory stimuli. However Lukas (1975) points out that the probability of obtaining a result is not simply related to stimulus intensity, but also to stimulus duration. He asserts that the implication of this is that AAT values determined using the method of limits are likely to be biased towards giving the appearance that participants will appear to be more responsive than they actually are. It is believed he was referring to alterations in EEG patterns such as K-complexes or bursts of alpha activity, rather than an awakening.

Although the characteristics of normal sleep outlined above describes the usual sleep patterns for many, it is problematic for the designers of alarm signals that AAT research has revealed important individual differences that are likely to affect whether a sleeping person will respond to an auditory signal. In fact it has been suggested that individual differences account for more variability in AATs than sleep stage or age (Bruck, 2001). Some of these differences are linked to variations in normal sleep patterns. For example sleepy individuals (defined as sleep latency ≤ 5 minutes), and alert individuals (defined as sleep latency ≥ 10 minutes) who have been deprived of sleep, do not show the usual decline in AATs across the night (Rosenthal, Bishop, Helmus et al., 1996). Zimmerman (1970) has also claimed that increased reports of sleep mentation in a group of light sleepers compared to deep sleepers when awoken from stage 2 sleep is evidence of increased cerebral arousal in the former group. However it has also been found that AATs are not related to an individual's subjective judgement regarding their depth of sleep (Bonnet & Johnson, 1978). Additionally, it has been shown that sleep deprived young adults will not reliably awaken to an alarm signal, regardless of sleep stage (Bruck & Horasan, 1995).

Information processing during sleep

In the 1960's variations in the response of sleeping individuals to different signals began to excite the interest of researchers. Specifically it was explored why individuals might respond better to one signal over another. Two primary methodologies were used including observations of changes in autonomic responses to external stimuli and arousal thresholds to auditory stimulation. Findings of this body of research first put forward the notion that the salience of the auditory stimuli used was important. Oswald and colleagues (1960) found that participants responded significantly better to their own name than to another name during sleep. They also found increased response to a primed name, however this effect was not as marked as the response to own name. It was noted however, that these effects disappeared entirely during very deep sleep (SWS) (Oswald, Taylor & Treisman, 1960). Subsequent studies have continued to explore response to a person's own name with some variations in results. One study reported different response patterns to a participant's own name compared to different names and tone stimuli in REM and stage 2, but not in stage 4 (McDonald, Schicht, Frazier et al., 1975).

Given the increased attention that response to extrinsic auditory stimuli from sleep was attracting in the field one group of researchers set out to test whether complex psychological patterns operated similarly when participants were asleep compared to when they were awake. They set out to do so using different stimuli that were matched for equal loudness in phons, but of different physical intensities. They explained that lower frequency tones needed to be transmitted at a higher physical intensity to be judged as loud as higher frequency tones (see Robinson & Dadson, 1956) when people were awake. They found that the subject's level of arousal to the stimuli from slow wave sleep was directly related to its physical intensity, rather than the subjective judgement of loudness in the waking state, but arousals from REM showed the opposite (LeVere, Bartus, Morlock et al., 1973). They concluded that "the laws that relate an individual's responsiveness to acoustic stimuli during the waking state do not appear to easily transfer to the sleeping state" (p. 57).

In 1976, LeVere and colleagues investigated response of sleeping individuals to three similar but different signals using varying schedules of reinforcement. They found increased responsiveness to signals according to reinforcement schedule, especially during slow wave sleep. They suggested that stimuli that have a history of significance for the individual have a greater potential for intrusion into sleep, and that conversely, extrinsic stimuli that carry little significance might be ignored or possess reduced potential for arousal (LeVere, Davis, Mills et al., 1976). Subsequent research has provided ample supporting evidence in that the increased significance of auditory stimuli has been found to lower AATs, regardless of sleep stage, (Langford, Meddis & Pearson, 1974) and to increase the overall probability of a response (Williams, Morlock & Morlock, 1966). It has also been found that participants could discriminate auditory signals to which they had been motivated to respond to prior to sleep in all sleep stages, with motivating stimuli increasing response rates (Zung & Wilson, 1961). However a subsequent study reported that conditioned discrimination between different stimuli acquired during wakefulness persisted in sleep stages 2 and 4, but not during REM (McDonald et al., 1975).

Generally it has been concluded that cortical analysis of the meaningfulness of auditory stimuli precedes arousal. Most particularly it has been put forward that the sleeping brain effectively processes the emotional content of auditory stimuli. One particular group of researchers took a novel approach to explore this assertion. Auditory arousal thresholds were measured in response to stimuli of putatively different emotional content. Researchers used a vomiting sound as a negative stimulus, a jet plane flyover sound as a neutral stimulus, and a person humming a tune as a positive stimulus. Results showed that the negatively charged emotional stimulus (vomiting) lowered AATs particularly in stage 4 (Strauch, Schneider-Düker, Zayer et al., 1975).

In more recent times, research using functional MRI technology has confirmed that sounds with an affective significance lead to lower AATs and increase the probability of a response (Portas, Krakow, Allen, et al., 2000). It was found that *during sleep only*, presentation of a participant's name showed activation in the left amygdala and left prefrontal cortex. Since the role of the amygdala is well established in the processing of emotion (Zillmer & Spiers, 2001), it was concluded that the amygdala may process the affective significance of a participant's name and activate the prefrontal cortex to induce arousal. This is supported by neuropsychological research which has found that the amygdala can process emotional information directly, without cortical input. Most particularly a "pathway of learned fear" has been proposed which implicates the amygdala in the production of a physiological response to affective stimuli.

Purpose of the project

The purpose of the current project was to expand upon what is known about the response of sleeping individuals to smoke alarm signals with a view to identifying important factors for future investigation that may impact upon the improvement of international standards. To this aim a series of five studies was undertaken with a view to accomplishing the following:

- The first study (Chapter 2) was undertaken with the purpose of selecting and designing a new smoke alarm signal that would be used in later studies to test the response of groups who are currently vulnerable to death in a fire. This study was comprised of two separate phases.
    - Phase one took a novel approach to signal design. Several possibilities for innovative alternative signals were selected for pilot testing with sleeping individuals.
    - Phase two involved pilot testing between the new signals with the aim of producing a single stimulus for use in the ongoing project.
- The purpose of the second study (Chapter 3) was to test the newly developed signal against smoke alarm signals that are currently used in Australia and overseas with young adults in three alcohol conditions;
    - sober
    - .05 BAC
    - .08 BAC

- The third study (Chapter 4) compared the performance of the signals used in the second study with children aged between 6 to 10 years-old. An additional signal that was made up of a recording of the mother's voice delivering a scripted message in an urgent tone was also included.
- The fourth study (Chapter 5) was a preliminary investigation of two additional new signals that were developed specifically in response to the findings of the second study with young adults under the influence of alcohol. Only two alcohol conditions were included;
  - Sober
  - .08 BAC
- The final study (Chapter 6) was a preliminary investigation to explore the effectiveness of a flickering light as a stimulus with naturalistic appeal both on its own, and administered simultaneously with a naturalistic fire sound.

Where studies are described as preliminary they represent an extension of a previous experiment in response to questions and ideas that emerged from the findings. These studies were undertaken because they naturally evolved from the results of the previous study. Since a repeated measures design was used, any new ideas could only be tested using the same people who had participated in the earlier study, without extending the scope of data collection beyond the resources available. For this reason sample sizes are smaller, and the conclusions drawn would benefit from replication before they are considered substantive. Further details are discussed in each chapter where appropriate.

Ethics

All studies reported in this thesis received approval from the Victoria University Ethics Committee.

CHAPTER TWO

<u>EXPERIMENT 1</u>

The importance of the salience of auditory signals used to wake sleeping individuals: A novel approach to smoke alarm signal design incorporating signal selection and pilot testing.

Previous research conducted across several decades and using an array of methodologies has consistently found that sleeping individuals respond best to auditory stimuli that are of emotional significance. The emotional impact of signals would seem to be a very important consideration in the modern world where our lives are inundated with an assortment of beeps, bleeps and buzzes designed to remind us of an array of things that vary greatly in importance, for example the ring of a mobile telephone, the electronic alarm clock, the sound of a truck backing up, or the timer on a cooker. A direct consequence of our noisy lives seems to be that the salience of a beeping alarm signal has greatly decreased to the extent that many have become capable of ignoring such sounds (Bruck, 2001). It could be argued that the message of urgency has, to a certain extent, been lost.

A similar problem emerges when we consider signal recognisability. As has been previously discussed, since 1987 International Standards have recommended that the T-3 rhythmic pattern be used in evacuation signals (International Organisation for Standardisation, 1987). Recent research has found that few people are likely to correctly identify the Temporal Three Evacuation Signal as a fire alarm (Proulx & Laroche, 2003). When the signal was played to participants in public buildings in Ottawa, Canada, participants rarely identified the signal as a fire alarm or evacuation signal. Rather, the sound was frequently identified with domestic sounds such as a busy signal on a telephone, or an alarm clock.

This problem is not new. In 1984 Kahn used a General Electric model 4201-401 household smoke alarm in a US study that was designed to investigate the identification of fire related cues upon awakening. He reported that the alarm emitted a "bi-periodic signal peaking at 2000 and 4000 Hz" (p. 22). Results showed that only one of 16 participants was able to identify the sound as a smoke alarm signal despite extensive probing. Most subjects reportedly identified the signal as loud or high pitched, or simply as noise. Thus the difficulty in identifying smoke alarm sounds seems to have existed before the change was made to the T-3 pattern. Taken together, these findings suggest that research is required to address the problem of alarm signal salience from a different and novel perspective.

A different approach to signal design can be taken by returning to the basics of human perception and information processing. Recent innovative research has done this by drawing from Gibson's theory of perceptual affordances to develop alarms with sounds that closely matched the emergency situations within a hospital intensive care ward (Stanton & Edworthy, 1998). In 1966, psychologist James Gibson put forward a theory of perceptual affordances which stated that the way humans perceive an object is determined by our own experience (Gibson, 1979). He proposed that our perception is based upon our interpretation of what is being looked at (e.g. it can be climbed, sat on, used for shelter, etc.) rather than the purely physical aspects of what is seen (e.g., the size, colour, or shape). So if we see a rock with a flat, even surface we see something to rest upon or a seat, rather than simply just a rock. According to Gibsonian theory perception is enhanced if a stimulus is naturalistic and conveys meaning directly, with a minimum of interpretation (Gibson, 1979). Stanton and Edworthy (1998) found that naturalistic alarm signals that were representative of what they were trying to convey were more effective than the current beeping signals in alerting novice medical staff who were not trained using the current sounds. Staff who were already trained to work with the currently used generic beeping signals did not show this effect. What this suggests is that naturalistic alarms may be more effective in rapidly alerting untrained people to situations that need their immediate attention. This conceivably matches a fire emergency situation.

The idea of using a naturalistic signal in a smoke alarm is clearly novel, but what are the practical implications of this? One approach would be to use an alarm that transmits naturalistic fire sounds. Indeed it is well established that building occupants will not usually respond immediately to a beeping smoke alarm signal. It is usual for people to wait for confirmatory information or additional cues before taking action. Many studies have demonstrated that a common response to alarms is to misinterpret them in the first instance (e.g. Scanlon, 1979). This effect is increased in buildings where alarms are heard frequently, when it becomes highly likely that occupants will wait for further information before taking any action. Added to the findings mentioned above that people will often misidentify smoke alarm signals, a naturalistic fire sound has inherent appeal.

However it is important to note that an alarm transmitting naturalistic fire sounds has the added advantage of being directly representative of the immediate situation *only* if it can be distinguished from other environmental sounds. The sound of a roaring fire may be difficult to identify clearly, for example it may sound like static when played out of a speaker. The challenge is also to find a sound that is evocative of an emergency situation, so the sound of fire alone may not be enough. In the absence of other cues it may be evocative of a pleasant scene, for example many people find the sounds of an open fire soothing. In order to evoke a fire emergency any naturalistic fire signal would have to include other associated sounds. Indeed Brennan (1998a) reported that people who alerted emergency services to a fire in a neighbour's home often reported that the sound of glass breaking as the windows exploded was the first cue that roused their attention.

A second and less novel alternative approach would be to consider the use of a human voice for warning signals. On the face of it this is not a naturalistic sound as dictated by Gibsonian theory, but a human voice alarm does fit the criterion of the ability to convey direct meaning. It would also have distinctive appeal in that it has the possibility of directly conveying emotional significance, which we know to be important for waking sleeping individuals.

An extensive body of research exists in the field of ergonomics which has explored the way humans react to different auditory alarm signals for industrial applications. The research has found that individuals can successfully identify the emotion being conveyed when listening to recordings of actors delivering signal words or phrases (Banse & Scherer, 1996). The researchers studied 14 emotions including hot anger, cold anger, panic fear, anxiety, despair, sadness, elation, happiness, interest, boredom, shame, pride, disgust, and contempt. Accuracy of identification was best for hot anger, boredom, and interest. The authors reported that others which were identified at a less-than-chance level were usually confused with another emotion from the same 'family', e.g. cold anger confused with hot anger, or panic fear with anxiety. Specifically it was found that participants were able to identify emotions from the "fear family" (panic fear and anxiety) 63% of the time.

It has also been found that the words used within the message delivered by a voice alarm will influence its strength. The level of urgency perceived varies for different written signal words with 'deadly' and 'danger' perceived as most urgent, followed by 'warning', 'caution', and 'note' (Hellier, Edworthy, Weedon et al., 2002; Wogalter & Silver, 1990). These findings have also been replicated exactly when the words are presented as spoken (Barzegar & Wogalter, 1998) (minor exception is that 'note' was spoken as 'notice'). Most interestingly the level of hazard portrayed by these same words when written have been found to be equally understood by Chinese immigrants who could read and speak English, but for whom it was their second language, and native English speaking Londoners (Leung & Hellier, 1998). This was not true for signal words that are ranked as weaker in perceived urgency or hazard, where significant differences were found between the Chinese and English groups. Wogalter and Silver (1995) also compared the strength and understandability of a list of words across several groups including psychology undergraduate students, school children (4^{th} to 8^{th} grade), the elderly (residents of retirement homes, mean age 74), and non-English speakers (enrolled in an English as a second language class). They reported that the rank ordering of the signal words 'danger', 'warning', and 'caution' was consistent across all groups. They also compiled a list of words that could be understood by at least 95% of the youngest children studied and at least 80% of the non-English speaking participants, giving a total of 15 words (from an original list of 43). Of the words reported earlier, danger was ranked third, behind 'poison' and 'dangerous'. The other words 'warning', 'caution', and 'notice' appeared in that same order interspersed throughout the list of 15.

Most importantly for warning signal design it has been determined that the way in which signal words are spoken determines the believability, appropriateness, and most importantly, sense of urgency being conveyed (Edworthy, Clift-Matthews & Crowther, 1998). When the parameters of the voice that denote different emotional states are considered, it has been found that an increase in pitch of voice is equated with an increase in the perceived intensity of the emotion being conveyed, whether this emotion is positive or negative (Bachorowski & Owren, 1995). Along with increased pitch, urgency or high emotion is also conveyed by speaking louder (Hellier et al., 2002) and at a faster rate (Barzegar & Wogalter, 1998). Interestingly, it has also been found that the female voice is perceived as more urgent than the male voice (Barzegar & Wogalter, 1998; Hellier et al., 2002). These two results are in keeping with each other because the female voice is generally delivered at a higher pitch than the male voice. However caution must be taken in simply assuming that it is variations in pitch between male and female voices that is responsible for this phenomenon. There may be other social psychological factors that play a part. Regardless of whether the voice projected is male or female, human voice alarms are perceived as more urgent (Hellier et al., 2002) and intelligible (Paris, Thomas, Gilson et al., 2000) than computer synthesized voice alarms, even when the computer generated sound has been manipulated to convey urgency (Hellier et al., 2002). Paris and colleagues (2000) report that inappropriate breaks in the prosody of computer generated speech make it more effortful to process. According to Gibson's theory it might then be said that perception of the computer generated voice is less direct, whereas the human voice is naturalistic and perception is faster because less effort is needed.

Finally, in order to try to improve auditory warnings researchers have surveyed the subjective ratings of users of alarm signals across a wide range of industrial applications and used results to calculate an exponential function to indicate what level of proportional change was required to alter the perceived urgency, or urgency mapping, of a signal. The purpose of doing so was to enable researchers to predict the perceived urgency of a signal at the design stage. The exponents were calculated for five parameters including signal speed, repetition rate, length, pitch, and level of inharmonicity. Results predicted that the smallest alterations were required in the speed of the signal to cause a change in the perceived urgency of a warning signal, followed by repetition rate and length which were extremely closely matched, and again followed by pitch and finally inharmonicity (Hellier, Edworthy & Dennis, 1993). Levels of perceived urgency as rated by participants were found to match calculated levels to a very high degree. It was further found that the effects are additive, for example a signal with increased speed and repetition rate would be perceived as more urgent than one with increased speed alone.

The overall aim of Experiment 1 was to use Gibson's theory of direct perception to select and design a novel and naturalistic alarm signal that was to be tested against established smoke alarm signals in future experiments. This was carried out in two distinct phases. Phase one aimed to select appropriate stimuli to be developed into three signals for later pilot testing by posing questions to participants about emotional and attitudinal responses to different sounds. Both novel approaches outlined above, a *naturalistic* sound and an *urgent* voice signal, might be expected to stimulate an emotional cognitive response, which should facilitate arousal. Because the literature highlighted these two possibilities, a general approach was taken during phase one using the terms 'naturalistic' and 'emotional' as boundaries so as not to unnecessarily restrict the range of possibilities brought forward. The second phase aimed to incorporate the findings of phase one to design three new signals, and then to conduct pilot testing between them to determine which was the most successful in awakening sleeping individuals. This best new signal would be tested against the widely used established signals in subsequent experiments. The challenge was to design a meaningful signal that would awaken sleeping individuals most easily, that is at the lowest possible volume.

It was hypothesised that a more directly meaningful signal in keeping with the theory of perceptual affordances, and/or a signal with increased emotional significance, would decrease the required arousal threshold and therefore be more successful in waking those people currently at risk of not responding.

Each of the two phases of Experiment 1 study are presented as distinct from each other. The method, results and discussion of phase one are presented, followed by phase two. This was done because the results and discussion of each phase inform the next in turn.

PHASE ONE – Signal Selection

METHOD

Participants

Information was gathered from 163 individuals who were staff and students of Victoria University in Melbourne, Australia. Details were not formally collected regarding the age and sex of participants, however it is estimated that ages ranged from 17 to 65 years, and that approximately ¾ were female. The assumption regarding age was based upon the source of participants. The lower bound was assumed because students would have to have completed year 12 at secondary school before gaining entrance into University and were therefore unlikely to be aged under 17 years-old. The upper bound was assumed because University employees aged over the local retirement age of 65 years would be rare. The proportion of females was assumed from the names of respondents to a global e-mail, and because the majority of students who provided answers were observed to be female. In most cases participants provided multiple responses to the questions posed.

Materials

The following questions were designed to elicit a range of responses based upon the previously presented research concerning the success of stimuli with an emotional significance, and the necessity that a person will be awakened, and then respond to the signal.

The following three open-ended questions were posed to participants:

- What sounds would make you feel a negative emotion?
- What sounds would draw your attention when sleeping?
- What sounds would you feel the need to investigate upon awakening?

The terminology 'negative emotion' was used because it was intuited that a sound eliciting more positive feelings may not be a strong enough stimulus to cause a response. Further, a smoke alarm signal is designed to alert a person to the possibility of danger, so a positive sound was clearly incongruous and not compatible with this.

Procedure

The questions were put forward to students and staff by two methods:

Firstly a global e-mail was sent to all University staff requesting a reply to the author by return e-mail (see Appendix 1). The e-mail contained the questions as outlined above, but did not mention that the purpose of the study was to select a new smoke alarm signal because it was thought that this knowledge may unnecessarily restrict the range of responses, and valuable information may be lost.

Secondly, the researcher visited a number of undergraduate lectures and tutorial classes in the School of Psychology at the St Albans campus of Victoria University and gathered responses from students. Once again the purpose of the study was not revealed for the reason stated above.

RESULTS

Results were collated using SPSS Version 14, and frequencies of the different responses were examined. A total of 1447 individual responses from the 163 participants were received across the three questions combined, yielding over 130 different sounds. Responses varied widely between individuals, with many unusual sounds being put forward only once, for example "Ronan Keating's latest song" was submitted by one respondent for a sound that would make them feel a negative emotion. Resulting responses were ranked and the top fifteen sounds nominated with the highest frequency of response for each question are shown in Tables 2.1, 2.2 and 2.3 respectively.

Table 2.1.

Top fifteen most frequently nominated sounds that would induce a negative emotion in respondents.

Question	Rank	Sound	Freq.	% of total
What sounds would make you feel a negative emotion?	1	People yelling	27	6.1
	2	Sirens	25	5.6
	3	People screaming	24	5.4
	3a	People crying/sobbing	24	5.4
	5	People arguing	20	4.5
	6	Any high pitched sound	13	2.9
	7	Sound of a car crash	12	2.7
	7a	Screeching tyres	12	2.7
	9	A baby crying	11	2.5
	10	A child crying	10	2.2
	10a	People in pain	10	2.2
	10b	Gunfire	10	2.2
	13	Any loud sound	9	2.0
	14	Alarm clock	8	1.8
	15	Animals in pain	7	1.6
Total			222	49.8

Examination of the data shown in Table 1 reveals that some of the sounds nominated are very similar in quality, although they were put forward as distinctly separate notions. It was therefore considered useful to further collapse this data to reflect distinct groupings. For this question, most sounds could meaningfully be grouped under two distinct headings:

Expressions of human emotion – including all human sounds nominated; (sounds ranked 1, 3, 3a, 5, 9, 10, 10a giving a total of 126 responses or 28.25%); and

Manufactured alerting sounds- including any synthesised sound produced for the purpose of alerting individuals to a stimulus; (sounds ranked 2, 6, 13, and 14 giving a total of 55 responses or 12.3%).

This leaves sounds ranked 7, 7a, 10b, and 15 (31 responses or 6.9%) to be classified as 'Others', although it could be argued that all of these sounds (car crash, screeching tyres, and animal in pain) convey at least the potential for emotional distress of some kind.

Table 2.2.

Top fifteen most frequently nominated sounds that would draw a person's attention when sleeping, (N =534).

Question	Rank	Sound	Freq.	% of total
What sounds would draw your attention when sleeping?	1	Child crying or calling out	38	7.1
	2	Loud voices	24	4.5
	3	Dogs barking continuously	22	4.1
	4	Baby crying	21	3.9
	4a	Sirens	21	3.9
	6	Telephone ringing	20	3.8
	6a	Alarms	20	3.8
	8	Alarm clock	16	3.0
	9	Smoke alarm	15	2.8
	10	Loud bangs	14	2.6
	11	Any loud sounds	13	2.4
	11a	Tapping on window or door	13	2.4
	11b	Footsteps	13	2.4
	11c	Glass breaking	13	2.4
	11d	Screaming	13	2.4
	11e	Sounds that don't belong	13	2.4
Total			289	54.1

* Table actually includes 16 responses due to the lowest ranked sounds being nominated an equal number of times.

The responses in Table 2 can be collapsed similarly to those from Table 1 above.

Expressions of human emotion; sounds ranked 1, 2, 4, and 11d, giving a total of 96 responses (18%)

Manufactured alerting sounds; sounds ranked 4a, 6, 6a, 8, and 9, giving a total of 92 responses (17.2%).
Other; sounds ranked 3, 10, 11, 11a, 11b, 11c and 11e

The "other" sounds from question 2 are not so easily labelled. It could be argued that the remaining sounds are 'naturalistic alerting sounds', meaning that they would be out of place in the normal quiet of the usual sleeping hours. The assumption is made here that people reporting that such sounds would need to be investigated would find them unusual while they are asleep. The term 'naturalistic' is used here to contrast with 'manufactured', in that they directly relate to the stimulus with which they are associated. For example the sound of footsteps naturalistically alerts us to the possibility of an intruder, in contrast to a manufactured alarm which has been designed to alert a person to the possibility of an intruder ('burglar' alarm).

Table 2.3.

Top fifteen most frequently nominated sounds a person would feel the need to investigate upon awakening, (N =467)

Question	Rank	Sound	Freq.	% of total
What sounds would you feel the need to investigate upon awakening?	1	Child crying or calling out	31	6.6
	2	A disturbance in the house	29	6.2
	3	Sounds that don't belong	26	5.6
	4	Crying or screaming	22	4.7
	4a	Banging	22	4.7
	6	Glass breaking	21	4.5
	7	Dogs barking continuously	20	4.3
	8	Telephone ringing	18	3.9
	8a	Loud voices	18	3.9
	8b	Footsteps	18	3.9
	11	Alarm sounds	16	3.4
	12	Baby crying	15	3.2
	12a	Water dripping or rushing	15	3.2
	14	Smoke alarm	11	2.3
	14a	Door creaking or closing	11	2.3
Total			293	62.7

This set of sounds can be classified as follows:

Expressions of human emotion; sounds ranked 1, 4, 8b and 12a, giving a total of 86 responses (18.4%).

Manufactured alerting sounds; sounds ranked 8, 11 and 14, giving a total of 45 responses (9.6%).

Naturalistic alerting sounds; sounds ranked 2, 3, 4a, 6, 7, 8a, 8b, 12a and 14a totaling 167 responses (35.8%).

DISCUSSION

Results for all three open-ended questions revealed reasonably uniform categories of responses. When given the opportunity to nominate ANY sound within the bounds of the three questions put forward, people overwhelmingly referred to expressions of human emotion such as a baby crying or a person screaming, followed by manufactured alerting sounds such as a smoke alarm, and by other sounds that may naturalistically alert them to the possibility of danger, such as the sound of footsteps. There was considerable variation within each category, however the most frequent responses correspond well to the categories imposed.

It must be acknowledged that the organisation of the data into categories was guided by previous research findings and that the data could have been organised differently. However, the categories used captured all the data in a meaningful way and objectively indicated that for all three questions sounds that were either in the 'expressions of human emotion' or 'naturalistically alerting' categories were consistently ranked among the top first few.

As a result of the distilling process, new signals were developed from the 'expressions of human emotion' and 'naturalistically alerting' categories. No new signal was developed from the 'manufactured alerting sounds' category because the purpose of this project was to develop a new approach that would be tested against the current beeping signals, rather than simply another manufactured beeping signal. Further, development of another manufactured sounds is outside the scope of the current study because selecting meaningful parameters to be adjusted from the current signals would require in depth study and extensive testing. The 'expression of human emotion' and 'naturalistically alerting' categories also fit extremely well within what was expected from the literature.

The first new signal developed was from the category of a 'naturalistically alerting sound'. The development of this sound was not simply a matter of selecting one of the sounds nominated because the purpose of this research was to alert sleeping individuals to the possibility of a *fire*. Therefore, the sound selected needed to be situationally congruent, consistent with Gibson's theory of direct perception (i.e. that a stimulus is perceived more efficiently if its meaning is conveyed directly). Since participants were not told that the purpose of the project was to develop a new smoke alarm signal, their responses did not necessarily match this situation. Matching the situation is important because it allows a person to make swift judgments regarding the appropriate course of action. For example if the sound of footsteps was used as a smoke alarm signal, a person may be successfully awakened, but then have to process what the sound means from several possibilities, including that it may be a smoke alarm signal. This obviously would make no sense at all, and is not in keeping with Gibson's theory. To directly convey the message that there may be a fire in the home the new signal should then be a naturalistic fire sound. More specifically, it should include sounds that naturalistically occur during a house fire since the signal is to be used to alert sleeping individuals in a residential setting.

The overwhelming support from this data for a signal conveying an expression of human emotion is compatible with the research that suggests that sleeping individuals will respond best to a sound with emotional significance. Ethical considerations dictated that caution be exercised in the development of this signal because of the possibility of false alarms. It would be socially irresponsible to use the sound of genuine human distress because of the danger of desensitising people as a result of multiple pairings of such sound with no situation of distress or imminent danger, as is the case with repeated false alarms. The second signal developed was a female actor's voice conveying a message about fire delivered in an urgent tone. A female actor was preferred over a male actor because as mentioned above the female voice is subjectively rated by participants of previous research as more urgent than the male voice (Barzegar & Wogalter, 1998; Hellier, et al., 2002).

The process for the development and pilot testing of these signals is outlined in Phase 2.

PHASE TWO – Signal Development and Pilot Testing

Three new signals were developed and tested during phase two of this project including the naturalistic house fire signal and the female actor's voice signal. The third new alarm signal incorporated a shifting signal that alternates between the previous two sounds. It was thought that a shifting signal may be more successful since studies have noted major individual differences in auditory arousal thresholds (Bruck, 2001) and a shifting signal increases the chance that one of the sounds will be perceived and acted upon by sleeping individuals, even if the other is less successful with that particular individual.

A sample of deep sleeping young adults took part in the current experiment. All testing was carried out in Stage 4 sleep, the aim being to attempt to wake the deepest sleepers in the deepest stage of sleep. Young adults were chosen because it has been shown that auditory arousal thresholds decrease with increasing age (Busby et al., 1994), and because they have larger amounts of deep sleep than their older counterparts (Zillmer & Spiers, 2001), increasing the likelihood that three awakenings in Stage 4 sleep could consistently be achieved. Deep sleepers were specifically targeted to increase the possibility of discerning differences between the signals, the logic being that light sleepers could conceivably respond very quickly to all signals making distinctions more difficult to draw. It was thought that it would take higher intensity of sound to awaken deep sleepers, thereby reducing the possibility of a floor effect and maximising the generalisablility of results. It logically follows that the best sound for waking heavy sleepers in the deepest stage of sleep would also be the most successful with those who sleep more lightly.

The aim of Phase 2 was to perform pilot testing that would enable the best of the three new signals to be selected for comparison with existing alarm signals in future experiments. It was hypothesised that the voice signal would display the lowest auditory arousal threshold. No sizable difference in auditory arousal threshold was expected between the signal shift and voice alarm because it contained elements of *both* sounds, meaning that the signal shift also encompassed the aspects that were expected to make the dominant stimulus successful. The naturalistic house fire sound was expected to display a longer arousal threshold because although it was designed to be immediately salient according to Gibsonian theory, it may be perceived as slightly incongruous when coming from a speaker and hence may require a degree of interpretation before being properly identified and understood.

The method will be presented in two distinct sections – signal development followed by pilot testing.

METHOD – Signal Development

The following three signals were acquired or developed:

*Note that a copy of all sounds appears on a CD that is included on the back page of the thesis

Naturalistic house fire

The naturalistic house fire sound was purchased from the website *sound-effects-library.com* (Description – Explosion with glass & fire; Reference – s_378564). It was edited down to 30 seconds duration. It included the sound of glass explosions and the roaring, crackling, and popping of a fire (assumed to be a high energy fire). This sound was selected over a pure fire sound for two reasons. Firstly, because the addition of the glass and explosion sounds added to the naturalistic sound of a fire in a domestic dwelling, and secondly because people who alert emergency services to a fire in a neighbouring residence often report that it was the sound of breaking glass that drew their attention (Brennan, 1998a).

The further signals were constructed specifically for the current project.

Female actor's voice

The actor's voice was recorded in a single session using the equipment of the professional radio production suite at Victoria University. She was instructed to use an emotional tone, and speak as though she was alerting a loved one to the presence of a fire (see Barzegar & Wogalter, 1998). Specific direction was given that she should use her voice to emphatically project the emotional significance and ***urgency*** of the situation, but without the likelihood of inciting feelings of panic or hysteria (although these are known to be rare in emergency situations). She was further instructed that she must use the words DANGER and FIRE more than once, and that the message should instruct the person to WAKE UP and INVESTIGATE. Repeated recordings were made of the actor repeating each key phrase or word several times using different vocal intonations on each occasion. A number of different recordings were then made of the actor free-associating a message according to the instructions outlined above. The actor was paid $150.00 AUD for her services plus $10.00 AUD travel expenses.

The resulting message was constructed by editing together the phrases and words judged the most appropriate and emphatic using cut and paste tools. Words were selected that were spoken with an increase in pitch (Bachorowski & Owren, 1995). Repetitions of key words and instructions were included to emphasise the urgency of the situation and to make clear imperative instructions. The content was as follows:

> "DANGER, DANGER there is FIRE. WAKE UP. You MUST get up and INVESTIGATE, there is FIRE. GET UP NOW!"

Words presented in upper case were delivered with the most emphasis. Although it has previously been found that an increase in speed of delivery indicates increased urgency (Barzegar & Wogalter), this pertains to the delivery of single words. Since the actor's work was to be pieced together to form a script she was instructed to speak clearly and deliberately so that each of the signal words could be heard distinctly and the script could be comprehended as a whole. The duration of the message was 10 seconds, which was looped into a total of 30 seconds.

Signal shift

The signal shift was constructed by splicing together portions of the naturalistic house fire sound and the female actor's voice. The signal began with a 5 second edit of the actor's voice taken directly from the material reported above as follows:

> "DANGER there is FIRE. GET UP NOW!"

This was followed without pause by a 5 second edit of the naturalistic glass and fire sound that included the roaring, crackling and popping fire noises, as well as an explosion of glass. Total duration of the signal shift was 10 seconds, which was looped into a total of 30 seconds.

Sound Delivery Program

It was necessary to develop a computer program for the current study to administer sounds according to the modified method of limits. This program was made by staff of the Centre for Environmental Safety and Risk Engineering at Victoria University (CESARE) in consultation with the researcher.

As previously stated, the modified method of limits requires that stimuli be presented in increasing increments across time (in this case 5dBA). In order to maximise experimental control over these increments it was necessary to record a separate sound file for each 5dBA step (extending from 35dBA to 95dBA). Therefore for the program to operate as was required it was necessary to include 13 separate files for each of the sounds, one for each incremental step.

The individual sound files were recorded in the Victoria University television studio, located on the St Albans campus. This was necessary because the first sound intensity level required was 35dBA which is lower than the level of background noise in most rooms, especially on air conditioned premises. The television studio is a sound-proofed space with levels of background noise fluctuating around 30dBA. To record the sounds a set of stereo speakers was attached to the laptop, and a Lutron SL-4001 Sound Level Meter was placed at a distance of 1 metre from the speakers. 'A' weighting was always selected on the meter, and it was also set to hold the display of the maximum sound level. Each sound varied in intensity throughout its duration, so a sound designated 60dBA will have a maximum intensity at that level, although the levels may fluctuate considerably throughout, and it may be lower than the maximum for much of the signal. Original sound files were played using the Soundforge Nero Wave Editor program and the volume was adjusted up or down until the correct level was attained within a tolerance level of plus 2.5dBA. The sound meter was reset between each adjustment. Three settings were available on the sound level meter to be used when sounds of different intensity are being measured. These settings adjust the accuracy of the meter and include 30-80dB, 50-100dB, and 80-130dB. The 30-80dB setting was used for recording sound intensities from 35 to 60 dBA, the 50-100dB setting for intensities from 65-85dBA, and the 80-130 setting for intensities from 90-95dBA.

METHOD – Pilot testing

Participants

Participants for the pilot study were 8 self-reported deep sleepers (4M, 4F). They were recruited from amongst the student body of Victoria University, and their friends and family. Ages of participants ranged from 18 to 25 years (mean = 21.63, sd = 2.00) and they were paid $50.00 per night as compensation for the inconvenience sustained in participating in the study. Individuals reporting any hearing difficulties, sleep disorders or neurological conditions that may have affected their ability to perceive or respond to an auditory signal were excluded from the study.

Materials

Testing mostly took place in participants' own homes, with the exception of two participants (1M, 1F) who requested that they be tested in the Victoria University Sleep Laboratory to avoid disruption to their families by alarm signals sounding during sleeping hours. Polysomnographic recordings were conducted using the Siesta wireless data acquisition system whereby electroencephalogram (EEG) is monitored by a portable unit that can be easily carried or strapped to a belt worn by the person. This allowed participants the freedom to move about without being anchored to the recording equipment. The Siesta transmitted EEG data via radio waves to a laptop monitored by a research assistant in another room of the house. The automated sound delivery system to initiate and control the alarm sounds was also operated from the laptop computer.

Sounds were emitted from a set of stereo speakers that were placed at a distance of at least one metre, and no more than two metres from the centre of the participant's pillow. The speakers were permanently joined with one on each side of the sub woofer to ensure standard configuration in all rooms. There were always placed directly facing the pillow. They were attached to the laptop via a ten metre extension cord. Sound levels were measured using a Lutron SL-4001 Sound Level Meter.

A button was placed beside the bed to receive the participant's behavioural response. This button illuminated a small blue light located near the research assistant when pressed by the participant. The behavioural response button and light were also connected via a ten metre extension cord.

Procedure

The sounds delivered were the Female voice, the Naturalistic House Fire Sound and the Signal Shift as described earlier. All were delivered on a single study night, with order of presentation counterbalanced across participants.

Data was collected by the researcher and three paid research assistants (1 male and 2 female) who were Honours or Postgraduate students in the School of Psychology at Victoria University. Every effort was made to match the sex of the research assistant to the participant. When this was not possible, participants were asked for their permission for their data to be collected by a person of the opposite sex.

Recruitment fliers advertising the study were posted on student noticeboards across the Footscray Park and St Albans campuses. Additionally, the researcher visited several lectures giving a brief explanation of the study and distributing information to interested students. In all instances students were asked to contact the researcher to register their interest. Information letters were then posted to all who registered (see Appendix 2). A follow-up phone call was made to confirm interest after which the participant was assigned to a research assistant (RA) who would contact them to arrange a mutually convenient time for the study to take place.

The RA arrived at the participant's home at a prearranged time one hour prior to the participant's usual bedtime (as nominated by them). The electronic equipment was set up including the laptop, speakers, and behavioural response light. Sound levels were then calibrated at the pillow. This was an important step because the size and configuration of different rooms, including the weight and positioning of furnishings, are known to affect the audibility of sounds (Halliwell & Sultan, 1986). The sound meter was placed in the centre of the pillow and the 60dBA T-3 signal was played continuously (see experiment 2 for a description of the T-3 signal). The RA then adjusted the volume on the speakers until the sound meter displayed 60dBA (+/- 3dBA).

After the equipment was correctly set up and the sound level calibrated, the electrodes for polysomnographic recording were applied. The participant was asked to be changed for bed prior to electrodes being put in place. Electrodes were attached according to the standard placement set down by Rechtschaffen & Kales (1968). Electroencephalogram (EEG) electrodes were attached at C3, C4, A1 and A2. Electro-oculogram (EOG) electrodes were placed at approximately 1cm above the outer canthus of the eye on one side, and at approximately 1cm below the outer canthus of the other eye, and electromyogram (EMG) electrodes were placed beneath the chin. Additionally, a reference electrode was affixed to the middle of the forehead, and a ground electrode was placed at the collarbone. Electrode placement is demonstrated in Figure 2.1.

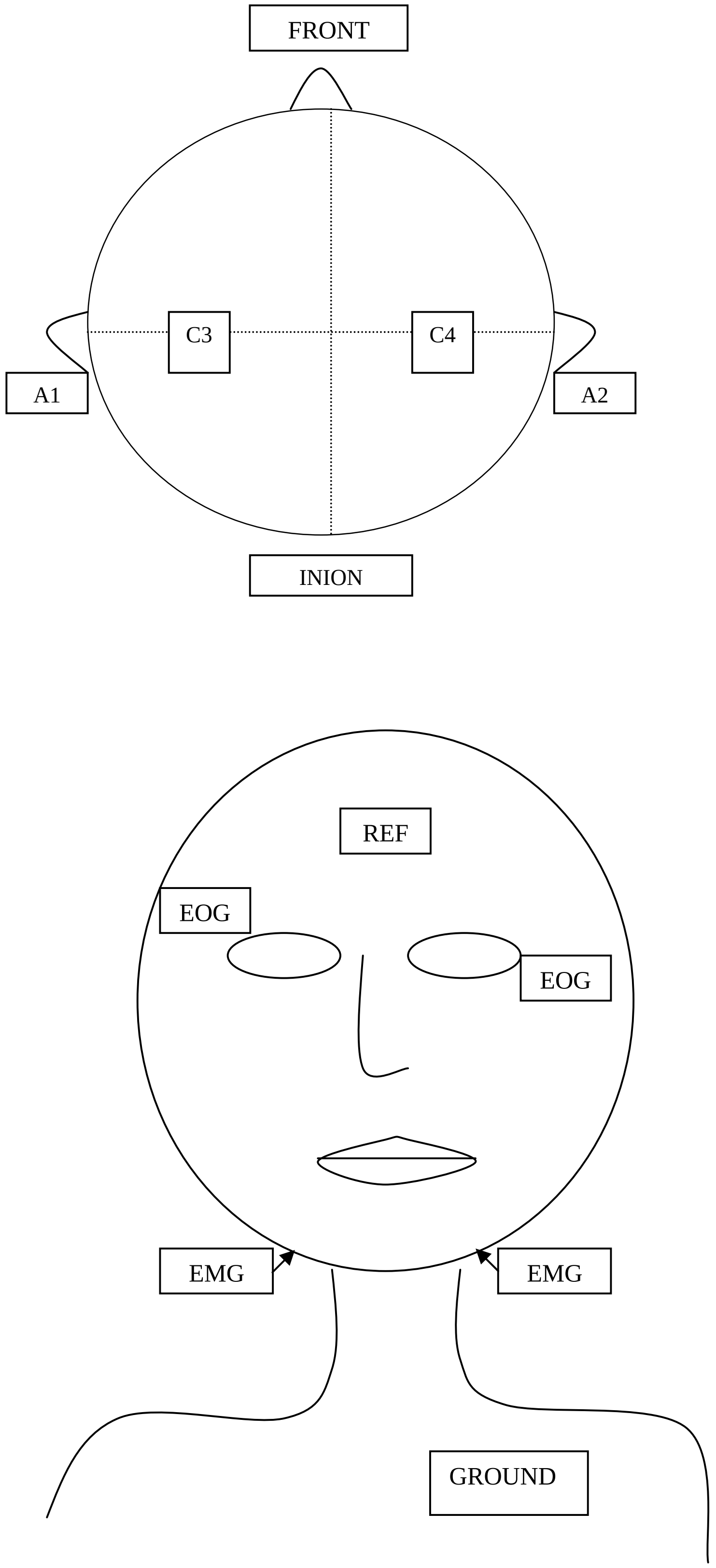


Figure 2.1. Electrode placement

Before electrodes were attached, the skin was cleaned first with an alcohol swab, and then with Nuprep abrasive cream. Gold cup electrodes were used for C3 and C4, and minidot snap-on electrodes were used for all others.

After the participant was prepared for polysomnograhic recordings they went to bed and the lights were extinguished. Prior to lights out they were instructed on the procedure to follow when they became aware of the signals sounding. Immediately upon becoming aware of a signal, they were asked to depress the behavioural response button placed next to their bed three times to signify that they were awake. After lights were extinguished, the RA monitored the participant's EEG output until Stage 4 sleep was confirmed for a minimum of three consecutive 30 second epochs in keeping with to the criteria laid out by Rechtschaffen & Kales (1968). Once stage 4 sleep was confirmed the sound delivery system was activated to start the required sound through the speakers in the bedroom at the lowest experimental level. All sounds were presented using the modified method of limits. Sounds were commenced at 35 dBA, which corresponds generally to the sound intensity of a whisper. The volume was then increased in 5 dBA increments up to a maximum level of 95 dBA, which is equivalent to loud industrial noise. The sounds played continuously for 30 seconds at each volume level, followed by an equal period of silence before increasing to the next level. This time period was chosen to allow participants ample time to respond at any given intensity. It has previously been stated that if people are going to respond to their smoke alarm, then it will usually occur within the first 30 seconds of it sounding (Bruck & Horasan, 1995).

When a participant responded by depressing the behavioural response button, the research assistant notified the sound delivery programme to record the exact time, and the sound was immediately ceased. If there was no response after 30 seconds at 95dBA (the highest level), the sound continued for a further three minutes without an intervening period of silence before being terminated spontaneously. All behavioural response times were calculated as number of seconds from sound commencement.

All EEG response times were calculated as number of seconds from sound commencement to the first sign of wakefulness which was determined from the EEG. The assessment of the EEG was carried out independently by the researcher and the research supervisor (Professor Dorothy Bruck). Each assessor independently examined the EEG trace of all participants to determine the exact moment of awakening according to the criteria established by Rechtschaffen & Kales (1968). Specifically awakening was considered when the EEG pattern changed to very high frequency very low amplitude waves. This was usually accompanied by alterations in both the EMG (muscle tome) and EOG (eye movements). The following epoch was also perused to ensure that there was a period of sustained arousal. Both researchers conferred regarding disputes and an exact time was documented.

Data Analysis

It was planned to use Repeated Measures Analysis of Variance to calculate differences response times. The independent variable of 'Sound' comprised three levels corresponding to the Naturalistic House Fire, the Female Voice, and the Signal Shift between the two. The time taken to EEG response was the dependent variable, and alpha was set at .05.

A significant strength of repeated measures statistics is that they eliminate variance in the equation that is due to differences between individuals. This makes them a particularly powerful statistic. They are also generally robust to small violations in their underlying assumptions, and need smaller sample sizes to find real differences where they exist (Gravetter, 2006). On the negative side, missing data collection for just one single data point for any individual means that all of their data will be excluded from the analysis. Further, repeated measures designs are vulnerable to practice effects since each participant is exposed to all levels of the independent variable. Practice effects can be minimised by presenting levels of the independent variable in counterbalanced order across participants (Brace, Kemp & Sneglar, 2003).

The assumptions of Repeated Measures ANOVA are as follows:

- Normal population distribution
- Homogeneity of variance
- Homogeneity of covariance

Normality is reasonably assumed for the variables measured in the current study.

Homogeneity of variance is measured using Mauchly's test of Sphericity, which is routinely calculated by SPSS when ANOVA is performed. The assumption of sphericity is violated if the 'p' value of this test is significant. When not violated, the 'Sphericity Assumed' numbers can be examined. When violated, the 'Hynh-Feldt' or 'Lower Bound' tests should be used (Brace, Kemp & Sneglar, 2003).

During data analysis a problem emerged that was directly related to the methodology of the current study. Past studies using the method of limits have presented stimuli of only short duration, punctuated periods of silence. For example Rosenthal et al (1996) used a sound duration of two seconds followed by ten seconds of silence, and Bonnet and Johnson (1978) presented a signal of two seconds duration followed by a period of 30 seconds silence. When describing typical use of the method of limits, Bonnet (1982) described methodology where sounds were presented for five seconds punctuated by periods of fifteen seconds silence. For the purposes of the current study, the duration of presentation of a sound at any given intensity was 30 seconds, followed by 30 seconds of silence. As has been explained, the length of stimulus presentation was selected in order to maximise the opportunity for a response at any given level. It was also thought that 30 seconds of stimulus presentation would increase the ecological validity of the study because smoke alarms sound continuously.

However as can be seen ahead in the results section there was enormous variability in mean response times between participants. This was because *both* the signal delivery and silence times were of such considerable length, each being 30 seconds. Consider the situation in which one participant was awakened quickly by a signal at its lowest level (35dBA). This person's EEG response time would be less than or equal to 30 seconds. Now consider results for an individual who did not awaken until the sound intensity reached the highest level of 95dBA. Incorporating both sounds and silences, this person's response time would be between 720 and 780 seconds. As a way to alleviate (but not eliminate) this concern it was decided to partial out the periods of silence from the equation. There were two possible ways of achieving this aim. One was to subtract from the total response time the accumulated amount of silence for each signal presentation, but this would not accurately reflect results if a person happened to awaken during a period of silence rather than during stimulus presentation. The other alternative was to consider silence as a separate variable whose influence could be held constant between participants by entering it as a covariate in the calculation of statistics. This latter method was selected. It was valid to consider silence as a separate variable because it could be measured as a discrete and continuous variable that shared a linear relationship with the dependent variable (Brace, Kemp & Sneglar, 2003).

All statistics were calculated using SPSS version 14. Output for all statistics appears as Appendix 3.

RESULTS

Means and standard deviations for EEG response times and AAT at EEG awakening were calculated for each sound. These are presented in Table 2.4.

Table 2.4.

Means and standard deviations for EEG response time and EEG auditory arousal threshold to three different signals, (N = 8).

	Naturalistic House Fire		Actor's Voice		Signal Shift	
	M	SD	M	SD	M	SD
EEG response (secs)	198.00	172.84	167.00	147.81	203.13	208.85
AAT (dBA)	50.00	14.39	47.50	12.82	51.25	17.47

Aside from large standard deviations across all signals, examination of Table 2.4 shows response times for the naturalistic house fire sound and the signal shift to be closely matched, and the voice alarm to somewhat more successful. The Analysis of Covariance (ANCOVA) found significant difference between the response times to the different sounds $F(2,8) = 4.77$, $p = .043$. Perusal of the means presented in Table 2.4 show that the actor's voice was the most successful signal, with little difference found between the naturalistic house fire sound and the signal shift.

DISCUSSION

The hypothesis that the voice signal would display the lowest auditory arousal threshold was supported. However the expectation that no difference would be found between the signal shift and voice alarm was not supported. The hypothesis that the naturalistic house fire sound was expected to display a longer arousal threshold was supported.

It was somewhat surprising that the signal shift did not perform as well as the voice alarm because it incorporated a portion of the actor's message. It is possible that the advantage of the complete actor's voice signal was that the message was more detailed and contained repetition of key words, thereby enhancing both the understandability of the message, and its emotional significance. It is possible that the slower mean response time for the signal shift is more informative about the recommended length of a voice signal when it is to be used to awaken sleeping individuals, rather than the success of a signal shift in itself. Future research could explore the optimal signal length for voice alarms.

Both new alarm signals were thought to have the apparent advantage of directly conveying information, however the voice alarm would seem to have the added benefit of also conveying emotion. The problem with the naturalistic house fire sound may be that it is not effective in isolation. Since an actual fire would result in stimuli being processed in several sensory modalities simultaneously, perhaps the presence of an auditory stimulus alone is insufficient to produce arousal until it reaches a higher intensity. This would explain the advantage of the actor's voice because the emotion is able to be conveyed equally and as directly as the immediately salient information.

It must be noted that this study is preliminary only. The sample size of eight individuals is not sufficient to claim conclusive findings, but is adequate for a pilot study. The substantial standard deviations are accounted for by the fact that the sample size was not sufficiently large to absorb the effects of the considerable variability between individuals, and stems from some participants being awakened at the lowest volume level, while others responded at the higher levels. The addition of 30 seconds of silence between the increments of sound added to this problem. However the results are sufficiently robust considering that the current project serves merely as a pilot study that was designed to select a single new signal that will be tested against existing signals.

CHAPTER THREE

EXPERIMENT 2

The effect of alcohol upon behavioural response times to different alarm signals in deep sleeping young adults.

As was noted earlier alcohol has been identified as the single most significant risk factor for death in a fire. Other risk factors have also been found to combine with alcohol to increase vulnerability including being male, smoking cigarettes, and suffering a mental illness.

It is relatively simple to make the connection between alcohol intoxication and death in fire through the examination of blood assay results of victims. However without eyewitness accounts, it is less easy to determine in what way the alcohol affected the person's ability to survive. The physiological effects of alcohol are well documented, and a relationship between alcohol intoxication and overall chance of suffering accidental injury or death is firmly established. It is suggested that the effects of alcohol elevate the risk for death or injury in a fire in the following ways:

- By affecting a person's ability to perceive the signal coming from a smoke alarm
- By affecting their ability to correctly interpret the alarm signal once it has been heard
- By reducing the effectiveness of cognitive processing, thereby increasing the chance of an inappropriate response, such as failure to avoid a dangerous pathway

- By adversely affecting motor functioning, for example causing poor balance and coordination which can delay and reduce the effectiveness of escape behaviour

The increased mortality rate for those who have been drinking is a very important issue for young adults who are perhaps less experienced drinkers than their older counterparts, and whose lifestyle traditionally provides more opportunities for partying, but who also have more deep sleep. This has been tragically highlighted in a number of campus accommodation fire deaths in the USA where alcohol use was implicated (Comeau, 2001). A recent survey undertaken by the Salvation Army in Australia reports that binge drinking in young adults is becoming a rapidly increasing problem for society, with 35% of teenage males, and 22% of teenage females admitting to binge drinking on occasions (RoyMorganResearch, 2003). Given the relationship between alcohol intoxication and elevated risk for mortality in a fire, this group are engaging in behaviour that potentially leaves them very vulnerable.

Although many hypotheses have been put forward to explain the elevated mortality rate when alcohol is involved, no previous systematic research has been undertaken to investigate whether this is due to victims' failure to awaken to their smoke alarm, or whether they awaken but are too impaired to take the appropriate steps to save themselves. This is a vitally important question for fire safety research because both possibilities have very different implications. Alarm signals are designed to alert individuals to the possibility of threat with sufficient time to take action. The outlook for avoiding injury or death is therefore substantially worse for a person who is not awakened by their alarm because they will be denied the opportunity to act, unless something or someone else alerts them in time.

The effects of alcohol on sleep may alter the way a person is able to respond to their smoke alarm. Alcohol ingestion does not alter the amount of time spent in each sleep stage across the night, but has been shown to cause changes in the distribution of the various sleep stages, or 'sleep architecture'. Changes pertaining to deep sleep include that the amount of deep sleep experienced in the early part of the night is increased (Landolt, Roth, Dijk et al., 1996), but decreased in the later hours (Stone 1980). It has also been suggested that alcohol ingestion alters EEG power density in non-REM sleep including increases in the delta waves associated with deep sleep (Dijk, Brunner, Aeschback et al., 1992; Landolt et al., 1996). Taken together these findings are likely to suggest reduced ability to respond to external stimuli in the early hours of sleep.

Since time to evacuation is a critical element for survival in a fire, the time taken to awaken and respond to a smoke detector alarm signal is important from a fire safety perspective. But is a beeping alarm signal a sufficiently effective stimulus? It is well established that sleeping individuals are able to discriminate between different auditory stimuli when asleep (Kahn, 1984; Langford, Meddis & Pearson, 1974; LeVere, Davis, Mills & Berger, 1976; Oswald, Taylor & Triesman, 1960; Portas et al., 2000) and it is purported that they respond best to signals that are immediately salient (Wilson & Zung, 1966) or that have an emotional significance, for example their own name (Portas et al., 2000). If speed and reliability of arousal are important factors, perhaps a beeping signal is not the most appropriate sound to use when alerting sleeping individuals to the possibility of a fire, as an electronically generated beep may not be perceived as of emotional significance. In fact, when beeping alarms are heard, it has been found that many people are unlikely to recognise the sound as a fire alarm (Kahn, 1984; Proulx & Laroche, 2003). It has been suggested that the salience of beeping alarm signals is diminishing in the context of modern life (Bruck, 2001). With this in mind a voice alarm was developed and tested in Experiment 1 and found to be an effective stimulus compared to a naturalistic house fire sound and a signal that shifts between a voice and fire sound. The key advantage of voice alarms was thought to be that they can be spoken in an *emotional* tone, and can also directly convey their meaning through the words spoken. If the characteristics of emotional tone and direct meaning are primary, then a voice alarm should be more effective than any beeping signal in waking individuals from sleep.

The aim of the current study was to explore the arousal threshold of deep sleeping young adults in the deepest stage of sleep (Stage 4), to three different alarm signals including a Female Voice alarm, the rapid-paced high-pitch beeping smoke alarm signal found in most in Australian homes and the Temporal-Three (T-3) beeping alarm that has been adopted as the International Standard evacuation signal (ISO 8201). Most importantly, the research also aimed to explore the arousal threshold to these signals in three different alcohol conditions; sober, .05 blood alcohol concentration (BAC), and .08 BAC, and to compare performance across the sexes .

The alcohol levels of .05 and .08 BAC were selected to represent 'mild' and 'moderate' levels of intoxication. These figures were selected based upon the standards imposed by society regarding legal driving limits. In Australia the .05 BAC level is uniformly used across all states and territories as the legal driving limit. Legal limits vary across state lines in the USA from .05 to .08, and even .10. The implication of these limits is that a person's performance is impaired by alcohol if they exceed them. It was decided that the maximum alcohol level should be .08 BAC for the current to study to protect the health of participants. This limit was imposed in an effort to minimize the risk that a person would become ill or injured as a result of the alcohol consumed for the study.

It was hypothesised that participants would respond to the Female Voice alarm at the lowest volume, and in the fastest time, but that no significant difference in the response patterns to the two beeping signals would be found. It was also hypothesised that for all signals, participants would respond at the lowest volume and with the most speed when they were sober, followed by .05 BAC, and then .08 BAC. Differences in response patterns between the sexes were not expected.

METHOD

Participants

Participants for the current study were recruited from the student body of Victoria University, their friends and family. Complete data was collected from 14 participants (7 male, 7 female) aged from 18 to 26 years (mean = 21.1, sd = 2.2). Several of the participants from Experiment 1 also took part in this study.

Participants were required to be "regular drinkers" of alcohol according to the definition laid down in the National Drug Strategy (1998). To fit this criteria they needed to report drinking alcohol on at least one night per week. This was an ethical decision to try to avoid alcohol causing sickness in participants. Non-drinkers were excluded from the study, as were those who reported any hearing difficulties, sleep disorders, or neurological conditions that may have affected their ability to perceive or respond to an auditory signal. All sleep testing was carried out in participants' homes in order to increase the ecological validity regarding response to auditory alarm signals during the sleeping hours.

Materials

Equipment for polysomnographic recording and the delivery of sounds was the same as for Experiment 1.

The alcohol used for the current study was vodka (Smirnoff, 37.5% alcohol volume). This was mixed with unsweetened reconstituted orange or cranberry juice, according to participant preference. A Lion Alcometre S-D2 breathalyser was loaned to the study by the Victoria Police to measure blood alcohol content (BAC). This unit was recalibrated every 3 months to ensure accuracy of measurement. Victoria Police advised that the Lion Alcometre was a preliminary breath testing unit only, and that a confirmatory blood assay of BAC was also required when it was used by them.

Unit Specifications

The manual describes that the Lion Alcometer S-D2 measured the concentration of alcohol vapour in expired breath by using an electrochemical fuel cell which contained two platinum electrodes. This fuel cell generated a small voltage that was directly proportional to the amount of alcohol concentration present in breath that is drawn into the unit (Lion Laboratories, 1982). The exact specifications of the unit are reported as follows:

Model	Lion Alcometer S-D2
Detector	Electrochemical fuel cell
Specificity	Responds only to alcohol in breath and is unaffected by other possible contaminants, such as acetone
Accuracy	+/- 10mg per cent blood alcohol concentration around the calibrated level
Analysis time	Approximately one minute per test.
Dimensions	120 x 63 x 30mm

Adapted from Lion Alcometer Manual (Lion Laboratories, 1982)

The effectiveness of the following three sounds was compared:

Female Voice

The human voice alarm developed during Experiment 1 was used. This signal was a female actor’s voice that warned of danger due to fire in an emotional tone, and said that the person must wake up and investigate. The parameters of the pitch of this signal are shown below in Figure 3.1.

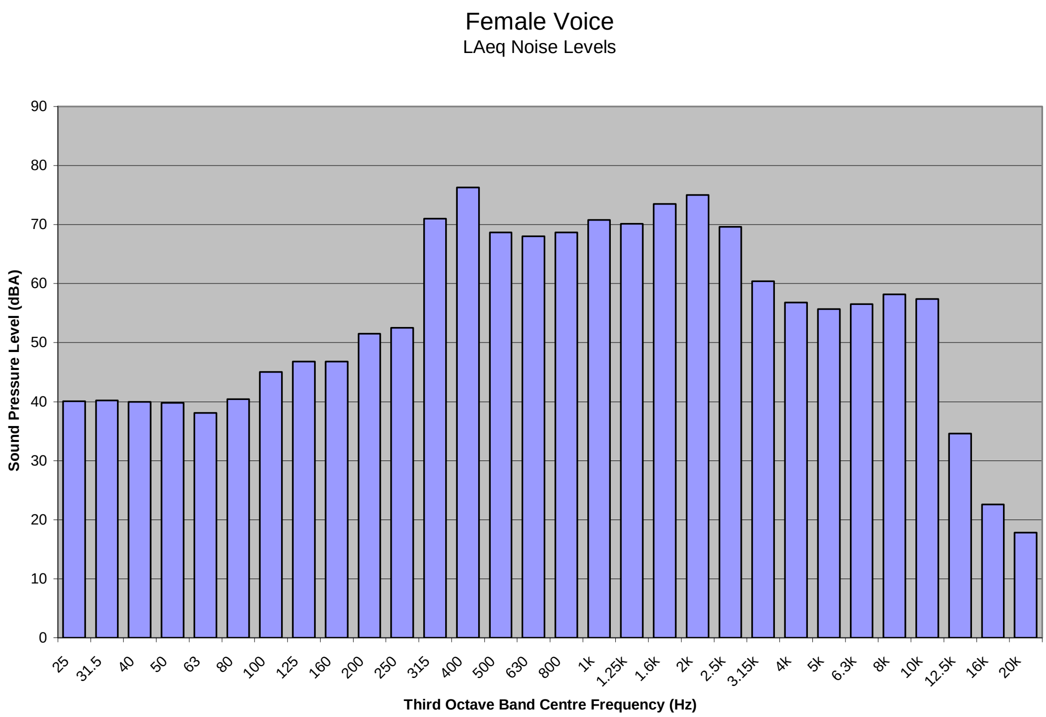
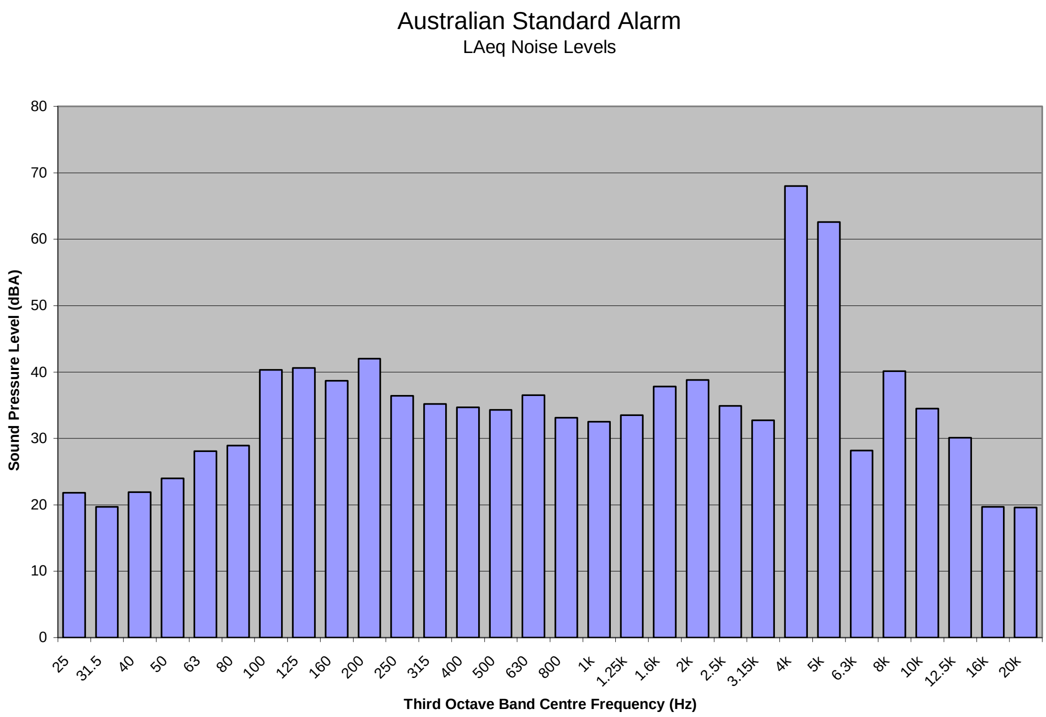


Figure 3.1. Pitch of the female voice alarm.

When peaks that occur above 60dBA are examined, it can be seen that the Female Voice displayed dominant tones across the 315Hz to 2500Hz range. Rather than revealing a specific dominant peak, the frequency pattern is somewhat wedge-shaped indicating that is a complex sound with several overtones.

Australian Standard Alarm (ASA)

The modulating high frequency beeping alarm signal that is used in the manufacture of residential smoke alarms in Australia was used. The parameters of the pitch of this signal are shown below in Figure 3.2.



<u>Figure 3.2.</u> Pitch of the Australian standard alarm

The Australian Standard Alarm showed just two specific peaks above 60dBA, falling at 4000Hz and 5000Hz. The dominant of these is clearly at 4000Hz. This sound is best described as a pure tone, with a single undertone occurring at a similarly high pitch.

Temporal-Three Evacuation Signal

This is a lower frequency alarm signal that sounds the Temporal-Three (T-3) pattern as laid down in International Standard 8201. This sound was sourced directly from the study undertaken by Proulx & Laroche in 2003. Pitch parameters are graphed below.

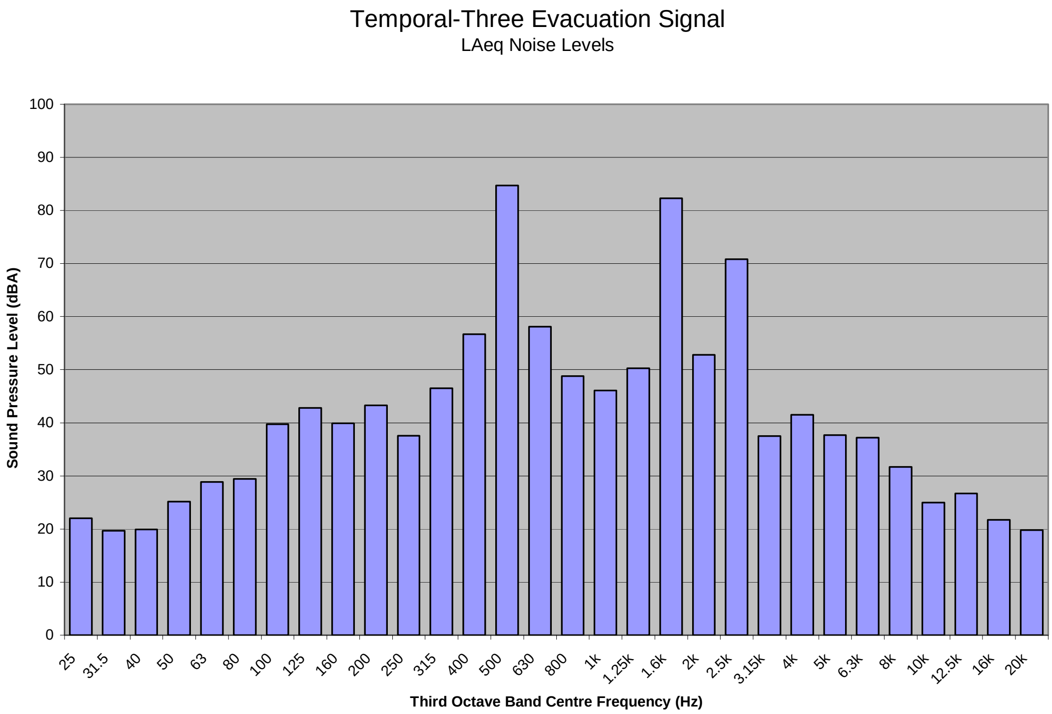


Figure 3.3. Pitch of the T-3 alarm signal.

The T-3 showed several different peaks. Specific peaks occur at 500Hz, 1600Hz, and 2500Hz. Given the appearance of three specific peaks and the range of frequencies covered by those peaks, the T-3 is revealed as a moderately complex sound, with several overtones across a moderate pitch range. In order to reflect the tonal qualities of this sound, as well as the rhythmic pattern, this signal will be referred to as the "mixed T-3" from this point forward.

***Note that this same signal was used in ongoing studies conducted by our research team beyond the bounds of this thesis. When the spectral analysis was recalculated using different methodology for a future study it was revealed as a square wave with a dominant fundamental frequency of 520Hz. It has been referred to in future studies and reports as either the 'mixed T-3" or the "520Hz square wave".*

Procedure

Procedure for recruitment of participants, polysomnographic recording, and delivery of sounds was the same as for Experiment 1. (See Appendix 4 for the information provided to participants).

The three experimental conditions were tested across three nights, usually one week apart, but always with a minimum of three intervening nights to allow for adequate sleep recovery. Where it was unavoidable due to availability of the participant, testing was sometimes separated by several weeks. The sober condition was always the first night of testing. This allowed rapport to be established between the RAs and the participants prior to the alcohol conditions. Alcohol was administered on the remaining two nights at .05 BAC, and .08 BAC in a counterbalanced order across participants.

For nights when alcohol was administered, participants would commence drinking alcohol while the electrodes for polysomnographic recording were applied. (This occurred after all equipment was in place and the sound level had been calibrated).

All sounds were played to participants prior to lights out on the first night. This was done because a level of familiarity was assumed with the current high pitched, fast paced alarm signal used in Australian homes that may have caused it to be more effective in waking participants. Conversely, it was equally possible that novelty could have provided an advantage for the new sounds over the more familiar current signal. It was hoped that prior exposure would minimize the impact that any novelty might have upon the speed of waking. Participants were informed that the sounds may not be presented in the same order. On subsequent nights participants were informed that they would be hearing the same sounds as the last time, and once again that they could be presented in any order. All three signals were presented on each of the three nights to all participants. Sounds were presented in counterbalanced order across participants and across nights for each participant.

Participants were asked to abstain from drinking alcohol on the day of testing, with the exception of any alcohol provided by the researcher. When required, alcohol was provided in measured standard doses as laid out by the Australian Transport Safety Bureau. The operational definition of one standard drink used for the current study was 1 standard nip of vodka (30ml), mixed equal parts of the participants' choice of juice as described above (60ml total).

Participants ingested the alcohol drink at their own pace. The number of standard drinks administered to attain the desired BAC on any given night was estimated by the research assistant in consultation with the participant. Estimations were based upon factors that are known to affect the absorption of alcohol such as the participant's previous experience with alcohol, their sex, size, time since their last meal, etc. A conservative estimate was always made to minimise the possibility of overshooting the desired level. This was important because of the way alcohol is absorbed in the system. It is known that BAC continues to rise rapidly before peaking at 30 to 45 minutes after a person's last alcoholic drink. The BAC level then slowly decreases in a linear fashion at an average rate of about .015 per hour (Sadler, 1999). This meant that the BAC of participants who had consumed the right amount of alcohol to reach the desired BAC without overshooting would continue to rise for about 30 minutes after they went to bed. The consequence of over-shooting would mean that the person was on the downward slope of the alcohol absorption curve.

Breath testing was conducted ten minutes after the prescribed amount of alcohol estimated to attain the required BAC was completely consumed. Although the

Lion Alcometer manual recommended a pause of 20 minutes before breath testing take place to ensure there were no traces of alcohol still present in the mouth, Victoria Police advised that their standard procedure had found that ten minutes was sufficient for this aim. In all instances, before breath testing a ‘ready check’ was performed to ensure the breathalyser fuel cell was completely free of alcohol. The ready check was performed by depressing the read button on the unit, and holding it down fully for 10 seconds. The unit was considered to be ready for use, and free of residual alcohol, if the display showed ‘000’. If any alcohol at all was present, indicated by a reading above ‘000’, the researcher waited for two minutes before repeating the ‘ready check’ procedure.

When a satisfactory ‘ready check’ had been completed, the researcher depressed the ‘set’ button on the breathalyser until it locked. A fresh mouthpiece was then attached to the sampling port of the unit and instructions were administered to the participant. Participants were instructed to fill their lungs and blow into the lipped end of the mouthpiece tube strongly enough to illuminate light ‘A’, and to then continue blowing long enough to illuminate light ‘B’, continuing until told to stop. The researcher depressed the ‘READ’ button immediately after instructing the participant to stop. Participants were asked to keep their hands down away from the testing unit in order to protect against obstruction of operation of the sampling mechanism which would affect results. Testing was repeated if the participant failed to provide sufficient breath to illuminate both sampling lights. In the instance that the alcohol reading was below the prescribed condition for that evening, another dose of alcohol was administered, followed ten minutes later by further testing. If the reading was too high, BAC testing was carried out every 20 minutes until the appropriate level was registered, at which time the participants were asked to go to bed, and lights were extinguished. Fortunately this was very rare, only happening on one occassion (the consequences of overshooting have been explained above). A tolerance level of plus or minus .01 BAC was allowed at any given level.

The participant went to bed and the lights were extinguished after the required alcohol level was reached. As with Experiment 1, prior to lights out they were instructed on the procedure to follow when they became aware of the signals sounding.

All behavioural response times were calculated as number of seconds from sound commencement. The 'modified method of limits' was slightly altered from Experiment 1. The procedure was changed so that the periods of silence between the incremental increases in intensity were eliminated. This was done for two important reasons. Firstly, it was hoped to reduce the sizeable differences in standard deviations between individuals. Secondly, it was done to reduce the total amount of time that the signal took to play. This was especially important because alcohol leaves a person's system at a steady rate over time. Maintaining the silences potentially added a full six minutes to the administration time of any given signal (if the person required maximum intensity or did not respond). Since signals were to be delivered in stage 4 sleep, it was possible that most of the alcohol could have left a person's system prior to the study finishing. However it must be acknowledged that eliminating the silences may have contributed to increasing AATs across the board because of the possibility of sensory adaptation. It is possible that the presentation of the sounds as a constant stimulus, albeit one that is steadily increasing in volume, may have caused a slight decrease in responsiveness. This was not thought to constitute a serious problem in comparing the effectiveness between the signals or alcohol conditions because the methodology was the same for all of them.

If a participant failed to respond at all, awakening was recorded as taking 600 seconds (30 seconds longer than the actual total time from sound commencement to termination). For sound intensity level, responses non-awakening was recorded as 100 dBA (5 dBA higher than the maximum level).

Data Analysis

A 3x3x2 Split Plot Analysis of Variance (SPANOVA) was used to calculate differences in time to behavioural response. Although EEG was carefully monitored for each signal presentation for all participants, unfortunately equipment failure resulted in the EEG tracings not being appropriately saved for all signal presentations for two participants which prevented the post hoc calculation of EEG response times for this data. The nature of repeated measures designs meant that *all* data for these participants would be eliminated from calculations if EEG response time was considered the dependent variable, therefore it was necessary to use behavioural response times. The first within subjects factor was designated 'sound', with three levels corresponding to Female Voice, Australian Standard Alarm, and mixed T-3 alarm. The second within subjects factor was designated 'alcohol', with the three levels corresponding to sober, .05 BAC, and .08 BAC. The third factor was the between subjects factor of 'Sex' which explored differences in response times between males and females. Alpha was set at .05, and all statistical analyses were performed using SPSS Version 14. See Appendix 5 for the output for all statistics performed as a part of Experiment 2.

RESULTS

In order to examine gross differences between the sounds and in the different alcohol conditions, descriptive statistics based upon the responses according to sound intensity level were calculated. As previously noted, sounds were presented with the range of intensity from 35dBA to 95dBA. Where participants slept through the signal, this was assigned a value of 100dBA. The descriptive statistics for sound intensity level appear below in Table 3.1

Table 3.1.

Descriptive statistics for sound intensity level (dBA) according to sound type and alcohol level (N = 14).

	ALCOHOL					
SOUND	**Sober**		**.05**		**.08**	
	Mean	Median	Mean	Median	Mean	Median
Female Voice	56.4 (15.3)	52.5	75.0 (22.5)	80.0	75.0 (21.7)	75.0
ASA	69.3 (17.2)	62.5	81.1 (16.0)	82.5	82.1 (16.3)	87.5
Mixed T-3	57.9 (14.8)	60.00	74.6 (20.4)	80.0	75.7 (21.5)	77.5

*Standard deviations are presented in brackets below the means

Examination of Table 3.1 shows that mean dBA levels for both the Female Voice and the mixed T-3 were very closely matched, although median results show a lower AAT for the sober condition. Both signals alerted individuals at a sound intensity that was usually lower than the Australian Standard Alarm (ASA) signal. It can also be seen that there is increased variability in response times for these two signals in the alcohol conditions, but not for the ASA. Most importantly, Table 3.1 also shows the substantial increase in magnitude required for all signals when alcohol was administered.

The data presented in Table 3.1 does not fully capture the finer details of differences in response patterns at the highest sound intensity level. It is useful to examine how the different signals performed compared to the current sound intensity level prescribed in international standards (75dBA). This is presented below in Table 3.2.

Table 3.2.
Sound intensity response patterns compared to current standards of 75dBA at the pillow. (N = 14).

	SOBER (n = 14)				**ALL ALCOHOL** (n = 28)			
	Woke at or below standard (≤75dBA)	***Woke above standard (80+dBA)***	***Slept through***	***Total above standard***	***Woke at or below standard (≤75dBA)***	***Woke above standard (80+dBA)***	***Slept through***	***Total above standard***
FV	12/14 (85.7%)	2/14 (14.3%)	0	14.3%	15/28 (53.6%)	9/28 (32.1%)	4/28 (14.3%)	46.4%
ASA	8/14 (57.2%)	5/14 (35.7%)	1/14 (7.1%)	42.8%	10/28 (35.7%)	15/28 (53.6%)	3/28 (10.7%)	64.3%
T-3	13/14 (92.9%)	1/14 (7.1%)	0	7.1%	13/28 (46.5%)	9/28 (32.1%)	6/28 (21.4%)	53.5%

Table 3.2 shows that 42.8% of participants failed to respond to the ASA at or below the international standard when sober. This figure was elevated to 64.3% when alcohol was given. Both the Female Voice and the mixed T-3 were more effective that the ASA in the sober condition. Most significantly it also shows that participants responded at little better than chance levels to *all* signals when alcohol was given.

Means and standard deviations for behavioural response times (measured in seconds) were calculated and are shown in Table 3.3.

Table 3.3.
Overall Mean behavioural response time (seconds) according to sound and alcohol level (n = 14).

	ALCOHOL					
SOUND	**Sober**		**.05**		**.08**	
	Mean	SD	Mean	SD	Mean	SD
Female Voice	143.9	86.9	311.6	202.6	298.4	184.6
ASA	232.9	138.6	315.8	133.7	348.9	163.6
Mixed T-3 Alarm	150.0	86.0	268.9	157.6	310.4	208.2

Perusal of the overall sample means shows that the Female Voice and the mixed T-3 alarm consistently resulted in faster response times than the Australian Standard Alarm signal. It also shows that response times are appreciably increased for all signals when alcohol was taken, with the major increase in response time from sober to .05. The magnitude of the standard deviations for all signals indicates that there were sizeable differences between individual responses for all signals in all conditions.

Means behavioural response times were calculated for each signal for males and females. These can be viewed graphically in Figure 3.4.

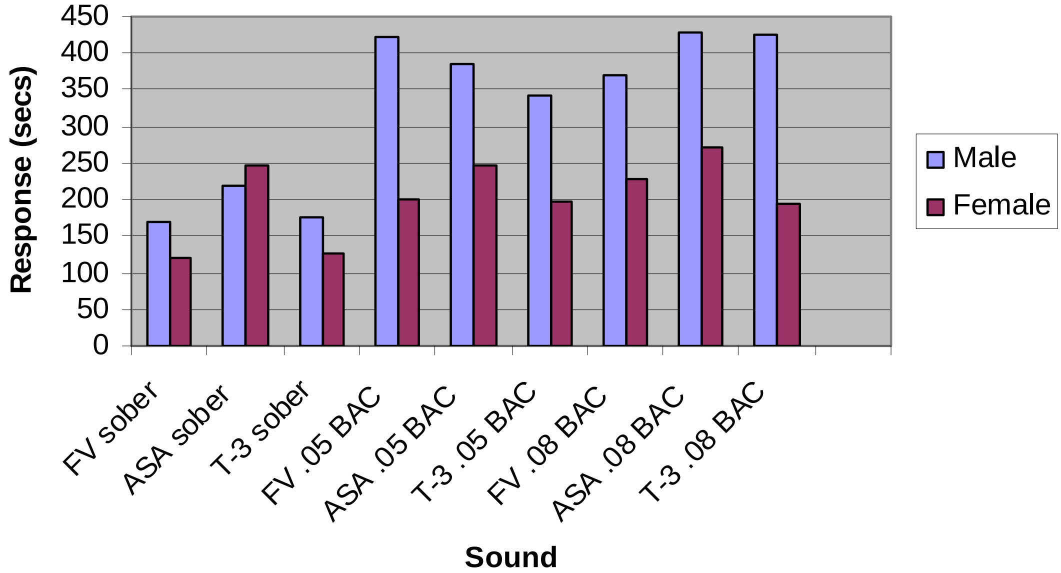


Figure 3.4. Mean behavioural response times for males and females

The differences between males and females in all alcohol conditions are clearly visible in the above graph. Although an increase in behavioural response time is evident for females when alcohol was administered, the differences for males are uniformly of a considerably greater magnitude.

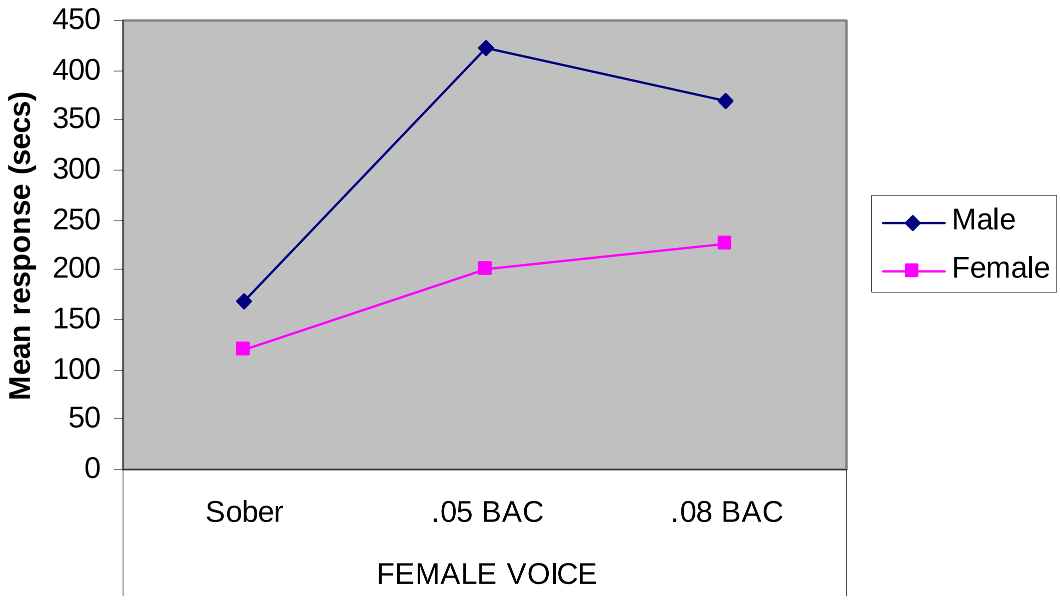
Given the hypothesised relationships planned comparisons were included in the statistical analyses. For the purpose of the current study simple contrasts were calculated. Simple contrasts calculate comparisons between the last level of the independent variable entered with all preceding levels individually (Francis, 2004). Therefore meaningful results are possible if care is taken in selecting the order that the levels are entered into the equation. For the independent variable of 'sound' the literature predicts that the most meaningful comparisons using the simple contrasts method would be between the Female Voice and the two beeping signals. To be sure that these comparisons were made the Female Voice was therefore entered last. This methodology would not allow direct comparison between the mixed T-3 and the ASA (levels one and two of the independent variable ‘sound’) without recalculating the SPANOVA with one of these signals entered last. Changing the order of entry of variables does not alter the overall results, so this was done for exploratory purposes. For the ‘alcohol’ condition it could be reasonably expected that performance would become progressively worse with increasing alcohol consumption, so comparisons for alcohol would best be made between sober and either one of the alcohol conditions, and between.05 and .08 BAC. Therefore the order of entry for levels of this independent variable was sober, followed by .05 BAC and .08 BAC. Once again direct comparisons were not possible between levels one and two, that is sober and .05 BAC, without recalculating the SPANOVA. This was done with sober entered last.

Results of the SPANOVA showed no violation of the sphericity assumption so the ‘Sphericity Assumed’ figures are reported. Significant main effects were found for sound $F(2,24) = 7.19$, $p = .004$, for alcohol condition $F(2,24) = 11.79$, $p = .000$, and for sex $F(1,12) = 4.85$, $p = .048$. A significant interaction was found between alcohol condition and sex $F(2, 24) = 3.61$, $p = .043$. There was no significant interaction found between sound type and alcohol level.

These results confirm the significance of the trends displayed in Tables 1 and 2 which distinguish the time and sound intensity differences required for the different signals under the different alcohol conditions. Planned comparisons for sound showed a significant difference between the Female Voice alarm and the ASA $F(1,12)=8.62$, $p=.012$, and the mixed T-3 and the ASA $F(1,12)=12.83$, $p=.004$, but not between the Female Voice and the mixed T-3 $F(1,12)=.27$, $p=.418$. Perusal of the means shows that the participants took longer to respond to the ASA than both the Female Voice and the mixed T-3. Comparisons for alcohol condition showed a significant difference between sober and .05 BAC, $F(1,12)=18.38$, $p=.001$ and sober and .08 BAC, $F(1,12)=19.34$, $p=.001$, but not between .05 BAC and .08

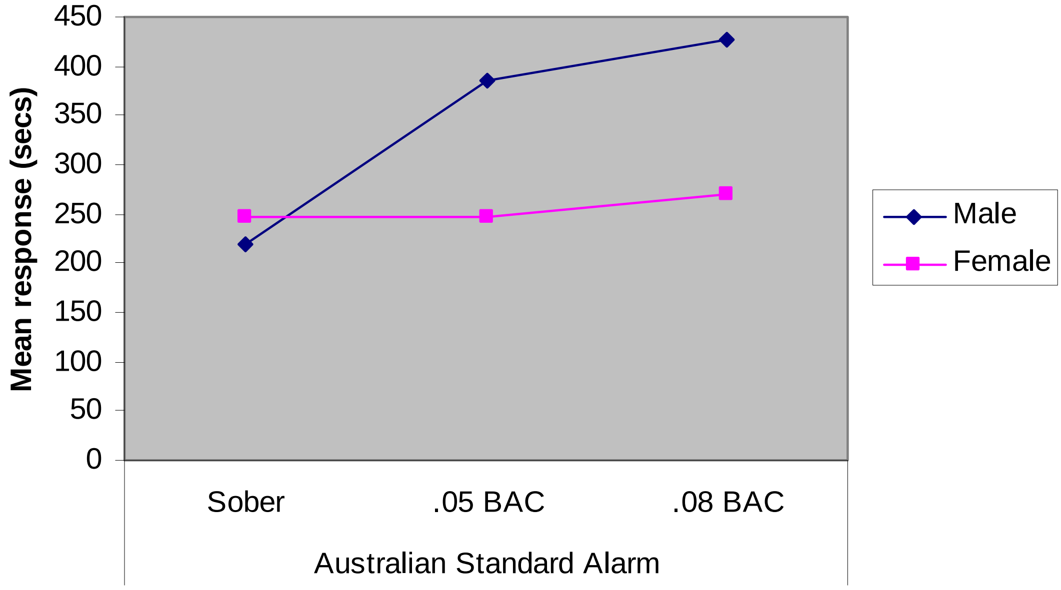
BAC. Examination of the means shows this to be in the expected direction, with awakenings in the sober condition significantly faster than when alcohol was given. The simple contrasts also showed that the significant difference between the sexes involved sober and .05 BAC, $F(1,12)=6.32$, $p=.027$ and sober and .08 BAC, $F(1,12)=5.48$, $p = .037$, but that there was no difference between the .05 and .08 conditions. No other comparisons were significant.

To aid understanding of the interaction between sex and alcohol condition mean behavioural response times for males and females in each condition were plotted for each sound. These graphs are displayed below as Figures 3.5 to 3.7.



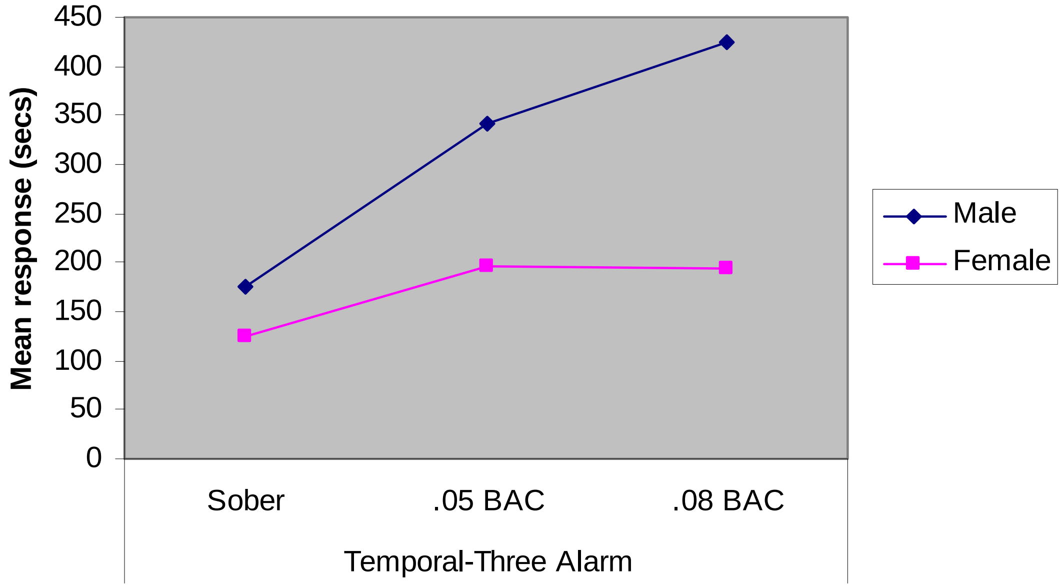
(Standard deviations: Sober, M = 92.0, F = 80.6; .05 BAC M = 216.7, F = 116.9; .08 BAC M = 162.0, F = 189.2)

<u>Figure 3.5.</u> Mean behavioural response times to the Female Voice alarm for males and females across alcohol conditions.



(Standard deviations: Sober, M = 70.2, F = 190.6; .05 BAC M = 124.8, F = 108.8; .08 BAC M = 137.4, F = 157.0)

Figure 3.6. Mean behavioural response times to the Australian Standard Alarm for males and females across alcohol conditions.



(Standard deviations: Sober, M = 88.4, F = 82.4; .05 BAC M = 173.7, F = 106.1; .08 BAC M = 166.8, F = 187.3)

Figure 3.7. Mean behavioural response times to the mixed Temporal-Three alarm for males and females across alcohol conditions.

Perusal of Figures 3.5 to 3.7 above displays a clear trend that is consistent across all three sounds (and therefore independent of sound). What these figures make clear is that behavioural response time was not dependent upon sex when participants were sober, but *was* dependent upon sex when any alcohol was given.

It is acknowledged that the following information contains details of methods as well as results. It was decided to present it in the results section because new data specific to the current study was generated.

Finally, the signals used in the current study could be described using the methods used by Hellier and colleagues (1993) and the perceived urgency might then be accurately predicted. Recall that these researchers calculated an exponential function to enable prediction of the perceived urgency of warning signals using measurements of the following parameters:

- Pitch, defined as fundamental frequency
- Speed as measured by pulse rate
- Repetition rate defined as the number of repetitions of a unit of sound
- Inharmonicity described as the number of inharmonic partials between the fundamental frequency and the first harmonic, and
- Length which indicates the total duration of stimulus

An estimation of all of these parameters was possible for the current study with the exception of inharmonicity. Instead this has been simplified to a measure of ‘complexity’ of sound, whereby a sound was considered to be low in complexity if it was a pure tone showing only one or two dominant peaks of frequency, with both of those peaks not widely discrepant in fundamental pitch. Sounds were considered to be moderate in complexity if they showed two dominant peaks that were discrepant in pitch, or three peaks regardless of similarity, and high in complexity if they showed in excess of three dominant peaks. It must be noted that these categories were created arbitrarily and were influenced by knowledge of the pitch parameters of the sounds under discussion here. Obviously the more dominant peaks a sound displays, the higher the chance is that there may be inharmonicity, but this cannot be strictly assumed. Table 3.4 shows a breakdown of the signals used for the current study according to the parameters put forward by Hellier et al. (1993).

Table 3.4. Estimations of parameters of signal sounds for the current study using the criteria described by Hellier et al., 1993

Parameter	Female Voice	Mixed T-3	ASA
Speed (pulses per sec)	2.4	0.8	4.5
Repetition rate (units per sec)	0.1	0.25	4.5
Length (secs)	10	4	0.22
Pitch (Hz)	315 - 2500	500 – 2500	4000-5000
Complexity	High	Moderate	Low
Overall urgency (accumulated rank score)	11	11	7

Speed for the beeping signals was calculated as number of pulses per second. For voice signals the number of 'pulses' is not so easily determined. It was decided to count the number of syllables present in the scripted message to formulate a basis for reasonable comparison. The ten second message was found to contain nineteen words, with twenty-four syllables in total. This produced a speed of two point four syllables per second.

The repetition rate is a measure of the pattern of the sound. For the sounds used in the current study it was considered based upon the units of repetition for each signal across a period of time. The number of repetitions across ten seconds was calculated, and for consistency with the measurement used for speed, this was converted to the number of repetitions across 1 second. For example the voice signal consists of a message that repeats over periods of ten seconds, so the repetition rate was calculated as point one. For the mixed T-3 the periods of silence are considered part of the pattern in this instance, so the each discrete unit of three beeps punctuated by a longer pause takes a total of 4 seconds, so 2.5 repetitions of the pattern occur over a 10 second period. This is then divided by ten to give the number of repetitions per second. Since the unit of repetition for the ASA is a single beep, the repetition rate for this signal is equivalent to the speed.

To estimate overall urgency a rank position was formulated for each of the above parameters with the value of one representing the most urgent, and three representing the least urgent (in case of a tie, both signals were assigned a score of two). This represents a considerable over-simplification of the methods outlined by Hellier and her colleagues because each of the parameters exert exponentially different amounts of influence upon the perceived urgency, so ranking one for speed has a much higher influence upon perceived urgency than a ranking of one for complexity. Although this is an oversimplification the direction of the difference could be expected to be valid because a higher rating will always increase urgency, but to a varying degree that is dependent upon the exponent. Therefore the differences can be estimated by looking at the overall score which shows that the ASA would be ranked as the most urgent (indicated by the lowest score), and that the mixed T-3 and female voice alarms would be seen as roughly equal. These figures represent an under-estimation of urgency because the ASA is ranked number one for the four most influential parameters.

DISCUSSION

The hypothesis that participants would respond to the female voice alarm at the lowest volume, and in the fastest time, and that no significant difference in the response patterns to the two beeping signals would be found was not supported. Somewhat surprisingly, it was found that both the female voice alarm and the mixed T-3 were equally successful in all alcohol conditions, and that they were both significantly more successful than the Australian Standard Alarm signal.

The further hypothesis that for all signals, participants would respond at the lowest volume and with the most speed when they were sober, followed by .05 BAC, and then .08 BAC was upheld, with the difference of the highest magnitude between the sober and .05 BAC conditions.

The hypothesis that no differences would be found in the response patterns of males and females was not upheld. Males displayed a markedly decreased sensitivity to auditory stimulation compared to females across all signals, but only when alcohol was given.

Response to different signals

Regardless of which independent variable was considered (response time or sound intensity), the Female Voice and the mixed T-3 Alarm were equally successful in arousing individuals from sleep in all conditions, with both being significantly more successful than the Australian Standard Alarm signal. Most interesting is that both elicited mean behavioural response times in the sober condition 80 to 90 seconds faster than the Australian Standard Alarm. This constitutes a difference of considerable magnitude that was in excess of a priori expectations. (Note that response times and increases in sound intensity are dependent upon each other when the method of limits is used).

In the .05 BAC condition these differences are diminished, and for the .08 BAC condition the Female Voice elicited a mean response 50 seconds faster, and the mixed T-3 38 seconds faster than the Australian Standard Alarm.

Not surprisingly, there was considerable difference in the amount of alcohol that was necessary for each of the participants to reach the desired BAC. More surprising is that it took two participants more alcohol to reach .05 than to reach .08. This points to the possibility that uncontrolled variables may have exerted some influence. Although participants were asked to have a normal night's sleep the evening before a sleep study, this was not strictly controlled and it is possible that some participants were more fatigued on a given night which may have increased the effects of alcohol. They were also asked to eat a normal sized evening meal at their usual hour, but it is also possible that less food was ingested on any given night, which also would have affected the influence of the alcohol.

Regardless of the variability in response times, the overall pattern of results indicated significant differences that separated both the female voice and the mixed T-3 clearly from the Australian Standard Alarm.

The failure to find a difference between the Female Voice and the mixed T-3 would seem difficult to understand given that previous research has found that for sleeping individuals, the important parameter in determining a response to auditory stimuli was emotional significance (Langford et al., 1974; LeVere et al., 1976; Oswald et. al., 1960; Portas et al., 2000). In fact, Portas and her colleagues (2000) used MRI and EEG technology to show that the brain regions associated with emotional processing are stimulated to precipitate wakefulness in response to a participant's name *only when they are asleep.* The Female Voice alarm was specifically scripted and delivered with emotional overtones in order to maximise this effect. When this signal was played to participants prior to lights out in the sober condition, informal assessment of their reactions suggested it always elicited an emotional response. These responses ranged from embarrassed giggles, to remarks that it caused a person to feel a mild physiological fear response such as tingling or shivers. The mixed T-3, on the other hand, elicited no such responses. In line with what has been found previously, most people failed to recognise the mixed T-3 as a fire alarm (Proulx & Laroche, 2003), and many remarked that it sounded like the busy signal on a phone, or the sound emitted from a reversing truck.

Closer examination of the parameters of the different sounds reveals that they vary in more than simply emotional content. Inspection of Figures 3.2 through 3.4 shows that the sounds differ in quality in two distinct ways - pitch and complexity. These parameters can be easily understood if we consider musical notes played on a piano. Pitch, as would be expected, refers to the tonal quality of a sound and is related to the frequency of sound waves. Complexity refers to the number of overtones that are present in any given sound, for example the sound of a single note being played is pure and uncomplicated, however the sound of a chord results from several individual notes resonating simultaneously. If we consider the signals used for the current study in this way then the Female Voice can be described as complex, because of the range of peaks from 315Hz to 2500Hz. Dominant peaks, or overtones, are present at 400Hz, 1600Hz, and 2000Hz. Although the mixed T-3 is a less complex sound than the Female Voice, it can still be considered moderately complex, with specific peaks at 500Hz, 1600Hz, and 2500Hz. Note the similarity in the parameters of these two sounds, particularly the dominant overtones. The parameters for the Australian

Standard Alarm, on the other hand, are demonstrably different. This is a less complex tone at a considerably higher pitch, with dominant peaks at 4000Hz and 5000Hz. These pitch levels are unlikely to be produced by the human voice.

Therefore it is suggested that the mixed T-3 signal was equally as successful as the Female Voice because of the similarities in pitch and complexity they share. This provides support for the assumption first put forward by Weir (1976) that the sleeping human brain monitors the external environment preferentially for sounds of pitch in the human voice range. Should this supposition be borne out, the implications are vitally important because signal specifications laid out in both the international and Australian standards make no recommendations regarding the pitch of a signal. If continuing research supports the importance of pitch, then standards should be amended accordingly in the hope of increasing the efficiency of smoke alarms for sleeping individuals.

It is possible that the success of the mixed T-3 may have been contributed to by a priming effect. Although efforts were made to maximise the ecological validity of the study all participants were aware that they were taking part in a sleep study, and that their response to auditory signals from sleep was being measured. Bruck and Horasan (1995) have previously suggested that participants taking part in sleep studies of this kind are primed to respond equally to all signals. This priming effect could lead to all signals being considered as equally significant, which would render the emotional content of any of them redundant. If emotional significance is no longer a factor, then physical components of the sound, such as pitch, would become paramount.

Another interesting implication of these findings is that factors identified as conveying urgency by people when they are awake may not be perceived in the same way when they are asleep. The Female Voice signal was constructed based upon the findings of research carried out to optimize the meaning and level of urgency conveyed by emergency alarms with an industrial application as was outlined in Experiment 1. This same body of work has laid down parameters that will maximize the perceived urgency conveyed by beeping signals. An analysis using an approximation of the method laid down by Hellier and colleagues (1993) for predicting the urgency of a warning signal showed the ASA to be rated as clearly more urgent than the Female Voice or the mixed T-3, whose urgency was closely matched. Researchers have determined that important parameters for urgency are increased speed, pitch, and repetition (Hellier & Edworthy, 1999). If this holds true for sleeping individuals, then the Australian Standard Alarm signal should have been the most successful, rather than the least. Instead, it seems reasonable to suggest that sleeping individuals are more sensitive to sounds that occur within a certain pitch range that is similar to the human voice.

The effects of alcohol

Perhaps the least surprising but most important finding of the current study is that drinking alcohol significantly affects a person's ability to awaken to auditory alarm signals. What is surprising, however, is that participants were affected at a blood alcohol concentration as low as .05. Perusal of the mean response times presented in Table 3.3 shows that increasing the amount of alcohol intoxication to .08 also increases this effect, but to a much lesser degree. The meaning of this is that even at what many would consider to be low-to-moderate levels, alcohol can seriously affect a sleeping person's ability to respond to their smoke alarm. In fact many participants reported feeling only slightly 'tipsy' at bedtime in the .05 BAC condition. It is of vital importance that the general public be provided with this information in the hope that awareness will lower the number of alcohol implicated fire fatalities. Results of a telephone survey of 938 randomly selected individuals in the United States found that although people tend to accurately estimate the proportion of victims of fatal drowning, poisoning, falls, and motor vehicle accidents who are legally drunk, they tend to underestimate the proportion of victims of fatal fires who are likewise intoxicated (Girasek, Gielen & Smith, 2002). Given that social drinking is embraced in Western societies it is no surprise that people who are under the influence of alcohol are perishing in fires.

Also of concern is the number of occasions upon which participants slept through a signal when alcohol was administered. The most compelling data presented in Table 3.2 shows that, regardless of signal, 54.8% of all trials resulted in no response at or below prescribed sound intensity standards when alcohol was administered. The international standard for audible emergency evacuation signals requires that the minimum sound intensity level at the bed head should be 75dBA when the signal is being used to awaken sleeping individuals (ISO 8201). The results imply that it is unlikely that the mandated sound level would have aroused about half of participants under the influence of alcohol. This is raised to almost two thirds for the Australian Standard Alarm on its own.

As has been previously raised, the AATs for the current study may be somewhat elevated because of the elimination of the silences between the incremental increases in sound intensity. It is possible that this methodology allowed for a degree of sensory adaptation that would not have been present if the sounds cut in from silence at any given level.

Alcohol and sex differences

Somewhat surprising was the significant interaction found between participant sex and alcohol level. Examination of Figures 3.5 through 3.7 showed that response time was dependent upon sex only when alcohol was given. This could be related to differences in the way each sex metabolises alcohol. Certainly it is well known that males usually take more alcohol to attain the same BAC as females, and that females' cognitive performance is affected to a greater degree than males when the same amount of alcohol is taken (Mumenthaler et al., 1999). However for the current study the females took on average about as much alcohol as the males to attain the required BAC. This may be an artifact of recruitment procedures because 'regular drinkers' were targeted which may have been perceived differently by participants of different sex. Given Australian cultural norms it is possible that females may have been more used to drinking strong alcohol such as spirits, and males may have been more likely to be regular drinkers of less potent alcohol, such as beer. It may also have been due to the females of the study being generally older, and perhaps more experienced drinkers than the males (mean age F = 22.4, M = 19.7, legal drinking age in Australia is 18 years).

The above explanations put forward suggestions as to why females took as much alcohol as males to attain the required BAC, but they do not account for why females responded faster than males. Indeed given that females have been found to show greater decrements in cognitive performance under the influence of alcohol than males it may have been reasonable to predict the opposite outcome. Once again age may be implicated because AATs gradually decrease with increasing age, but the differences in age between the males and females of this study should not be of sufficient magnitude to produce the results found. Sex differences should be systematically investigated in future studies.

The findings of the current study for the sober condition only are in keeping with Zeppelin and colleagues (1984) and Bruck and Horasan (1995) who both reported no sex differences. They are also somewhat in keeping with those of Wilson and Zung (1966) who reported that responses to auditory stimuli of a neutral tone were significantly higher for female participants compared to males in all stages of sleep except for REM, but no sex differences in the response to motivating stimuli. The doubt is raised because an alarm signal by definition should be motivating, and so it could be argued that no sex differences would have been expected on the basis of this. However because participants were aware that there was no fire they may well have perceived the signals as neutral which would bring the results of the current study into line with the previous findings.

The data from the current study was further explored in a stochastic model that was designed to estimate the probability of a delayed response. Using this model it was found that alcohol lowered the probability of response to an alarm signal in both sexes, but that males showed a decreased sensitivity compared to females both when sober and under the influence of alcohol (Hasofer, Thomas, Ball & Bruck, 2005).

Strengths, limitations and directions for future research

Testing in the participants' own bedrooms allowed for real world conditions to be closely maintained, thereby enhancing the ecological validity of results. This was considered an important factor in the current research as it allowed the alarm signals to be tested in close to real world situations, the only difference being that the sound was coming from speakers at approximately ear level, instead of from above, and the sound level at the pillow was carefully monitored, unlike the situation in most homes. As was explained earlier, the nature of the research also raises the possibility that participants were to some extent primed to respond.

It is possible that collecting the data for the sober condition always on the first night may have contributed to the lower response times in this condition due to a first night effect. However where first night effects for sleep studies have been found, they usually relate to differences in sleep latency (Kupfer, Weiss, Petre & Foster, 1974), or reductions in REM sleep (Browman & Cartwright, 1980; LeBon, Staner, Hoffman, Dramaix et al., 2001). First night effects for non-REM sleep have not generally been found, with the exception that there may be some delay in its onset (Agnew, Webb & Williams, 1966). They have also been found to be attenuated in a familiar environment with the exception of REM changes (Browman & Cartwright, 1980). Sleep quality has also been found to be unaffected by first night effects. Kronholm and colleagues measured psychomotor activity, which is commonly used as a measure of sleep quality, and found no significant difference in movements between the first and subsequent nights of sleep study (Kronholm, Alanen & Hyyppa, 1987). Since awakenings for the current study all occurred during stage 4 (non-REM), and testing was carried out in participants' own homes, it is unlikely that results were affected by a first night effect.

The decision to always carry out sober testing on the first night was made on ethical grounds, with participant comfort in mind. Since testing was carried out in participants' own homes while they were sleeping, it was thought important that rapport be established before alcohol was introduced. It was considered beyond ethical practice to expect participants to fall asleep leaving a complete stranger unmonitored in their home environment while they were under the influence of alcohol.

It must be noted that all findings from the current study apply to young adults who are self-reported deep sleepers. Our aim in choosing this group to study was that the best alarm should be capable of arousing the deepest sleeper, in the deepest stage of sleep. However this also means that caution must be taken in generalising these results. This is clearly a difficult population to awaken. It is unlikely that an older population would show such poor results in responding to the different signals. It is more likely that the effects would show the same trends, but not as marked.

Another result that demands further exploration is the question of sex differences. The finding that males are significantly more affected by alcohol than females in their response to auditory alarms when sleeping has important social ramifications. Campaigns warning of the elevated risk for males who have been drinking may be warranted. Additionally, males are known to be at greater risk for death in fire (Brennan, 1998, Marshall et al., 1998), especially when alcohol is involved (Berl & Halpin, 1978; Squires & Busuttil, 1997; Watts-Hampton, 2006). It would be interesting to explore whether these sex differences extend across the lifespan, or whether they only apply for young adults.

Further, a most important finding of the current study was that there was no significant interaction apparent for alcohol condition and sound. This means that the differences found between the alcohol conditions (sober, .05 and .08 BAC) were not related to the sound that was administered, but also and most importantly that the differences found between the separate sounds were not dependent upon alcohol being administered. There appear to be real differences between the different signals used that have nothing to do with whether or not alcohol was given. Therefore it is important that specific research be undertaken to explore the differences in response times between the signals for groups who have been found to be especially vulnerable for death in fire when alcohol is not implicated. This should most particularly include the elderly and children (Brennan, 1998; Barillo & Goode, 1996) (see Experiment 3 for children).

Results of the current study also suggest that future research is necessary to explore the optimal pitch of the smoke alarm signal. The ultimate aim of research of this type is to improve the body of knowledge regarding the response of sleeping individuals to auditory signals in order to affect changes to international standards. This will only be achieved through ongoing and systematic exploration that expands upon what has been found in the past, and includes new and innovative approaches. It should include exploration with a range of signals with larger sample sizes and incorporating more vulnerable groups, for example the elderly.

Another issue that should be investigated in future research is the possibility that presenting the increments of sound with intervening periods of silence using the method of limits causes a degree of sensory adaptation. Finally, it would also be useful to explore whether the trends displayed when alcohol is consumed also apply to other psychoactive substances such as sleeping tablets or over the counter medications that increase drowsiness.

Declaration

The following chapter covers two studies (3a and 3b) which involved other students. An Honours student, Sharnie Reid, completed Experiment 3a as her Honours thesis, and Jefoon Kouzma completed Experiment 3b as a special research project for her undergraduate degree. The candidate co-supervised these students (together with her supervisor, Professor Dorothy Bruck) and was involved in all stages of the design, recruitment, equipment development, data analysis and interpretation of this research. What follows is the bringing together of the results of these two studies (together with a previously published study by Bruck and Bliss, 2000) in an original work with a new set of analyses, comparisons and interpretations.

CHAPTER FOUR

EXPERIMENT 3

The effectiveness of different alarms in waking sleeping children.

Young children have been consistently been identified as a group in society who are particularly vulnerable to death in a fire (Australasian Fire Authorities Council, 2005; Barillo & Goode, 1996; Brennan, 1998; Karter, 1986; Marshall, Runyan, Bandiwala, Linzer, Sacks & Butts, 1998; Runyan, Bangdiwala, Linzer, Sacks & Butts, 1992; Sekizawa, 1991). Previous research has studied the response of children to the high-pitched rapidly repeating ASA smoke alarm signal. This research found that only 6% of children aged from 6 to 15 years-old reliably awoke from sleep to the alarm when installed in the hallway and received at the pillow at 60 dBA (Bruck, 2001). (Reliable in this context meaning awakening to two out of two alarm presentations). When the volume of the signal was increased to 89dBA at the pillow, by installing the alarm above the child's bed, the percentage who reliably awoke increased to 50% (Bruck & Bliss, 2000). However, the responsiveness of children is clearly age related, with the younger children being more at risk. Only 29% of those aged 6-10 years awoke reliably to 89 dBA.

The reasons why children seem to be particularly difficult to awaken may be related to their delayed prefrontal lobe development. This part of the brain develops mostly between ages 12 and 24 and is responsible for behaviours that include making judgements. If this includes both judgements while asleep as well as when awake then this may influence the arousability of younger children to a signal while sleeping. As has been previously raised, it is also known that the duration of deep sleep (stage 4) decreases with increasing age, so younger children spend more time in deep sleep than older children or adults. Perhaps more important, however, are the findings that children may have higher EEG energy levels within sleep (Aström & Trjaborg, 1992) making *all* stages of their sleep deeper and, it is hypothesised, harder to disturb than adults.

From a fire safety point of view the key question becomes - can we devise a signal that is more likely to awaken children than the high pitch beeping signal currently used in smoke alarms in Australia? It is not simply a matter of increasing the volume of the signal, as above 90 dBA there are concerns about the safety of the signals for hearing. In addition, one study found that some prepubertal children did not awaken to a signal being received during sleep at 123 dBA (Busby & Pivik, 1984).

Studies of cognitive processing during sleep with adults has shown that they continue to monitor the external environment and can make discriminations about what is relevant and meaningful to respond to. If this is also the case for children then their potential to respond to a signal may be enhanced if the signal is more significant to them. The literature would suggest that key factors in meeting this aim might include:

- ensuring the signal is not one that the child frequently hears while asleep, to prevent habituation (Bonnet, 1982),
- increasing motivation to respond through prior education/priming (Wilson & Zung, 1966),
- including relevant content in the signal eg. using a verbal message about the fire (Stanton & Edworthy, 1998),
- including words with an emotional content (Portas et al., 2000),
- using a female voice, found to convey more urgency than a male voice (Hellier et al., 2002),
- including the child's name as part of the signal (Oswald et al., 1960).

It has also been suggested that there may be some advantages to using a voice that is familiar to a child. Whether these advantages may include a comfort factor to the child on hearing a familiar voice in the midst of an emergency, or an hypothesised increased saliency of a signal that includes a familiar voice (and hence increased likelihood of waking up) is unknown.

The aim of the current study was to investigate the ability of four different 89 dBA alarm signals to awaken sleeping children aged 6 to 10 years-old. Data was collected across three separate studies as follows:

Experiment 3a: Two voice signals were presented for Experiment 3a. This included a message pre-recorded by the mother of each individual child that spoke of presence of a fire in an emphatic tone, and included repetitions of the child's name along with instructions for action. The other message was the female voice alarm first developed during Experiment 1. Data was collected for each signal once during the study.

Experiment 3b: The same mixed frequency mixed T-3 signal that was used previously in Experiment 2 was presented. Responses to this signal were gathered on two separate nights.

Bruck and Bliss: Data from the Bruck and Bliss study published in 2000 where the ASA had been used was available for comparative purposes. The ASA was not exactly the same as that used in Experiment 2. Instead of being transmitted through speakers connected to a computer, it was actually a store bought smoke alarm that transmitted the ASA signal. The signals sounded the same to the unassisted ear, but no investigation of the actual pitch or complexity of the store bought alarm signal was available. The original study included participants aged from 6 to 15 years-old. Data for the subset of participants who were aged from 6 to 10 years-old were selected for the current study.

The chronology of data collection affected the hypotheses that were drawn. Data collection for Experiment 3b was commenced before data analysis for Experiment 3a was completed, and both were commenced before data collection for all conditions of Experiment 2 was completed. This meant that the similarities in response patterns between the female voice and the mixed T-3 from Experiment 2 were suspected as trends, but not confirmed. Therefore the hypotheses reflect the expectations drawn from previous research, but not from the findings of Experiment 2.

It was hypothesised that the response rate for the two voice alarms would be greater when compared to the two beeping alarms, and that awakenings would occur within a shorter time period for the voice alarms.

METHOD

Participants

Participants of all experiments (3a, 3b, Bruck and Bliss) were children aged 6-10 years. They were a convenience sample recruited by word of mouth through friends of staff and students of Victoria University. Normal hearing of the children for Experiments 3a and 3b was ascertained through parental report, while for Bruck and Bliss all children had their hearing professionally assessed through an audiology clinic. Where audiology results were available, only children with hearing above the 90th percentile across all frequencies were included. Demographic details (number, age and sex) of the children in each study are shown below in Table 4.1.

Materials and Procedure

Signals across all experiments were received at the pillow at 89 dBA with a tolerance level of plus or minus 3 dBA, and were of three minutes duration. Background noise levels were not measured or controlled. The first night was always an adaptation night and alarms were not activated.

Experiment 3a

The mother's voice signal was pre-recorded in her own home using a script and included the child's name at the rate of about once every six seconds. If two children being tested shared a bedroom, both names were included (order counterbalanced). The message said that there was a fire, they were to wake up now, and quickly go outside. The female voice alarm was the same as for Experiment 2. Both voice signals conveyed urgency, although the female voice was typically more urgent. Each signal was looped to make a continuous signal of three minutes duration. The children and their parents were told that the total duration of the study was four nights, and that a signal could go off on any one or more of the four nights of the study. In actual fact the signals were always activated on the second and third nights and the study was terminated after the third night. This was hoped to reduce expectation effects that would result from the first signal being administered on the second night of a three night study. It also allowed for an initial adaptation night so that any effects of the novelty of the equipment and procedures could be reduced.

Experiment 3b

As has been mentioned above, the mixed T-3 signal from Experiment 2 was used. This signal was originally sourced from a study by Proulx & Laroche (2003) that investigated the recognisability of the mixed T-3 as an evacuation signal. To recap, the mixed T-3 signal was described as a moderately complex sound, with dominant tones in the lower frequency ranges; 500 Hz, 1500Hz and 2500Hz. In the same way and for the same procedural reasons as above children were told that a signal could go off on any one or more of four nights.

Bruck & Bliss (2000)

Data for this study was collected in 1999 and used a standard Australian smoke alarm bought in that year. This was a high frequency signal of approximately 4000 Hz. The children were told that an alarm would go off on two of the five nights of the study but they did not know which two nights.

Note that for Study 2 and 3 each child got the same signal twice, but for Study 1 each of the two signals was only presented once to each child. All presentations were considered as independent events for the purposes of analyses (this assumption is discussed further in the results section). Thus the total number of presentations for the mother's voice was 20, female voice 20, mixed T-3 28, and standard signal 28.

A summary including the key methodological details of all three experiments is shown in Table 4.1.

Table 4.1. Summary of the key methodological features for all experiments involving children.

	Experiment 3a	Experiment 3b	Bruck & Bliss (2000)
Signals	mother's and female voice alarms	Mixed T-3	Australian standard alarm
dBA	89 ± 3 dBA	89 ± 3 dBA	89 ± 3 dBA
Signal frequency	315-2,500 Hz	500-2,500 Hz	Approx 4,000 Hz
Time of signal	1am	1am and 3am	1am and 3am
Participants (n)	N = 20 (10M, 10F)	N = 14 (8M, 6F)	N = 14 (10M, 4F)
Participants (age)	6-10 yrs	6-10 yrs	6-10 yrs
Signal delivery	Via speakers & laptop	Via speakers & laptop	Via smoke alarm on ceiling
Signal activation	2nd and 3rd nights	2nd and 3rd nights	2nd and 4th nights
Awake measurement	Actigraphy	Actigraphy	Actigraphy

All studies were conducted in the child's own home with the sound equipment set up in their bedroom. For Experiment 3a the female voice and mother's voice were both presented at 1am on different nights counterbalanced across participants on either night 2 or night 3. For Experiment 3b the same mixed T-3 signal was presented at either 1am or 3am on either night 2 or 3, with the order counterbalanced. For Bruck and Bliss the children were told the study was over five nights and the ASA was presented on nights 2 and 4 at either 1am or 3am, with the order counterbalanced across all subjects. For all studies all children had been exposed to all relevant signals prior to going to bed, but they did not know on which nights the signals would occur. Study 3 was conducted several years before the other two studies and the test nights were made non-consecutive due to concerns about accumulating sleep deprivation. However, a questionnaire was repeatedly administered during that study that tested for sequential confounding effects of sleep deprivation and as none were noted, this precaution was eliminated from subsequent studies.

All children were instructed that they must adhere to their usual 'school night' bedtimes for all nights while participating in the study in order to minimise variable sleep patterns due to late nights or sleep deprivation (Bruck & Horasan, 1995). They were required to strap on a wrist actigraph prior to going to sleep. This recorded their movement in time "bins". For Experiments 3a and 3b the time bins were of 15 seconds duration, while Bruck and Bliss used older equipment that recorded time bins of 16 seconds. For the comparative purposes of this paper the data from Bruck and Bliss was slightly rescaled so that all data fitted into the 15-second categories. Therefore there may be minor inaccuracies of a few seconds in the sleep latency data for Study 3. In all cases the children were instructed to move their arm with the actigraph backwards and forwards for 10-15 seconds as soon as they awoke to the alarm, and then to leave their beds. This was to ensure that the actigraph recorded movement as soon as they awoke. In all cases a parent would awaken at the time of signal delivery. They were instructed to wait quietly until the child emerged from the bedroom (if awoken) and then the parent and child would go into the living room and together complete a short questionnaire. (Note that the results of this questionnaire are not strictly relevant to the series of experiments that constitute the current project and so are not presented here. However they were reported in the publication of the results of this study and can be viewed there. Refer to the Bruck, Reid, Kouzma & Ball (2004) reference in the list of publications). Children were paid $25 for their participation in Experiment 3a or 3b, and it was explained that payment was not contingent upon them waking up for. The only incentive to participate in the Bruck and Bliss study was the free hearing test.

RESULTS

Only data from children who reported that they were actually asleep at the time of signal presentation were included in subsequent data analysis. Of the 20 children in Experiment 3a (voice alarms), one child reported being awake at the time of the mother's voice alarm activation and another child was awake at the time of the female voice presentation, so those trials were not included. In Experiment 3b (mixed T-3) and Bruck and Bliss (ASA) all children were asleep at both 1am and 3am when the alarms were activated. It was observed that most children in all the studies had a strong sense of anticipation of the alarms and motivation was high to "beat" the alarm by waking up. All output can be found in Appendix 6.

Time of night

The first issue to be determined was whether there was a difference in awakenings between the 1am and 3am presentations. Table 4.2 presents a combination of this data from Experiment 3b and Bruck and Bliss and shows that the number of children who awoke at 1am versus 3am did not differ greatly. Analysis of the frequency data with a Chi Square test revealed no significant effect of time of signal presentation (Pearson Chi Sq $X^2 = 0.59$, df = 1, $p > 0.10$). Thus in all subsequent analyses the 1am and 3am data were combined.

Table 4.2. Number of different responses at different time of night presentations of the alarm signal. (Data from Experiment 3b and Bruck and Bliss only).

	Slept	**Awoke**
1am	7	21
3am	6	22

Awakenings to alarms

Figure 4.2 displays the number of children who did or did not awaken to the various alarms. It can be seen that of the 19 valid presentations of the mother's voice, all children awoke. One child did not awaken to the female voice (i.e. 94.4% awoke) and one child also did not awaken to one presentation of the mixed T-3 (i.e. 96.4% awoke). By contrast, of the 28 presentations of the standard alarm, only 16 (i.e. 57.1%) awoke. Analysis of the frequency data with a Fisher Exact Test revealed a highly significant effect of the frequency of awakening to the different alarms (df = 3, p=.000). The data suggests this significant difference is due to the lower rate of awakenings to the standard alarm.

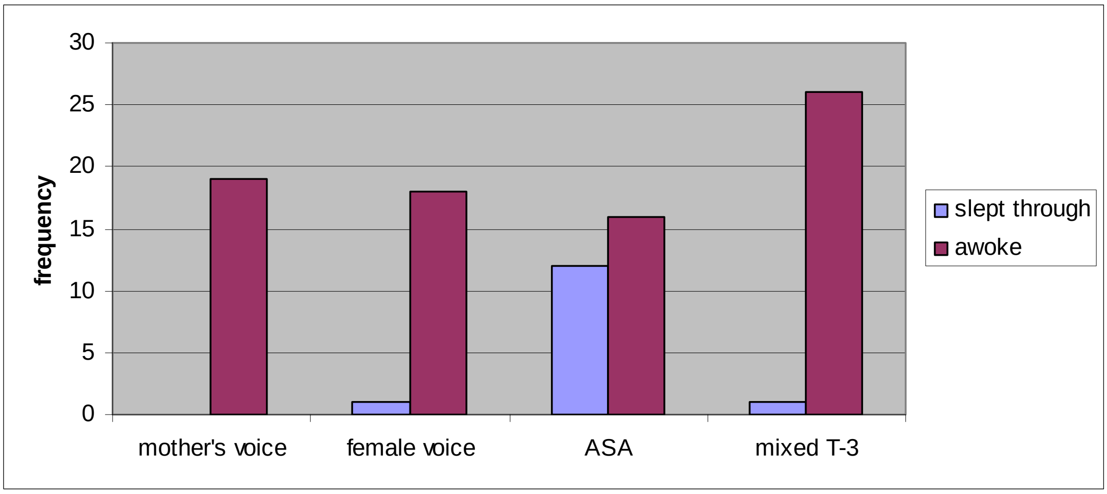


Figure 4.1. Number of children who did or did not awaken to the different alarm signals across all three studies.

In Experiment 3b (mixed T-3) and Bruck and Bliss (standard alarm), each child received two presentations of the same signal, while in Experiment 3a (voice alarms) each child received each signal only once. However, as stated above, the analyses assume that all observations are independent. Thus the issue arises as to whether the high rate of sleeping through the standard alarm is possibly a confound of the different study designs. In Bruck and Bliss the fact that only 2 of the 14 children who slept through an alarm, slept through BOTH presentations of the alarm, suggests no such confound exists. In other words, there was no evidence of a subgroup of children in Bruck and Bliss who were consistently hard to awaken that could distort the findings.

In Bruck and Bliss, of the 12 signal presentations that produced no awakening, in five cases the child stirred (as evidenced by movement recorded on the actigraph) but did not waken sufficiently to do the wrist movement for 15 seconds and leave their beds as instructed beforehand. Instead they returned to sleep. There were no cases of this happening with the other three alarm signals.

Time to awaken

Examination of the time required for the children to wake up (i.e. sleep latency) showed that the children took longer to arouse and begin shaking their arm (as required) with the ASA, compared to other alarms (see Figure 4.3). In order to determine whether significant differences were apparent in the sleep latency data the time categories were collapsed (enabling valid Chi Square calculations). The regrouped frequencies and percentages are shown in Table 4.3.

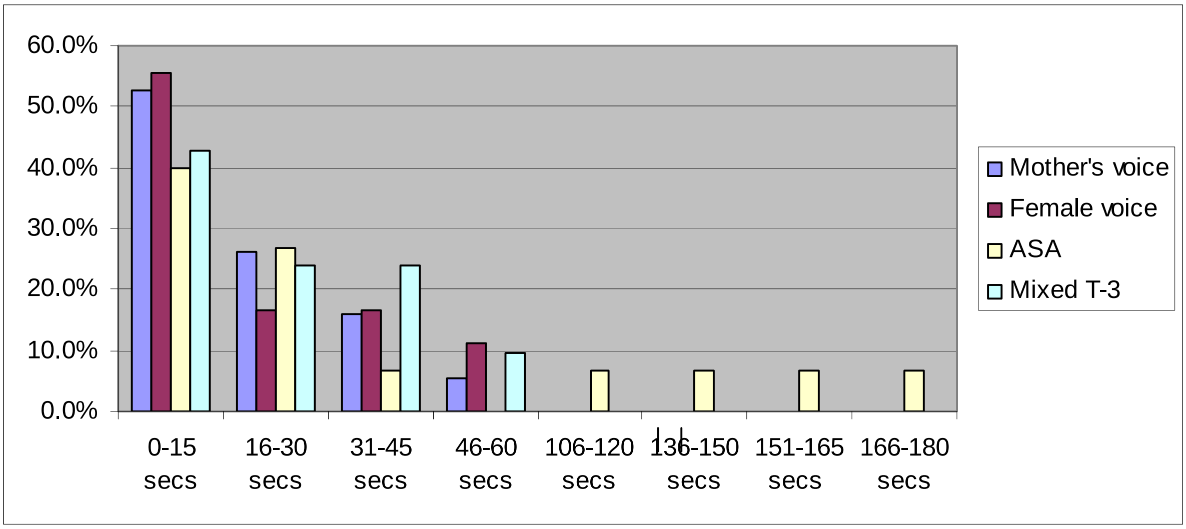


Figure 4.2. Percentage distribution of the time taken to awaken to different alarms.

Table 4.3. The number and percentage of children who woke within different time categories to different alarm signals.

	0 - 30 seconds	31 - 60 seconds	Over 60 seconds
Mother's voice	15 (78.9%)	4 (21.0%)	0
Female voice	12 (70.6%)	5 (29.4%)	0
ASA	10 (66.7%)	1 (6.7%)	4 (26.6%)
Mixed T-3	14 (66.7%)	7 (33.3)	0

For the voice alarms and mixed T-3, all children gave the behavioural response within one minute, while for the ASA only 73.4% of the children responded as instructed within one minute. For the ASA 26.6% of the children took 106-180 seconds to wake up. In terms of response within 30 seconds, the female voice, mother's voice and mixed T-3 were all similar, with the mother's voice performing slightly better. A Chi Square Test was performed on the frequencies as shown in Table 3 and it was found that the observed frequencies differed very significantly across the different alarm signals (Pearson Chi Square $X^2 = 18.022$, df = 6, p = .006). The data suggests that this significant difference is due to the slower awakening time with the ASA.

DISCUSSION

The hypothesis that the two voice alarms would awaken children more quickly and effectively compared to the two beeping alarms was not supported. In fact three of the signals were significantly more effective in awakening the children quickly than the fourth. The mother's voice awoke the children in 100% of the presentations, the female voice in 94.4%, and the mixed T-3 in 96.4%. In contrast, the high-pitched ASA awoke the children in only 57% of the presentations.

This difference in waking effectiveness across the alarms was also reflected in the time required for the children to show they were awake by beginning to shake their arm. All children showed they were awake within one minute of the sounding of the two voice alarms and the mixed T-3 signal. However, with presentations of the standard alarm only 73.4% awoke within one minute. Over a quarter of the children who awoke to the standard alarm took between 106 and 180 seconds to do so.

It was noted that in five cases with the standard alarm signal the child stirred but did not awaken, and that this did not happen with the other signals. It could be argued that the direct verbal instructions of the voice alarms may have played a part in fully awakening those children who had become aware, at a subconscious level during sleep, that there was a disturbance. However, this would not explain why the mixed T-3 was also effective at waking the children.

The data show that responses to the mixed T-3 and two voice alarms are all similar. The statistically significant findings arise from the poor performance of the standard alarm compared to the other alarm signals and are not due to differences between either the two voice alarms or between the voice alarms and the mixed T-3. Further studies with more children are needed to determine if real differences between the three better performing alarms exist. These findings suggest that the effectiveness of an alarm signal is primarily the function of the *frequency of the signal*, wherein signals that are in the same pitch range as a voice (2500 Hz or less) are more effective than those of a higher pitch. This hypothesis is consistent with the findings of Experiment 2 regarding the differential decibel levels needed to awaken intoxicated young adults with different alarm signals. In order to confirm this conclusion, and rule out the possibility that there was another reason for the difference in arousal to the mixed T-3 versus the high-pitched ASA, a similar study using a high-pitched T-3 needs to be conducted.

It is possible that the rate of awakenings in these studies may be higher than in real life circumstances because the children knew that a signal would be going off on one or more of the nights that the equipment was installed in their bedrooms. Such "priming" has been shown to increase the likelihood of waking up, in one study increasing awakenings in adults from 25% to 90% (Wilson & Zung, 1966).To determine the influence of this factor with children, studies are needed where the equipment is installed for weeks or months and the signals activated infrequently. Nonetheless, the possible effect of priming would not alter the central findings of this paper, as the expectation effects would be consistent with the different alarms. The possible effectiveness of priming may, however, have implications for fire safety education with children.

The finding of no significant difference between the 1am and 3am signal presentations indicated that the two time groupings could be collapsed for the purposes of further analyses. Both time periods are in the middle third of a child's sleep period and, given what we know about arousal and how sleep changes across the night (Bonnet, 1982; Okuma, Kakamura, Hayashi et al., 1966), we could generalise these findings to the final third of the night. Arousals from sleep in the first third of a child's sleep are, however, less likely, given that this is the time of the deepest sleep. Further research on the possible difference between different alarms should be conducted in this earlier part of the night, to overcome a possible ceiling effect, whereby all or most children awaken.

We know that more deep sleep occurs in younger children than older people, that the density of the power spectrum during sleep decreases with advancing age (Astrom & Trjaborg, 1992), and that the likelihood of arousal at lower volumes increases with age (Zepelin, McDonald & Zammit, 1984). It was found Bruck and Bliss (2000) study that the younger children (6-10 years) were more likely to sleep through alarm signals than older ones (11-15 years). Extrapolating from this data and what we know about sleep, we can assume that children aged below 6 years will generally be harder to arouse than the children tested in the studies reported here. In the course of an Experiment 3a re-enactment for the media a younger sibling (aged 5) of some participants also awoke to the voice alarms. Interestingly, he became distressed on hearing the female voice, hid under the bedcovers and needed comforting. This did not happen when he heard his mother's voice as the alarm signal. This anecdote may be worth following up to see if other young children also find an urgent, unfamiliar voice distressing just after waking up. In the absence of any findings to the contrary it should be assumed that most preschool children will need to be awoken and/or directed to safety by other members of the household in the event of a fire.

The results of these three studies suggest that sleeping children aged 6-10 years are very likely to awaken to a voice alarm or mixed T-3 presented at about 89 dBA during the middle third of the night, while only about half such children will awaken to a high pitch standard alarm under the same conditions. The fact that the mixed T-3 was as effective as the voice alarms suggests that the critical factor is not the urgency of the message, its verbal content, or use of a voice in itself. The evidence suggests that responsiveness is primarily a function of the *lower frequency* of a signal, or the presence of a variety of frequencies within a signal (such as occurs in the voice alarms and mixed T-3).

CHAPTER FIVE

EXPERIMENT 4

A preliminary investigation of response to signals manipulated for pitch in sober and alcohol intoxicated conditions

Results to this point have shown satisfying consistency across two populations known to be vulnerable for death in a fire. Groups of young children and young adults under the influence of alcohol have responded well to both the mixed T-3 and the female voice alarm. Most importantly the response of both groups has been better to these signals than to the high-pitched signal currently used in most Australian homes.

Both of the successful signals have been shown to share some similarities in the characteristics of the auditory signal they project that would seem to distinguish them from the current smoke alarm signal. They are both structurally more complex than the pure tone, and they share common dominant peaks in frequency, or at least fall within the same range. Additionally the less successful ASA is considerably higher in pitch, which is directly inverse to what was expected.

This highlights the interesting implication that emerged from Experiment 2 that factors identified as conveying urgency by people when they are awake may not be perceived in the same way when they are asleep. Research into warning signal design for industrial applications has determined that important parameters for conveying urgency are increased speed, pitch, and repetition (Hellier & Edworthy, 1999). However as has been mentioned above, results of the earlier experiments found that the alarm that best fits these criteria, the ASA, was consistently the least successful of those tested.

Previous research with participants who are awake has also found that the female voice is perceived as more urgent than the male voice (Barzegar & Wogalter, 1998; Hellier et al., 2002). The appropriateness of this choice when the alarm is to be used to awaken sleeping individuals may then also be called into question. Additionally, the male voice would be expected to be of a minimally lower pitch and, if such subtle differences are important, then it is possible that it might be more successful than the female voice. If pitch is not an important parameter at this minute level then there may be some other unknown factor that distinguishes the two, for example social psychological factors. Since it seems that other factors that are subjectively rated as important in conveying urgency when people are awake may not be as influential when people are sleeping, differences between the two voice signals are not expected if the content of the message and the tone with which it is delivered are closely matched. However it is important that this is explored rather than simply assumed.

The aim of the current study was to carry out a preliminary investigation into whether the pitch of an auditory signal is a dominant parameter in influencing awakening by testing both a high pitched signal delivered in the T-3 pattern, and a male voice alarm. All testing investigated the response of individuals when sober, and when under the influence of alcohol (.08 BAC). It was hypothesised that high pitched signals would be less effective than others in awakening sleeping individuals, and that there would be no difference in response times between a female voice alarm and a male voice alarm. It was also expected that response times for all signals would be significantly slower when alcohol was given.

METHOD

Participants

Participants for the current study were drawn from the deep sleeping young adults who participated in Experiment 2. Returning to the same participants allowed direct comparison between data collected from both experiments while maintaining the integrity of the repeated measures design. It was hoped to return to all 14 participants, but several were unable to be contacted. Ten participants were successfully contacted and consented to take part (5M, 5F; mean age = 20.8, sd = 2.4).

Materials

Equipment for polysomnographic recording and the delivery of sounds was the same as for Experiment 1.

The following three signals were used:

Male Actor's Voice

A voice alarm spoken by a male actor was developed using the same methodology as for the female actor's signal from Experiment 1. Briefly, he was instructed to use an emotional tone, and speak as though he was alerting a loved one to the presence of a fire (see Barzegar & Wogalter, 1998). He was further instructed to emphatically project the emotional significance and ***urgency*** of the situation with his voice, but without the likelihood of inciting feelings of panic or hysteria. He was also asked to enunciate clearly.

To allow direct comparison between the female and male voice signals the same script was used. However once again recordings were made of the actor repeating each key phrase or word several times using different vocal intonations. The most emphatic and urgent results were then edited together as previously to make the script:

> "DANGER, DANGER there is FIRE. WAKE UP. You
> MUST get up and INVESTIGATE, there is FIRE. GET
> UP NOW!"

As with female voice alarm, the duration of the message was 10 seconds, which was then looped to make a total of 30 seconds. As for the auditory signals from the Experiement 2, thirteen individual sound files were created in keeping with the sound levels determined by the modified method of limits. The actor was paid $150.00 AUD for his services plus $10.00 AUD travel expenses.

Displayed below in Figure 5.1 is a measurement of the pitch of the male voice alarm. Background noise levels were below 50dBA so only peaks above this level will be highlighted.

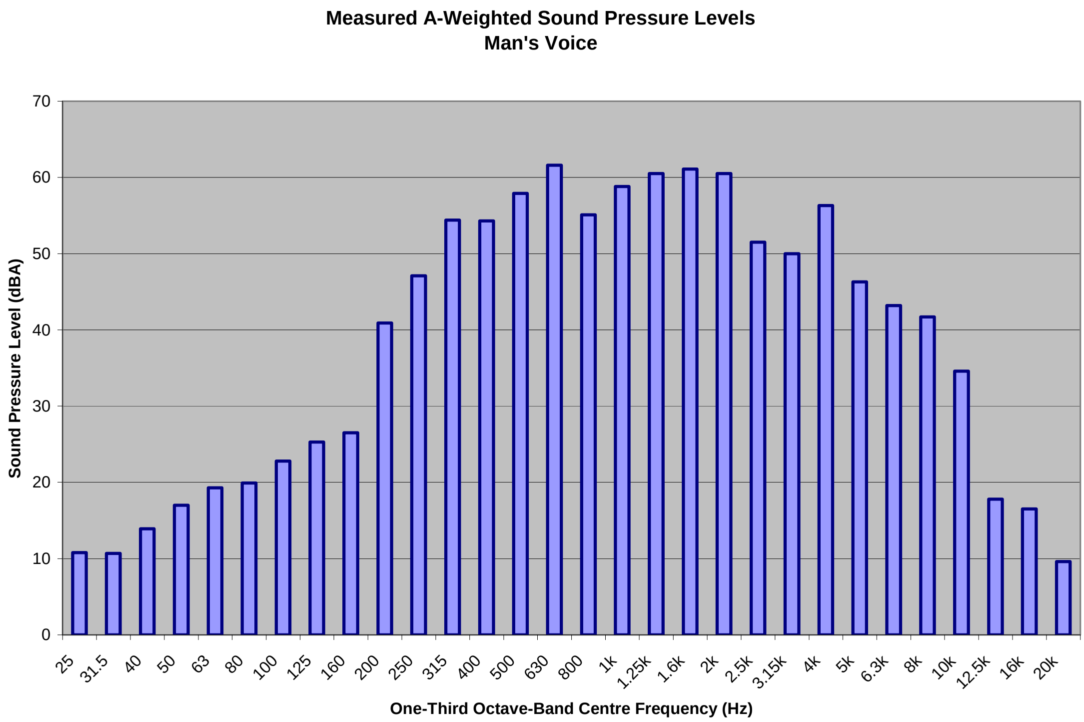


Figure 5.1. Pitch of the Male Voice alarm as displayed in A-weighted sound pressure levels.

The above figure reveals the Male Voice alarm to share several similarities with the Female Voice alarm. Like its counterpart, it too is a complex sound with several overtones. Identical to the Female Voice alarm it displays peaks in the range of 315Hz to 2500Hz. Unexpectedly it also shows a peak at 4000Hz. (The sound technician who performed this measurement advised that this peak may be due to the male actor's emphasis of 's' sounds). Specific dominant peaks over 60dBA lay at 630Hz, 1250Hz, 1600Hz and 2000Hz. This is also very similar to the Female voice alarm which showed peaks at 315Hz, 400Hz, 1000Hz, 1600Hz, and 2000Hz over 70dBA.

Comparing pitch parameters of the two signals it cannot reasonably be claimed that the Male Voice alarm is actually lower in pitch to the Female Voice alarm. However to the unassisted ear the two signals can clearly be identified as distinctly male or female. Subjectively the Male Voice alarm certainly sounds deeper throughout until the end phrase "GET UP NOW". The male actor has attempted to emphasise the urgency of this instruction by raising his pitch to a degree that appears to be greater than the female actor has done. Subjectively the Male Voice also sounds more strident, and the Female Voice more emotional.

High Pitched Temporal-Three

A 4000Hz beeping signal transmitted in the temporal-three pattern was created for the current study. The signal was created by manipulating the mixed T-3 signal that was used for Experiments 2 & 3 with the Sonic Foundry program. Once again Although every effort was made to 'clean' the sound waves to remove all artefact, the resultant signal seemed to have a clicking sound in the background throughout that became worse when transitioning to its 'off' stages. This artefact was not present or not easily perceived in the continuous beeping of the ASA, or in the unaltered lower pitch mixed T-3. The variation in the sound was not readily apparent at the lower sound intensities, but became more discernible as the sound intensity increased. Thirteen separate sound files were created for the signal delivery program, one for each sound intensity level from 35 to 95dBA.

Displayed below in Figure 5.2 is a measurement of the pitch of the High-Pitched Temporal-Three signal. Testing was done at the same time as for the Male Voice alarm so environmental conditions were the same, hence only peaks above 50dBA will be highlighted.

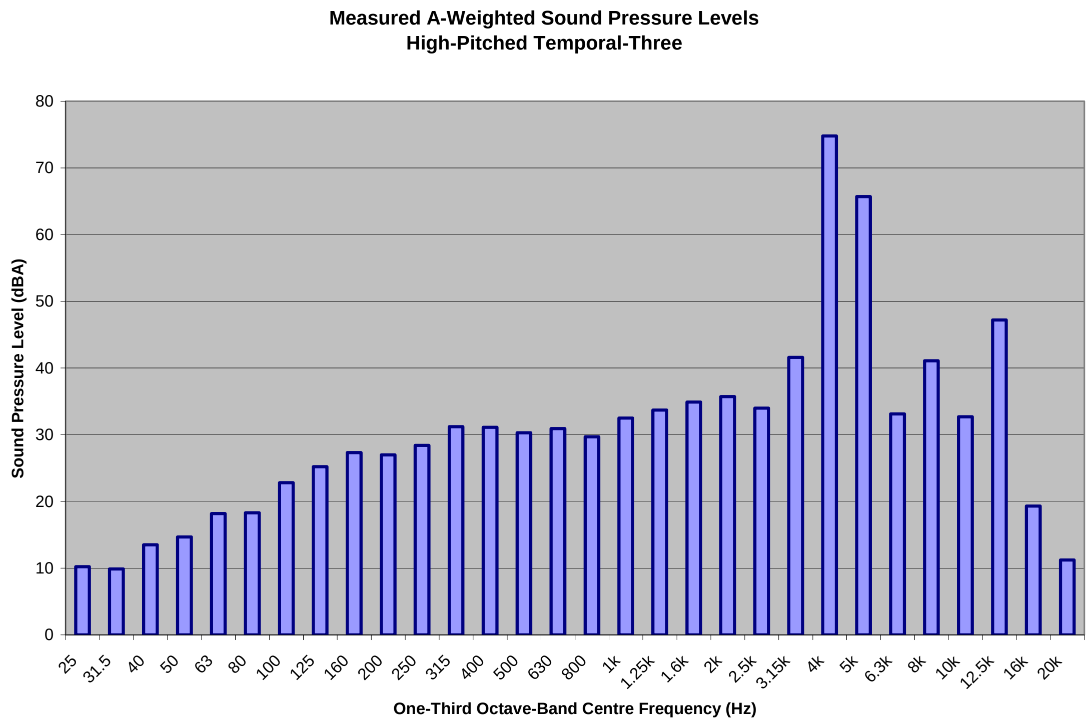


Figure 5.2. Pitch of the High-Pitched Temporal-Three signal as displayed in A-weighted sound pressure levels.

The High-Pitched Temporal-Three signal is a more simple sound and displays a specific peak at 4000Hz, and to a lesser degree at 5000Hz. From this point forward it shall be referred to as the 4000Hz T-3.

Procedure

Where possible data was collected by the same research assistant who had been assigned to each participant for the previous study, however this could not always occur due to staff turn-over. When this was not possible every effort was made to match the sex of the research assistant to the participant in keeping with the previous procedures. When sex could not be matched participants were asked for their permission for data to be collected by a person of the opposite sex.

Participants were contacted directly by the research assistant assigned to them and asked if they would like to participate in the current study. If verbal consent was obtained they were provided formally with written information and a mutually convenient time was arranged for the study to take place.

Procedure for polysomnographic recording and administration of alcohol was identical to Experiment 2, with the exception that the study was conducted over two nights only. One night was undertaken in the sober condition, and the other was the .08 BAC condition. It was possible to reduce the investigation to two nights because significant differences had been found between the sober and alcohol conditions, but not between the two alcohol conditions themselves. The higher BAC was selected because data for the following experiment (Experiment 5) was also collected on the same night, immediately following data collection for the current study. This meant that five signals were presented to participants for each night of the current study, but only two of them were relevant here. These were always the first two presented. Selection of the higher (.08) BAC condition served to ensure that participants would be reasonably estimated to show a moderate level of intoxication for the following study, with a BAC at around the .08 to .04 range depending upon how long it took to collect data for the first two signals.

An added advantage of reducing the study to two nights was that it also lessened the burden upon participants and their families who had already been very generous with their cooperation. When participants were being tested by the same research assistant as previously, the order of alcohol condition was counterbalanced across both nights. When data was being collected by an unfamiliar research assistant the first night was always the no alcohol condition. The order of presentation of the two signals was counterbalanced across participants and alcohol conditions.

The procedure for calibration of the sound levels and the administration of sound stimuli was the same as for previous experiments. Once again participants were exposed to all signals prior to sleep on the first night, and all awakenings occurred during stage 4 sleep.

Data Analysis

All statistics were calculated using SPSS version 14. The output can be found in Appendix 7. As outlined above, this was a repeated measures design using a subset of the participants from experiment 2 which allowed direct comparison between signals from both studies. To this end awakening times and dBA levels for the female voice, ASA, and mixed T-3 for both the sober and .08 conditions that had been collected for Experiment 2 were combined with the newly collected data in a separate database. A 5x2x2 repeated measures SPANOVA was used to calculate differences in awakening times. The within subjects factors were 'sound' with five levels corresponding to the five different auditory signals, and 'alcohol' with two levels (sober and .08 BAC). As with Experiment 2, the between subjects factor was sex.

Although adequate to uncover what might be trends in the data, it is important to note that the sample size of the current study was not sufficiently large enough for firm conclusions to be drawn. Every effort was made to contact all participants of the previous study, but unfortunately this was not always possible, and it is a necessary but unfortunate consequence of repeated measures research that the loss of a single data point means the elimination of all data for a given participant being lost from the calculations.

RESULTS

Descriptive statistics for sound intensity level were calculated for all signals in both alcohol conditions and are displayed in Table 5.1. This includes data for the female voice, ASA and mixed T-3 calculated for this subset of participants as distinct from the larger group who took part in Experiment 2. The procedure for calculating sound intensity at the extremes of measurement was the same as for Experiment 2. To recap, sounds were presented with the range of intensity from 35dBA to 95dBA. Where participants slept through the signal, this was assigned a value of 100dBA.

Table 5.1. Descriptive statistics for sound intensity level (dBA) according to sound type and alcohol level (N = 10).

	ALCOHOL			
SOUND	**Sober**		**.08 BAC**	
	Mean	Median	Mean	Median
Female Voice	58.5 (16.8)	60.0	77.5 (22.5)	82.5
ASA	71.0 (14.9)	72.5	81.5 (17.0)	85.0
Mixed T-3	58.0 (14.9)	57.5	76.0 (23.9)	77.5
Male Voice	52.5 (18.3)	45.0	80.5 (16.4)	87.5
4000Hz T-3	61.0 (10.2)	62.5	75.0 (15.8)	72.5

As was expected the pattern of results for the female voice, ASA and mixed T-3 followed the trends for Experiment 2 of which they represent a subset. The ASA remained the least successful signal by a fairly substantial margin in the sober condition when the new signals were also considered, and performed no better in the .08 BAC condition. Somewhat surprisingly the male voice alarm was the most successful of all signals in the sober condition, but the results for *both* voice alarms was comparable to the ASA in the .08 BAC alcohol condition. Also surprising was that the high-pitched T-3 signal performed as well as the voice alarms and mixed frequency T-3.

As with Experiment 2, the data presented in Table 5.1 does not fully capture the finer details of differences in response patterns at the highest sound intensity level. Table 5.2 below shows how the different signals performed compared to the current sound intensity level prescribed in international standards (75dBA).

Table 5.2. Sound intensity response patterns compared to current standards (N=10).

	SOBER				**.08 BAC**			
	Woke at or below standard (≤75)	***Woke above standard (80+)***	***Slept through***	***Total above standard***	***Woke at or below standard (≤75)***	***Woke above standard (80+)***	***Slept through***	***Total above standard***
FV	8/10 (80%)	2/10 (20%)	0	20%	5/10 (50%)	3/10 (30%)	2/10 (20%)	50%
ASA	5/10 (50%)	5/10 (50%)	0	50%	4/10 (40%)	4/10 (40%)	2/10 (20%)	60%
Mixed T-3	9/10 (90%)	1/10 (10%)	0	10%	5/10 (50%)	1/10 (10%)	4/10 (40%)	50%
MV	9/10 (90%)	1/10 (10%)	0	10%	4/10 (40%)	5/10 (50%)	1/10 (10%)	60%
4000Hz T-3	10/10 (100%)	0	0	0%	5/10 (50%)	4/10 (40%)	1/10 (10%)	50%

The above data highlights an unexpected contrast between both 4000Hz signals in the sober condition with 50% of participants needing a sound intensity above the standard to awaken to the ASA, contrasted with the 100% success of the high-pitched T-3. Similar to Experiment 2 it also shows that response rates to *all* signals when alcohol was given were consistently poor, with the best result being 50%.

Means and standard deviations for behavioural response times (measured in seconds) were calculated and are shown in Figure 5.3.

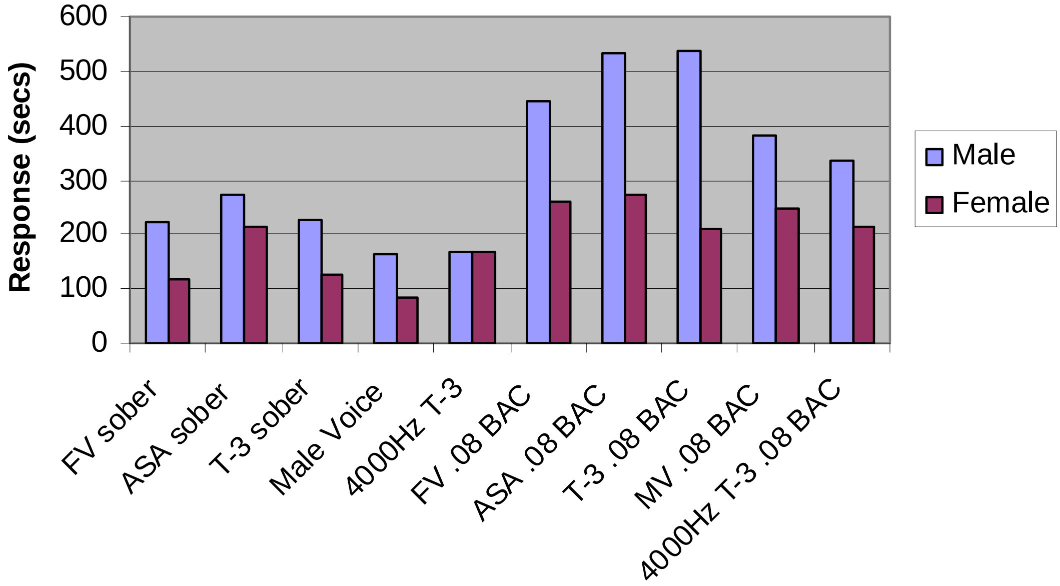


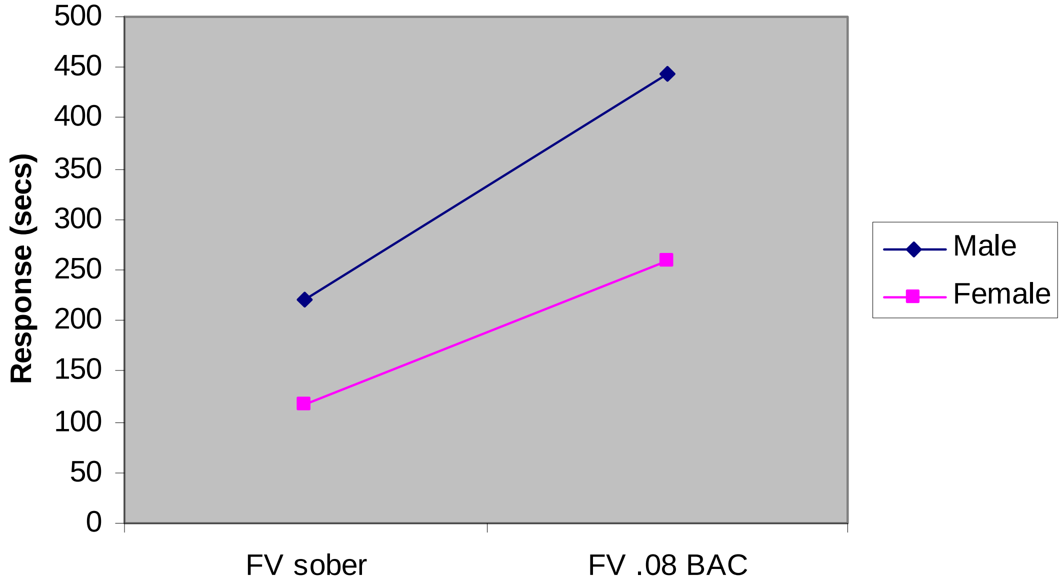
Figure 5.3. Mean behavioural response time for males and females (N = 10)

As can be seen the results are also consistent with the findings of Experiment 2 in that mean behavioural response times were notably increased for all signals when alcohol was taken. Also consistent is that males displayed considerably longer response latencies than females to all signals when alcohol was given.

Results of the SPANOVA showed significant main effects for sound $F(4,32) = 3.821$, $p = .012$, for alcohol $F(1,8) = 81.148$, $p = .000$, and for sex $F(1,8) = 8.140$, $p = .021$. A significant interaction was once again found between alcohol condition and sex $F(1, 8) = 13.553$, $p = .006$. No other significant results were found. The means displayed above show that results for alcohol condition are in the same direction as for Experiment 2, with alcohol significantly increasing the time to awaken for all signals. They also show that the male participants took significantly longer to respond than the females.

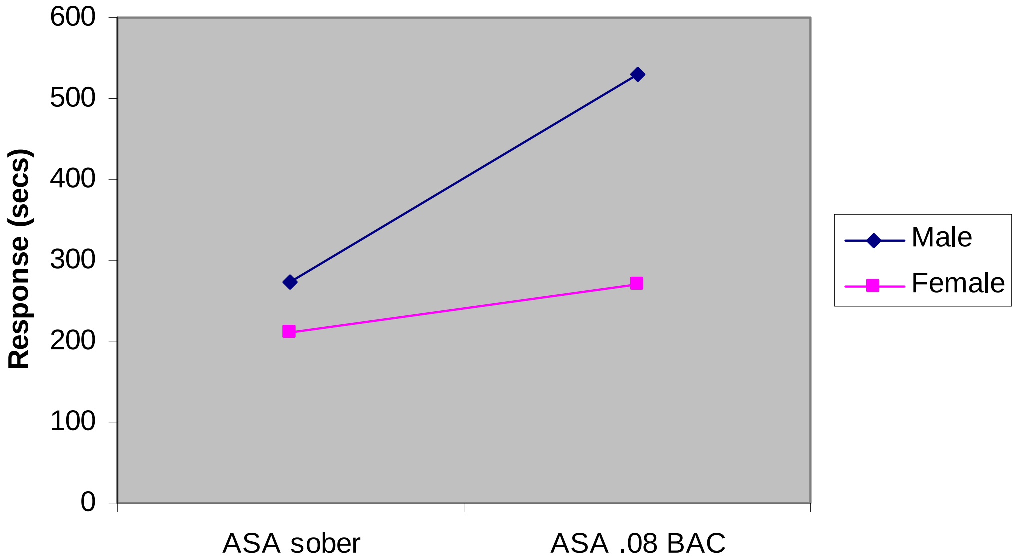
Once again planned comparisons were carried out in order to reveal precisely which variables underlay the significant differences found above. Since comparisons had already been made between the three signals carried forward from Experiment 2 it was not considered important to repeat them here. Instead it was thought important to obtain contrasts between the two new signals with all others, including each other. Hence the SPANOVA was calculated twice, once with the Male Voice entered last, and once with the 4000Hz T-3 signal entered last. Results showed significant differences lay between the Male Voice and the ASA, $F(1,8)=7.87$, $p=.023$ and the 4000Hz T-3 and the ASA, $F(1,8)=11.18$, $p=.010$. Perusal of the means shows that both of the new signals were more effective than the ASA. Since the independent variable 'alcohol' was only comprised of two levels for the current experiment planned comparisons were only relevant in relation to interactions with sound, and no significant results were produced.

In order to fully understand the interaction between sex and alcohol condition results were plotted as before. The resulting graphs for each sound are displayed below as Figures 5.4 to 5.8.



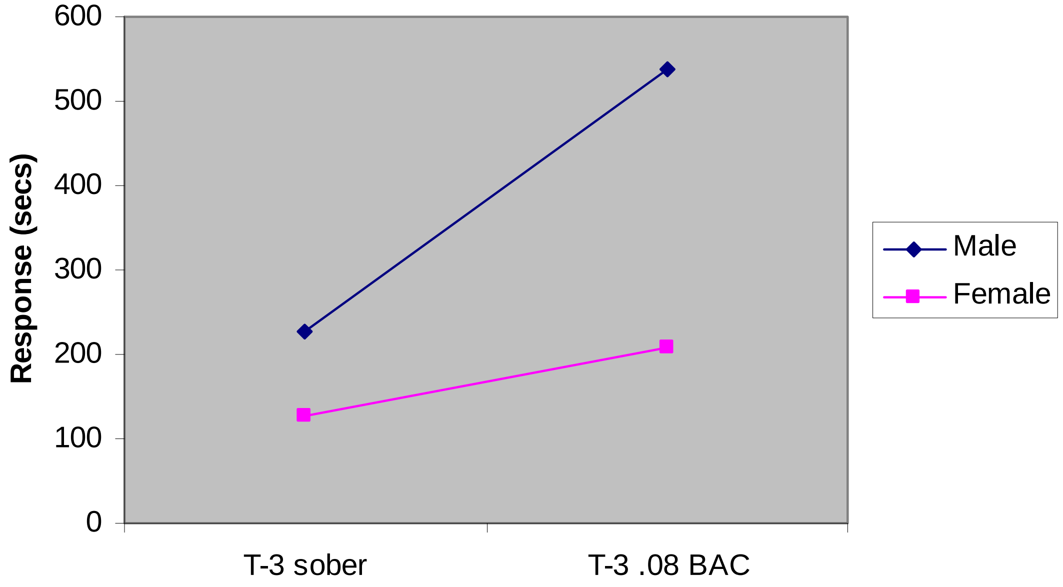
(Standard deviations: Sober, M = 102.5, F = 81.4; .08 BAC M = 111.3, F = 211.5)

Figure 5.4. Mean behavioural response times for the Female Voice alarm between males and females across alcohol conditions.



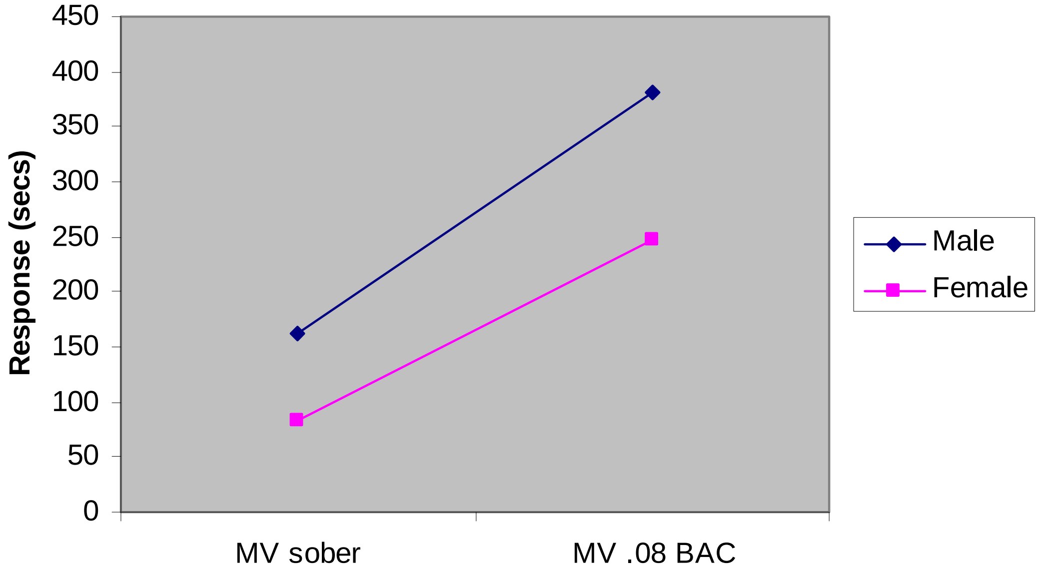
(Standard deviations: Sober, M = 47.4, F = 115.4; .08 BAC M = 107.0, F = 177.5)

Figure 5.5. Mean behavioural response times for the ASA between males and females across alcohol conditions.



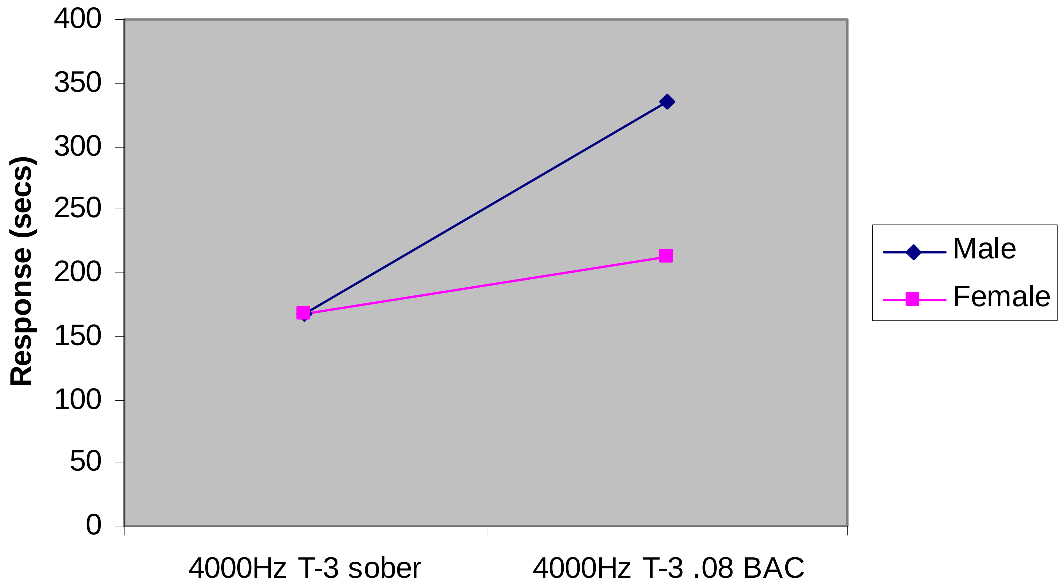
(Standard deviations: Sober, M = 106.3, F = 60.1; .08 BAC M = 140.9, F = 226.0)

Figure 5.6. Mean behavioural response times for the mixed T-3 alarm between males and females across alcohol conditions.



(Standard deviations: Sober, M = 127.8 F = 64.4; .08 BAC M = 147.7, F = 100.0)

Figure 5.7. Mean behavioural response times for the Male Voice alarm between males and females across alcohol conditions.



(Standard deviations: Sober, M = 42.1, F = 80.3; .08 BAC M = 161.4, F = 82.9)

Figure 5.8. Mean behavioural response times for the 4000Hz T-3 alarm between males and females across alcohol conditions.

Examination of Figures 5.4 to 5.8 above elucidates a trend that is most pronounced for the three beeping signals, but also apparent for the voice alarms (recalling that there was no significant three way interaction between sound, sex and alcohol level). When the magnitude of the distance between the data points for males and females in each of the alcohol conditions is examined the figures show that like Experiment 2, behavioural response time *was* dependent upon sex when any alcohol was given, but was not dependent upon sex when participants were sober.

DISCUSSION

The hypothesis that high pitched signals would be less effective than others in awakening sleeping individuals was not supported. Conversely support was found for the further hypothesis that there would be no difference in response times between the female voice alarm and the male voice alarm, and that response times for all signals would be significantly slower when alcohol was given.

Pitch

The results of Experiment 2 highlighted the pitch of alarm signals that are designed to be used to wake sleeping individuals as an interesting characteristic worthy of further exploration. Findings had emerged in contrast to previous research into warning signal design that predicted that a beeping signal with rapidly repeating beeps of high pitch would be perceived as most urgent. Instead it was found that the lower pitched and slower repeating signal of the two tested sounds was the most successful. In fact it was found that the high-pitched, rapidly repeating beep of the ASA alarm was the least successful of all signals tested.

Three important characteristics are outlined in the description of alarm signals as described above. These are speed, repetition rate or rhythmicity, and pitch (Hellier et al., 1993). Of the three pitch was settled upon as central because it was the characteristic shared between the successful mixed T-3 and the Female Voice signal. The current study attempted to explore the importance of pitch by manipulating the frequency of the successful mixed T-3 signal to match the poorly performed ASA, while maintaining its speed and rhythmicity. Comparison based upon pitch was then possible between the 4000Hz T-3 and the unaltered mixed T-3. At the same time it also allowed comparison between two signals that shared the same pitch, but varied on speed and rhythmicity, namely the ASA and the manipulated T-3 (4000Hz T-3).

Results of the current study failed to support pitch as an important characteristic. Instead it was found that the new high-pitched T-3 was not significantly different in performance to the unaltered mixed T-3, and that it was significantly better than the 4000Hz ASA. To explain fully, this means that the two signals that shared rhythmicity and speed in common were equivalent in their performance, regardless of pitch. It also means that the signal that was distinct from the others on the parameters of rhythmicity and speed performed at a significantly inferior level.

If the above results are taken at face value, then this would infer that rhythmicity and speed are more important characteristics than pitch regarding the design of warning signals to be used to wake sleeping individuals. However several methodological concerns mean that this should not be taken as correct without further investigation. Firstly, a consequence of the small sample size of the current study is that results can only be considered as preliminary. As has been explained this was an unfortunate consequence of using the same participants as Experiment 2, not all of whom could be contacted or continue. Nonetheless the current study would not have been possible if this methodology was not followed because it would have meant recruiting a whole new batch of participants and testing them for all five signals across two alcohol conditions which would have extended the data collection beyond achievable limits.

The second methodological concern refers to order of presentation of the stimuli. This also stemmed from the way the current study evolved out of Experiment 2. A significant confounding effect for repeated measures designs can be order effects. Under normal circumstances these can be effectively controlled with careful counterbalancing of the order of presentation of levels of the independent variable/s (Brace et al., 2003). Although systematic counterbalancing was possible for the three signals studied in Experiment 2, because the current study extended data collection by an additional two signals counterbalancing was limited. Instead of the order being counterbalanced across all five signals, data collection for the two additional signals meant that they were always presented first or second, rather than first, second, or third. This was thought to be a minor issue for the current study because AATs have been found to show significant reliability for same stage awakenings both between nights and within nights (Bonnet, Johnson, & Webb, 1978). This means that differences in AAT are likely to be due to the signals, rather than the order in which they were presented.

More important is that the new signals were always presented as the fourth and fifth signals overall, and on the fourth and fifth night of an individual's participation in the research protocol. What is important in raising this issue is the possibility of a practice effect regarding the overall methodology. Participants were always experiencing the required alcohol condition (sober or .08 BAC) for the second time, and were experienced in having their sleep interrupted by alarm signals. It could be inferred that they were well trained in the research protocols by the time data was collected for the current study, which may have improved their performance in a way that was beyond or unrelated to characteristics of the signals used.

A final difficulty related to the method was the amount of artefact in the 4000Hz T-3 signal that was purposely manufactured for the current study. As has been stated previously, every effort was made to 'clean' the sound waves to remove the clicking noise in the background of the signal, but success was quite obviously limited. It was decided to proceed with the imperfect signal because the spectral analysis did not reveal any peaks in the lower frequency levels related to the clicking even though it could be readily heard, especially at higher sound levels. In hindsight, however, the clicking sound could possibly account for the peak in the spectral analysis at 5000Hz. The logic is that this would be similar to the unexpected peak at 4000Hz in the Male Voice signal that the sound technician advised may be due to the male actor's emphasis of 's' sounds. However it does seem difficult to reconcile a hissing or clicking sound with a peak at a higher frequency. A better possible explanation may be that instead of being a pure tone, the 4000Hz T-3 was actually a more complex or "mixed" frequency sound because of the unexpected peak at 5000Hz. Smaller peaks also occur at 3150Hz, 8000Hz and 12500Hz above 40dBA that were not thought to be influential, but whose influence may not have been fully understood. This could suggest that complexity in tonal quality is perhaps even more important than pitch in causing an awakening. It was concluded that the presence of the artefact interfered with the ability to draw firm conclusions about the influence of the pitch of the signal. This must be avoided in future studies by sourcing 'clean' signals, or having signals generated from scratch by experts in the field of sound production.

Comparing the Female and Male Voice Alarms

As was expected no difference was found between the voice alarms made by the female and male actors. Generally both males and females responded slightly more rapidly to the male voice alarm, but these differences were not significant. Overall individuals responded well to both voice alarms that were designed for the current study. Although results are preliminary only they provide support for the inference that what individuals subjectively report to be important for conveying urgency when they are awake does not necessarily hold when they are asleep.

It is important to note that the methodological problems outlined above with possible order and practice effects also apply to this discussion. This applies particularly to practice effects that may have caused a bias in the data towards improved performance for the male voice alarm.

Alcohol

A strong main effect for alcohol provides consistency with the findings from Experiment 2. This must be considered in light of the fact that the participants for the current study were a subset from that experiment, and no new data was collected for the Female Voice, ASA, and unaltered mixed T-3. This meant that a significant result for alcohol was to be expected. However addition of the two new signals contributed to a substantial increase in the 'F' value and there was no interaction between alcohol condition and sound meaning that alcohol extended response times regardless of the signal.

CHAPTER SIX

EXPERIMENT 5

Response to visual and auditory naturalistic fire cues in sober and alcohol intoxicated conditions: A preliminary investigation

The original premise in designing a new smoke alarm signal was to use James Gibson's theory of perceptual affordances to create a novel signal that enhanced direct perception. At first thought, the voice alarms do not seem to fit this criterion, but as was explained they do hold the important advantage of being able to directly convey their message without need for further interpretation by the listener. Although a voice alarm is not *naturalistic* of itself, it does allow direct perception and so satisfies Gibson's theory to an extent.

However Gibson's theory does not account for the success of the mixed T-3 alarm. It came as most surprising that a benign sounding beeping signal was equally as successful as an emotional human voice in waking sleeping individuals. The success of this signal was not at all in keeping with our a priori expectations that were formulated based upon previous research. In fact the mixed T-3 fulfils none of the criteria thought to be important. It is neither naturalistic nor conveys direct meaning, and neither does it convey any emotion at all. Possible reasons for its success have been discussed and will not be repeated here. However the success of a signal with fundamental parameters that fail to satisfy the theory does not mean that the theory should be discarded as irrelevant without further investigation.

Without confirmatory evidence, people are unlikely to believe that there is a fire simply because their smoke alarm has sounded. They are more likely to act when additional cues that there may be a fire are present, for example if they can also see or smell smoke, or feel radiant heat. This is certainly the case for individuals who are alert and awake, but is it likely to also be the case when they are sleeping? The results of Experiment 2 certainly suggest that what we consider is important for conveying urgency when we are awake may not indeed be what draws our attention when we are asleep. Differences in what will cause a response between the wake and sleep states certainly warrants further investigation.

To date there has been little attention given to whether sleeping individuals will respond better to multiple cues. In theory multiple cues presented simultaneously should be more effective because this would represent a more naturalistic portrayal of a real fire emergency. However the ability to recognise and act upon naturalistic fire cues presented to different sensory modalities in isolation during sleep has been investigated. Bruck & Brennan (2001) investigated the responsiveness of unimpaired adult participants to low levels of fire related cues delivered to the auditory, visual and olfactory senses. For auditory cues the authors used a ‘crackling’ sound and a ‘shuffling’ sound, both reported to be regularly associated with fire, presented at a constant intensity of 42 to 48dBA. The visual cue was a flickering light from a 20 watt halogen lamp that was reflected off the ceiling and reached the pillow at a strength of five lux or less, and the olfactory cue was the smell of a chemical associated with smoke taste in food flavouring at 6 parts per million. Results showed a high rate of arousal from sleep to both auditory cues, but only 59% awoke to the smell, and just 49% to the flickering light. Sleep stage was not specifically controlled for this study, but stimuli were presented at a standard time after participants retired for the night and awakenings were estimated to be in stage 2 or REM.

The light used in the Bruck and Brennan (2001) study was transmitted from a flickering halogen bulb that was designed to mimic the light from a fire directly. Light as a stimulus has received some attention from researchers in the past, but with a different emphasis. Strobe lights have been considered as an alternative to auditory signals as an emergency alerting device for individuals who have difficulty hearing. In a US study in 1990 Nober and his colleagues (Nober, Well & Moss, 1990) found that college students with their eyes closed subjectively selected white light as the brightest when tested with white, red, yellow, and blue lights. They then compared the effectiveness of light stimuli including an industrial strobe, a household strobe (weaker in strength than the industrial), and a flashing 100 watt light bulb with groups of normal hearing and hearing impaired individuals during sleep. They reported that ninety percent of the hearing impaired participants awoke to the strobe lights, but that only 63% of normal hearing participants responded similarly. The flickering light bulb was considerably less effective. It should be noted that sleep stage was not controlled in this study.

Other studies have also investigated the response of hearing impaired individuals to strobe lights. A 1991 study undertaken by the Underwriters Laboratory in the US reported remarkable efficiency for strobe lights in awakening the deaf with a response from 100% of adults, 91% of high school students, and 86% of junior high school students. The signal was played between the hours of 1 and 4 am, however once again sleep stage was neither assessed nor controlled. Sleep stage was controlled for in a later study by Du Bois and colleagues (Du Bois, Ashley, Klassen & Roby, 2005) who report considerably less success. Their strobe light awoke 57% of deaf participants, 34% of hard of hearing participants, and 32% of normal hearing participants across the different sleep stages of SWS, stage 2 sleep, and REM. They reported an overall trend for the decreased response rates to the strobe in deep sleep.

Finally, Bowman and colleagues reported a study of thirteen unimpaired female participants (Bowman, Jamieson & Ogilve, 1995). These researchers controlled for sleep stage and reported an intensity of 19.9 lux at the pillow. The authors note that this exceeded the Americans with Disabilities Act (1990) recommended level of 75 candela. They reported that less than 30% of their participants responded to the strobe from deep sleep.

The aim of the current study was to further investigate whether naturalistic fire cues would be successful in alerting both sober and alcohol intoxicated sleeping individuals to a fire. The central purpose was to investigate whether a combination of naturalistic cues would further enhance direct perception to the extent that a faster response would be produced. The naturalistic signals included an auditory stimulus (house fire sound), a visual stimulus (flickering light), and most importantly a combination of both naturalistic auditory and visual stimuli. The design also constituted an extension to previous research through use of the modified method of limits with a light stimulus, thereby increasing information regarding the optimal brightness required to awaken sleeping individuals. The flickering light was selected over a strobe because it was thought to be more likely to be naturalistically associated with fire. It was hypothesised that the naturalistic auditory signal would wake participants faster and at a lower level that the flickering light. It was further hypothesised that the combination of the naturalistic auditory signal with the flickering light would be more effective than either signal presented in isolation. It was not know whether the two signals when presented together would have an additive effect, but this was not specifically anticipated.

METHOD

Participants

Participants for the current study were nine of the same group who took part in Experiment 4 (5M, 4F; mean age = 21.1, sd = 2.3). Ten participants completed data collection for Experiment 4, but one of these was lost to the study before data collection was completed due to illness.

Like for Experiment 4, the participants for the current study also represented a subset of those who had participated in the larger Experiment 2. Unlike Experiment 4 no data was drawn from the earlier studies for use in the current study.

Participants were paid AUD $50.00 for each night of their participation in the current study (total AUD $100.00).

Materials

Equipment for polysomnographic recording and the delivery of sounds was the same as for the earlier experiments. Alterations were made to the sound delivery system to allow for the presentation of a flickering light stimulus. This included adjustments that allowed the intensity of the light to be delivered in increasing steps according to the method of limits. The program was also altered to allow the simultaneous presentation of signals.

The following three signals were used:

Naturalistic house fire

The 30 second naturalistic house fire sound from Experiment 1 was used. This sound included the sound of glass explosions and the roaring, crackling, and popping of a fire. Deeper investigation of the characteristics of the pitch of this sound are not available. The central question of the current study concerned the naturalistic quality and value of this signal, rather than the range of frequencies it generates.

Flickering Light

The flickering light was a 20 watt halogen bulb which was mounted upon custom built frame. The frame consisted of a horizontal arm projecting at right angles from a metal stand with telescopic adjustment available to control the height. This allowed it to be mounted directly above the pillow as shown in Figure 6.1.

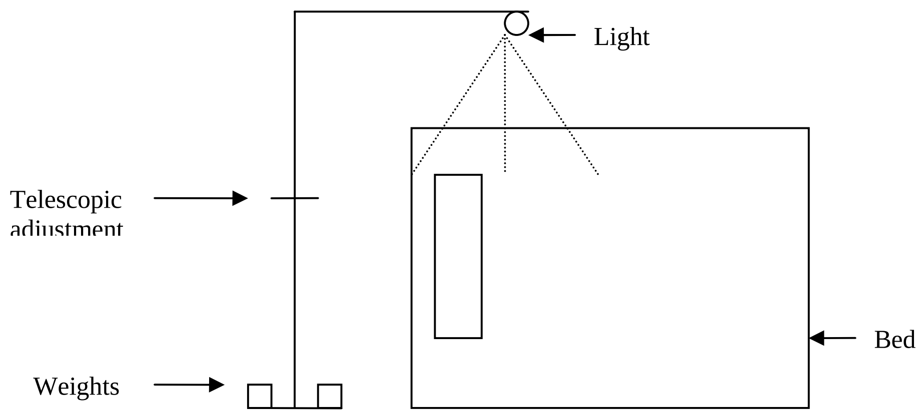


Figure 6.1. Configuration of flickering light over pillow.

The stand was supported by weights placed at the footings to ensure that it would not move or cause injury to participants by overbalancing on top of them.

In keeping with the modified method of limits, the light started at a very low level and was increased in strength incrementally every 30 seconds. The intensity of the light emitted at each step is shown in Table 6.1. The measurements were taken at a distance of 1m from the pillow against the background of a clean white sheet of A4 paper. All measurements were taken with a standard light meter. The corresponding sound levels are also included and indicate the levels when light or sound were administered either singly, or simultaneously. Note that a range of intensities is included due to the flickering nature of the light.

Table 6.1. Signal strength at each step of the modified method of limits

Level	Time (seconds)	Sound Intensity (dBA)	Light Intensity (lux)
1	0-30	35	0-1
2	30-60	40	2-3
3	60-90	45	5-6
4	90-120	50	13-15
5	120-150	55	21-26
6	150-180	60	29-36
7	180-210	65	42-53
8	210-240	70	57-72
9	240-270	75	74-93
10	270-300	80	91-114
11	300-330	85	110-138
12	330-360	90	136-170
13	360-570	95	153-202

As can be seen, the intensity of light was very low in the early stages. Up until the fourth increment (corresponding to auditory signal intensity of 50dBA) the signal was roughly equivalent to that used by Bruck and Brennan (2001), and at the fifth increment it was equivalent to the strobe used by Bowman and colleagues (Bowman et al., 1995) both of which were limited in their success.

From that point the light steadily increased until it reached peak intensity. The US NFPA 72 (2002) standard outlines requirements that must be met by a strobe light that is being used to alert the hearing impaired to the possibility of a fire, but these relate to the intensity at the light (110 candela if the strobe is mounted at more that 24 inches from the ceiling) and not to the received intensity at the pillow. For the current study a flickering, rather than a strobe light is being used and measurements are made at the pillow, therefore it is not known how this relates to the standard.

Unlike for the sound, it was not necessary to make a specific file for each increment of light intensity. The different levels of light were manipulated by a control box varying voltage input that was connected between the light and the signal delivery system on the laptop. This control box was designed and made by staff of CESARE.

Procedure

Data for the current study was collected simultaneously with data collection for Experiment 4. This was explained to participants when they were recruited and information on both studies was sent out and consent was obtained at the same time. Payment for participation in each study was made separately, meaning that individuals actually received a total of AUD $100.00 for each of the two nights of participation comprised of AUD $50.00 for each study (grand total AUD $200.00 for both nights).

Data for the current study was always collected directly after the completion of data collection for Experiment 4 on both nights of the study. This meant that a total of five signals were administered to each participant on each night, and the two signals for Experiment 4 were always collected first and second. The three signals for the current study included the naturalistic house fire sound from Experiment 1, a flickering light, and simultaneous presentation of the naturalistic house fire sound together with the flickering light. These signals were presented in counterbalanced order (always as the third, fourth, or fifth signal presented) across two alcohol conditions (sober and approximately .08 BAC) over two nights.

Since data was collected in tandem between the current study and Experiment 4 details of procedures for polysomnographic recording, sound stimulus calibration and presentation, and the administration of alcohol can be found there.

An important point of departure in the procedure for data collection that distinguishes the current study from the all preceding experiments was that awakenings were carried out in *stage 2 sleep* rather than stage 4. This was done because it was uncertain whether five awakenings would be possible in stage 4 on a single night. It was most important when alcohol was administered because it is known that alcohol continues to be absorbed rapidly for a period of 30 to 45 minutes after the last drink is taken before BAC reaches its peak level, and then begins to decline in a linear fashion at the rate of about .015 per hour (Sadler, 1999). It was possible that attaining five periods of stage 4 sleep may have taken a considerable amount of time for some participants which would have the consequence that data was being compared across different alcohol conditions within the one night. For example signal one may have been delivered within the first half hour of the sleep period, but signal five may not have been delivered until four or five hours later. In this circumstance the BAC when the first signal was delivered would be expected to fall between .08 and .09, but for the fifth signal it would be estimated to be as low as .02 to .03. These two extremes clearly do not represent equal levels of intoxication and the effects of alcohol between them could not be compared in a valid way. The same problem would occur in comparing data between participants who varied widely in the total amount of time taken to collect five stage 4 awakenings. Both of these difficulties were minimised in previous studies by collecting less data points and by appropriate counterbalancing. Since it was necessary to collect data for five signals, scheduling awakenings for the current study in stage 2 allowed this to be completed in a considerably shorter period of time which was hoped to minimise methodological concerns.

It must be noted that although it was known that BAC was at .08 when participants went to bed, the BAC would have varied between individuals before data collection was commenced for the current study depending upon how long it took to collect the two data points for Experiment 4 beforehand. The first two stage 4 awakenings usually happened quite quickly, so it was estimated that BAC would have remained at a moderate level, and was likely to fall within the range of around .08 and .04. This was considered within tolerance limits because no difference had been found in behavioural response times between the .08 and .05 BAC for Experiment 2.

The additional feature of this study was the inclusion of a light stimulus. The intensity of the flickering light was calibrated at the pillow in each room measured against the background of a clean white sheet of A4 paper. The use of the white paper allowed a standardised background across bedrooms in order to minimise differences in light intensity caused by reflecting off varying colours and patterns between pillow cases. The equipment was set up according to the configuration shown in Figure 6.1, and the paper and light meter were placed in the centre of the pillow, directly under the light. The light was commenced at increment six (29 – 36 lux), which corresponded to the calibration level of the sound signals (60dBA). The light meter was then checked and if the reading was too high (greater than 36 lux) the telescopic adjustment was used to raise the height of the light, thereby decreasing its intensity. If the reading was too low (less than 29 lux), then the height of the light was lowered in order to increase its intensity. These adjustments continued until the desired intensity was reached. It was endeavoured to calibrate the light at as close to the higher level of 36 lux as possible.

Data Analysis

A 3x2 repeated measures ANOVA was used to calculate differences in awakening times. The within subjects factors were 'stimulus' with three levels corresponding to the naturalistic house fire sound, the flickering light, and the combination of the two, and 'alcohol' with two levels, sober and .08 BAC. The between subjects factor of sex was not included because complete data was collected for only four female participants which makes the comparison questionable. All statistics were calculated using SPSS version 14. The output can be viewed as Appendix 8. Light was entered into the ANOVA as the last variable so that simple contrasts could be made between this variable and the other two. This was recalculated with simultaneous presentation of the two sounds entered last. The small overall sample size of the current study should also be noted when interpreting results.

RESULTS

It was not appropriate to compare AATs to international standards for the current study as had been the procedure for the previous studies because it was not known how the light stimulus related to standard requirements. Instead the number of participants who slept through all levels of the signals are presented. For the naturalistic house fire sound all participants responded when sober (at or below 75dBA), as well as when alcohol was given (one at a level above 80dBA). For the flickering light four (44.4%) participants slept through all levels when sober, and eight (88.9%) slept through when alcohol was administered. When the signals were combined once again all participants responded when sober (at or below 75dBA for the sound), and none slept through when under the influence of alcohol (one at a level above 80dBA for the sound). What is most apparent from this data is that the flickering light on its own performed poorly in all conditions. It is also apparent that the naturalistic house fire sound performed considerably better than expected if the results of the previous experiments are taken into account.

Means and standard deviations for behavioural response times (measured in seconds) were calculated and are shown in Table 6.2. As for the previous studies behavioural response time was recorded as 600 seconds if the person failed to respond.

Table 6.2. Descriptive statistics for behavioural response time in seconds according to stimulus type and alcohol level (N = 9).

	ALCOHOL			
	Sober		**.08 BAC**	
	Mean	**SD**	**Mean**	**SD**
House Fire	68.33	70.7	175.2	92.3
Light	284.0	300.6	541.7	175.0
Both	58.9	57.8	140.2	100.4

The descriptive statistics displayed above show that the flickering light performed poorly compared to the other two stimuli. They also show a tendency for the simultaneous presentation of fire cues to result in faster response times that either stimulus on its own.

Results of the ANOVA showed a significant result for Mauchly's test so the Lower Bound figures are reported. Significant differences were found for stimulus $F(1, 8) = 40.1$, $p = .000$, and alcohol $F(1, 8) = 16.8$, $p = .003$. Planned comparisons between the stimuli showed a significant difference between the naturalistic house fire sound and flickering light $F(1, 8) = 36.2$, $p = .000$, and between the simultaneous presentation of both signals and the light alone $F(1, 8) = 50.1$, $p = .000$, but not between the simultaneous presentation of both signals and the naturalistic house fire sound alone . Examination of the means shows that the flickering light when presented alone performed at a lower level than both the naturalistic house fire sound and simultaneous presentations of both. It can also be seen that response times were slower when alcohol was given.

DISCUSSION

The hypothesis that the naturalistic auditory signal would wake participants faster and at a lower level that the flickering light was supported. The further hypothesis that the combination of the naturalistic auditory signal with the flickering light would be more effective than either signal on its own was only partially supported. The expected differences were found between the naturalistic house fire sound and the light, and the light and the simultaneous presentation of both signals, but not between the naturalistic house fire sound and the combined signal.

The performance of the flickering light was in keeping with previous research that had reported a decreased response rate to a light stimulus in deep sleep (Du Bois et al., 2005). It was also in keeping with research that found less than 30% of unimpaired participants responded to a 19.9 lux light from deep sleep (Bowman et al., 1995). The strength of the light signal used for the current study reached levels well above this, peaking at a maximum of 202 lux, and still 44% of unimpaired participants failed to respond. When alcohol was given the effectiveness of the light was extremely poor with a response from only one of the nine participants. It is possible that the use of a flickering light in place of a strobe may have contributed to the limited success of the light stimulus in the current study since previous research has suggested that the former is less effective than latter (Nober et al., 1990), but other studies have reported similarly poor results with a strobe (Bowman et al., 1995; Du Bois et al., 2005). Furthermore, a flickering light was selected for use in the current study because of its naturalistic appeal which may have been somewhat decreased by the use of a strobe.

Other studies have reported greater success rates when lights are used to awaken deaf participants (Du Bois et al., 2005; Nober et al., 1990; Underwriters

Laboratory, 1991) but response rates from the deaf were still quite poor for some of them. Nober and colleagues reported a 90% success rate and the Underwriters Laboratory reported a 100% success rate. However Du Bois and colleagues recently reported only 57% of deaf and 34% of hard of hearing responded. Training and expectation may have played a role in the increased success of the light with participants who are used to relying on their visual sense, however sleep stage was only controlled in the Du Bois study for which the success rate was well below the others. Taken together with the results of previous research, findings of the current study suggest that light alone cannot be relied upon as a dependable stimulus to warn sleeping individuals of the possibility of a fire. If a light is necessary, then it should only be used in concert with an auditory signal.

When results from the previous experiments are considered, the naturalistic house fire sound appears to have achieved surprisingly rapid response times from the participants of the current study. However it is vital to remember that awakenings for the earlier experiments with this group of participants all occurred from stage 4 sleep, whereas awakenings were made in stage 2 for the current study. Faster response times were expected because AATs are known to be lower in the lighter stages of sleep (Rechtschaffen et al., 1966; Watson & Rechtschaffen, 1969).

As was first raised in Experiment 4, the possibility of practice effects existed because collecting the data for both studies simultaneously limited counterbalancing techniques. However since comparisons of the effectiveness of the signals used in the current study were only made between each other and not to any data collected earlier, this should not have affected the validity of results.

In conclusion results of the current study show that a flickering light is a poor stimulus to be used for waking sleeping individuals. Importantly, it was also shown that behavioural response times are significantly increased for this stimulus when alcohol is given. This effect has shown consistency across both auditory and visual stimuli. The implications of the practice effect found for the current study are not far reaching because the problem resulted from the chosen methodology.

CHAPTER SEVEN

GENERAL DISCUSSION

Summary of overall findings

The current project was undertaken with a view to combining knowledge regarding human sleep/wake behaviour with information from the field of ergonomics regarding warning signal design to improve upon the smoke alarm signal. The specific purpose was to add to the current body of knowledge about the response of sleeping individuals to different sensory signals with a view to identifying important factors worthy of deeper investigation. Individuals who belonged to groups in society who are particularly at risk for death in a fire were studied. It was hoped to identify factors affecting the response patterns of participants that could one day be used to improve the effectiveness of the smoke alarm signal and be incorporated into international standards.

An examination of the literature concerning cognitive processing during sleep and the responsiveness of sleeping individuals to extrinsic stimuli found that people can discriminate clearly between auditory signals and attend selectively to what is important for them. The emotional significance of a signal emerged as key to eliciting a response. Information that outlined the important factors for enhancing the direct perception of sensory information was also examined. In Experiment 1, information from both sources was integrated and applied to the development of a novel smoke alarm signal that was distinctly different to current beeping signals.

A set of questions was circulated to the University community asking what sounds would; (i) elicit a negative emotional response, (ii) draw a person's attention while sleeping, and (iii) induce them to feel the need to investigate upon awakening? The top fifteen responses to all three questions were categorised into distinct groups. Common categories for all three questions included “Expressions of human emotion”, and “Manufactured alerting sounds”. A third category, “Naturalistic alerting sounds”, was added for the last question.

As a result of the selection process three new alarm signals were developed including a female actor’s voice alarm, a naturalistic house fire sound, and a signal shift that incorporated elements of both. Pilot testing of the new signals was carried out to determine the best of the three to be used in continuing investigations. Participants were self reported deep sleeping young adults. This group was chosen because it is known that AATs decrease with increasing age, and it was hoped to find the best alarm signal that was capable of waking the deepest sleepers in the deepest stage of sleep. Results of pilot testing showed the female voice alarm to be the most effective, followed by the naturalistic house fire sound, and finally the signal shift. It had been expected that the voice alarm would be the most successful because it was able to directly convey information about its purpose, and because the script was spoken with an emotional tone. However it was surprising that the signal shift was the least effective because it was made up of shifting edits from the other two more successful sounds of five seconds each. It was thought possible that this may have implications for signal length, particularly for the voice alarm because the emotional impact and understandability of the spoken message may have been reduced.

The next step in fulfilling the purpose of the overall project was to take the most successful alarm from Experiment 1 and compare its effectiveness against commonly used beeping smoke alarms with vulnerable populations. The sample studied was young adults under the influence of alcohol. As was expected alcohol was found to increase response times for all signals. This was apparent even at BAC .05 which has important social implications because although this level of intoxication is known to cause some level of impairment in normal functioning, people often do not feel particularly drunk at .05 BAC. Significantly increased response times were also apparent at .08 BAC, but no difference was found in the amount of impairment between .05 and .08 BAC. Response times were found to be significantly lower for males than for females.

These results have important social implications for those who are concerned with the prevention or reduction of fire deaths, particularly the finding that males are more affected than females. This may explain why fire fatality statistics show that more males who die in fires have alcohol in their systems. It is also important that people understand that drinking at moderate levels may negatively affect their ability to respond to their smoke alarm.

Several surprising results also emerged in Experiment 2. It had been expected that the female voice alarm which projected an immediately recognisable and understandable signal in an emotional tone would be the most successful when compared to a mixed T-3 signal and the ASA. Instead it was found the female voice and the mixed T-3 were equal in their effectiveness, and that both were significantly more effective than the ASA. This was so surprising because emotional significance has repeatedly been reported as causing a reduction in AATs when a person's name was used compared to other spoken words or beeping sounds. It was proposed that the similarities in the effectiveness of the female voice and the mixed T-3 were due to shared characteristics of the type of sound they deliver. Both were shown to fall within the same range of pitch, and are comparable in their tonal complexity, whereas the ASA was distinguished from them on each of these points.

This is a reasonable explanation but there is another important theoretical consideration. If the emotional content of spoken words is paramount, then why is an emotionally delivered message not more successful than a signal that shares similar characteristics, but cannot be claimed to have an emotional content? Yet we know that emotional content is a distinguishing parameter because a person's name has been shown to lower AATs in comparison to the name of another person spoken in the same tone (Oswald et al., 1960). Perhaps the answer is that the effectiveness of a beeping signal is enhanced when it shares the pitch range and complexity of the human voice, but that it is less important that a human voice signal is delivered in an emotional or fear-inducing tone. Use of a person's name may be better thought of as important for attentional processes, rather than for its emotional content.

Results also raised another interesting theoretical question. The ASA fulfils many of the criteria that would classify it as a most urgent signal when people are awake (Hellier et al., 1993), yet it performed poorly for effectiveness in waking sleeping individuals in all conditions compared to the mixed T-3, which would not be classified as urgent at all. This implies that the process for deciding what is most likely to need our attention when we are awake may be quite different to the same process when we are asleep, and the two should not be assumed to be the same unless future research uncovers different results.

Taken together these two theoretical points suggest that the implication for smoke alarm signals is that the critical factor in inducing a response from a sleeping individual is the *pitch* of the signal used, rather than the concepts of urgency, or the use of verbal content.

The third experiment of the project involved testing of the signals with another group who are particularly vulnerable for death in a fire. The same three signals were used with a group of children aged between 6 and 10 years-old. A fourth signal was also investigated that was comprised of a recording of the child's mother using an emphatic tone to alert them to the possibility of a fire. To increase the effectiveness of this signal and because it was possible to record a unique alarm for each child, the mother used a script that included their child's name repeatedly. The signals were tested over two separate studies, and results were compared directly to a previous study undertaken by Bruck & Bliss (1999). Different methodology was used with the children that was less intrusive to their everyday life, and closely matched the Bruck and Bliss study.

Results showed 100% effectiveness of the mother's voice alarm, and virtually equivalent effectiveness of the female voice alarm and the mixed T-3 (94.4% and 96.4% respectively). This contrasted with the ASA which produced a response in only 57% of children. It was further found that where a response occurred it was produced by all participants within the first minute of a three minute presentation for the mother's voice, the female voice and the mixed T-3, but for the ASA 26.4% took longer than 60 seconds. These results show consistency with what was found for Experiment 2 in that the voice alarms and the mixed T-3 were equivalent in their effectiveness, and all were better than the ASA. They also provide additional support for the suggestion that the *pitch* of a smoke alarm signal is a critical parameter.

The consistency in findings across Experiments 2 and 3 regarding the importance of the pitch of a signal warranted further investigation. It was decided to carry out a preliminary study with participants who had taken part in Experiment 2 using a male voice alarm and a T-3 signal that shared the high frequency of the ASA (4000Hz). This allowed direct comparison between all five signals studied with the group of young adults in a repeated measures design. Unfortunately it was only possible to collect data from a smaller subset of this group so results were preliminary in nature. Data was collected for only two alcohol conditions; sober and .08 BAC.

Like Experiment 2 the expected differences were found for alcohol with response times being significantly increased when alcohol was given, and this effect was found to be more exaggerated for males than for females. However the expected differences for pitch were not found. The ASA continued to be the least effective signal compared to all others at a significant level. Unfortunately methodological difficulties with the production of the high-pitched T-3 resulting in a constant clicking noise in the background of the 'on' phase meant that results for this signal may not have been valid. It was possible that participants were responding to the clicking, rather than to the high-pitched signal itself. The possibility of practice effects also became apparent and prevented confident conclusions being drawn from results.

It was decided to return to principles of direct perception for Experiment 5. The concept of an alarm signal stimulus directly matching the situational context of its purpose has great intrinsic value. The failure of the naturalistic house fire sound to be more effective than the female voice in Experiment 1 may have been due to the fact that a real house fire would represent a complex perceptual experience, with information presented to several senses simultaneously. Although previous research had explored the effectiveness of naturalistic fire cues in isolation, no study had previously investigated whether simultaneous presentation of fire cues would enhance direct perception by increasing the naturalistic experience. To this end the naturalistic house fire sound from Experiment 1 was once again used along with a flickering light presented both singly and together. As expected the flickering light on its own was significantly poorer than the naturalistic house fire signal and the combined signal. Contrary to expectations the combined signal was not found to be more effective than the naturalistic house fire signal on its own.

Overall the results of the series of experiments generally showed pleasing consistency. Some of the findings were expected, but others were quite surprising. The first result that was consistently found was that alcohol ingestion significantly slowed response times to extrinsic stimuli. This was not surprising because alcohol has previously been identified as the single most significant risk factor for death in a fire (Runyan et al., 1992), however in the past its role in failure to wake to an alarm signal has been assumed rather than known. The current study has provided clear evidence that alcohol can cause a delayed response regardless of the signal used. Fire fatality statistics have also shown that the risk factor associated with alcohol is worse for males (Berl & Halpin, 1978; Squires & Busuttil, 1997; Watts-Hampton, 2007). Results across experiments also suggest that delayed response is more pronounced for young males compared to young females. The more unexpected finding for alcohol was that response times were affected to a significant degree at the moderate .05 BAC, and that this was not statistically worse at the higher .08 BAC. The implications of this for community fire safety messages were discussed above.

The most surprising consistent result found was that pitch and complexity were identified as critical parameters in predicting a response. The mixed T-3 alarm was found to be as effective as voice alarms in waking young adults (female voice and male voice) who were both sober and under the influence of alcohol, and with children aged 6 to 10 years-old (female voice and mother's voice). It was not anticipated that this benign sounding beeping alarm would prove as effective as a voice alarm that could convey direct meaning and urgency. It was also not anticipated that the ASA would perform consistently as poorly as it did. If just the beeping signals are considered, when the mixed T-3 and ASA are heard the mixed T-3 would be subjectively rated as louder than the ASA when they are transmitted at the same intensity. It has been reported that lower frequency tones (e.g. the mixed T-3 used in these studies) need to be transmitted at a higher physical intensity to be judged as loud as higher frequency tones (e.g. the ASA), but in the case of these signals the opposite seems to be true. Regardless, it has previously been found that arousal from slow wave sleep was directly related to the physical intensity of a stimulus, rather than the subjective judgement of loudness reported in the waking state (LeVere, Bartus, Morlock et al., 1973) so this should have been of little consequence since all signals were transmitted at equal physical intensity and the dBA scale across the frequencies under study approximates the subjective perception of the intensity (Lawrence, 1970).

The consistent failure to find a difference between the mixed T-3 and the female voice, together with the poor relative performance of the ASA across experiments emphasises differences between what is subjectively rated as urgent when we are awake compared to what will easily draw our attention when we are asleep. These findings are in keeping with the conclusion of LeVere and colleagues (1973) who suggested that the governing factors that determine an individual's responsiveness in the waking and sleep states may be different.

Various researchers have considered the nature of the most effective alarms and/or ringer tones for alerting people who are awake. Patterson (1990) notes,

> "Contrary to the general conception of pitch perception, we do not hear a separate pitch for each peak in the spectrum of a sound. Rather, the auditory system takes the information from temporally related components and maps them back onto one perception, namely a pitch corresponding to the fundamental of the harmonic series implied by the related components. This ….enables us to design warnings that are highly resistant to masking by spurious noise sources." (pg. 488)

The warning sound that Patterson advocates for the cockpit of a Boeing 747 is one with a series of harmonics that are at least 15 dB above the auditory threshold, which will vary depending on background noise. A sound with four or more components in the appropriate level range is advocated as it is much less likely to be masked (Patterson, 1990).

Berkowitz and Casali (1990) tested the audibility of various ringer tones in both 20-30 year olds and 70-95 year olds and found that the "electronic bell" had the lowest audibility thresholds for both age groups. They attribute the advantage of this ringer to its prominent energy peaks between 1000 and 1600 Hz, with the less effective alternatives having more high frequency content. Their findings were consistent with an earlier report by Hunt (1970) who used the theory of critical band masking to predict the most effective telephone ringer tone. Hunt concluded that at least two spectral components between 500 and 4500 Hz were desirable to aid detection of a ringer above background noises. Moreover, Hunt cited an earlier research report by Archbold and colleagues (1967) that concluded that at least one of these components should be less than 1000 Hz. This conclusion would help those with age related hearing loss who generally have better hearing below 1000 Hz. These recommendations are all consistent with the spectral profile of the mixed T-3.

Given the above research, the results of the current series of experiments are consistent with the idea that the signal with the lowest auditory threshold when awake (i.e. a signal of mixed frequencies in the same range as a voice, i.e. 250 – 2500 Hz) may also be the most alerting when asleep.

Theoretical framework

The ability of alarm signals to arouse sleeping individuals has emerged as a considerably more complex matter than was once believed. Behaviour in response to an audible emergency signal, whether activated when awake or asleep, can be thought of to occur via the following process –

Sensory processing (audible)

↓

Perceptual processing (recognisable, meaningful)

↓

Decision making (need to evacuate)

↓

Action (evacuate)

For a sleeping person we assume that sensory processing can occur in the absence of waking up. Sound waves may be acting on the structures within the ear but no conscious processing is occurring. Waking up occurs **after** sensory processing has successfully gone on to perceptual processing. After awakening the ability to make rational and effective decisions can be impaired by sleep inertia, especially in the first three minutes (Bruck & Pisani, 1999). The effect of sleep inertia on physical functioning with gross motor skills (that is, the action of evacuating) has not yet been documented.

Whether or not perceptual processing occurs in a sleeping person exposed to an audible emergency signal is a function of individual factors and an interaction between signal and environmental factors. These can be summarised as follows:

- *Individual factors* including age; gender; sleep stage; sleep deprivation; blood alcohol content; use of hypnotics or other drugs; hearing ability; physical or intellectual disability; priming; previous experience.
- *Signal factors* including sound intensity/volume in decibels; sound frequency/pitch in Hertz; sound rhythmicity, relating to the duration of sound and silence as illustrated by the T-3 pattern; signal type and significance (for example a beeping sound or a human voice).
- *Environment factors* including the level of background noise; the type and configuration of furniture and soft furnishings; placement of the alarm relative to the sleeping person.

The series of experiments in this project have all only considered variability in responsiveness at the sensory processing level because all the subjects have been primed to know which signal to expect while they are asleep (see below). There is no variability in perceptual processing because the subjects have all been instructed that they must give a certain behavioural response when they hear a certain signal.

Methodological concerns

Priming Effects

A difficulty exists with applying research of this kind to assess people's response to a smoke alarm signal. It is likely that a fire incident would be unanticipated, and therefore a sleeping individual would be responding to their smoke alarm as an unexpected event. In contrast to this the participants of the current series of experiments were all aware that they were taking part in a study that was planned to measure their response to different auditory (and in one case, visual) stimuli. They were compensated financially for their participation, and although they were informed that payment was not contingent upon their ability to respond to any of the signals, they were aware of the number of signals to be presented. This creates the possibility that the research protocol acted to prime participants to respond, and an increase in response to primed signals has previously been demonstrated (McDonald et al., 1975; Oswald et al., 1960; Zung & Wilson, 1975). However any such effects should not alter findings of differences between signals or alcohol conditions because expectation was consistent across all stimuli and conditions.

Where the effects of priming may have altered conclusions is when the concept of urgency is considered. Bruck and Horasan (1995) have earlier suggested that because participants of sleep studies are primed to respond they may not necessarily differentially perceive alarm signals as urgent. Thus it is possible that urgency is not a relevant factor for participants who are primed and their differential response to some signals at lower volumes than others is based on other factors, perhaps such as pitch.

Sensory adaptation

The decision to remove the periods of silence between the incremental steps of different sound intensity after Experiment 1 may also have constituted a methodological difficulty for the current study that has the potential to limit the generalisability of results. The inclusion of silences, or "off" phases, would have increased the ecological validity of results because a smoke alarm usually cuts in from silence. This is especially true when it is needed to wake a person from sleep. As has been previously explained the phenomenon of sensory adaptation may have resulted in higher AATs than would have been the case had the silences been included. Once again however, this should not alter findings of differences between stimuli and conditions because the possibility for sensory adaptation was equal for all of them.

Practice Effects

Due to limited resource issues data collection for Experiment 5 was undertaken simultaneously with data collection for Experiment 4. This meant that the possibility of practice effects were apparent because full counterbalancing across all signals was not able to occur. This is also the case for Experiment 4 because data from Experiment 2 was combined with the new data collected. This is explained below in Table 7.1.

Table 7.1. Data collection methodology for experiments conducted with young adults across differing alcohol conditions.

Experiment	N	Alcohol Conditions	Sounds	Notes
2	14	• Sober • .05 • .08	• Female Voice • ASA • T-3	Signals counterbalanced across conditions.
4	10	• Sober • .05	• Female Voice* • ASA* • T-3* • **Male Voice** • **4000Hz T-3**	Data was collected for only two new signals. Comparisons were then made with the data previously collected for Experiment 2 for this subset of participants. Data for Experiments 4 and 5 collected concurrently. The two new signals for Experiment 4 were always collected first. Order for the two signals was counterbalanced across alcohol conditions.
5	9	• Sober • .05	• Naturalistic house fire • Flickering Light • Both	Data collection always occurred after the two signals for Experiment 4 had been presented. Order was counterbalanced across alcohol conditions.

* denotes data collected as part of previous experiment

Instead of the order being counterbalanced across all five signals that were compared during Experiment 4, data collection for three of the total was counterbalanced across the first three nights of Experiment 2, then data collection for the last two signals occurred only across the last two nights. By the time data collection was commenced on the first night of Experiment 4 the person had already been exposed the procedures of the study for at least nine signal presentations. The previous experience of the participants with the research protocol may have acted as “training”. The effects of this training could be to cause faster response times which would have caused the two additional signals to appear more effective than if counterbalancing across all nights was possible, and to increase the chance of making a Type I error. The same logic would apply to the data collected for Experiment 5 which always occurred after the two signals for Experiment 4 had been collected on each of the nights.

Sample Size

Experiments 1b, 3 and 4 were of a pilot or exploratory nature. The samples were of sufficient size for preliminary findings to be claimed, and for some statistical differences to emerge at $p < .05$. However these should be further substantiated through future research before firm conclusions are made.

Directions for future research

Results of this project suggest the following areas for future research:

- The most pressing need for additional research is to further explore sounds of varying pitch in an attempt to determine an optimal range that can then be incorporated into smoke alarms standards.

- The effectiveness of the mixed T-3 should continue to be tested in groups who are vulnerable to death in a fire, most particularly including the elderly.

- An innovative approach to continuing research that aims to optimise the response of sleeping individuals to their smoke alarm should include methodology that reduces the effects of priming. One benefit of this would be to allow further meaningful investigation regarding whether the emotional tone of a voice signal is critical.

Conclusions

The following general conclusions can be drawn from the series of experiments that have been undertaken as part of the larger project:

- Results suggest that drinking alcohol, even in moderation, will adversely affect a person's ability to awaken to their smoke alarm. Public awareness campaigns have ensured that people are well aware of the role that alcohol intoxication plays in increasing the risk of accident or injury while driving, and have been advised on safe levels of drinking and appropriate behaviours. Few, however, are aware that having just a few drinks at home and going to bed increases the risk of them failing to respond to their alarm in case of a fire.

- The results of this study suggest that signal ***pitch*** may be a most important factor in residential alarm signal design, with lower pitch alarms eliciting a response at a lower intensity and in a shorter space of time compared to the high pitch signal currently used in Australian homes. The optimal pitch may be in the same range as the human voice but this would need to be confirmed through ongoing research. The tonal complexity of sound may also be implicated with more complex sounds that are nearer in dimension to the human voice being more effective. The possible importance of tonal complexity is highlighted by the unexpected success of the 4000Hz T-3 signal in Experiment 5.

- Voice alarms have been shown to be consistently more effective than the ASA, but only equally as effective as the mixed T-3. Like the above point, this implies that the critical factor for alarms that are needed to wake people is not the urgency of the message, but rather the pitch and complexity. It can be concluded that voice signals are not the most viable option for use in a smoke alarm if a beeping signal of equal effectiveness can be produced for less money. Moreover problems with a voice alarm being immediately recognised and understood by people of different languages are eliminated.

- The high-pitched rapidly repeating smoke alarm signal that remains in use in many Australian homes has consistently been found to be the least effective compared to the other signals tested. This applies across populations of self-reported deep sleeping young adults and children aged 6 to 10 years, and across all alcohol conditions.

- Light within the lux levels of 0 to 202 is an ineffective stimulus for waking people from sleep and there was no alerting advantage to adding a visual stimulus to an auditory stimulus.

- Factors that people highlight as important when they are awake may not be the things that are the most successful in gaining their attention while they are sleeping. Attentional resources may be allocated in a qualitatively different way between the two states that are linked to the tension between the need to maintain sleep and the need to attend to external stimuli.

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Appendix 1: Global E-mail text

Call for RESPONSES re the meaning of sounds

I am a PhD student in the Department of Psychology at St Albans campus
and am asking if people will take the time to briefly answer the
following 3 questions by return e-mail. The questions relate to sounds
and what their meaning is to YOU. Any answers you can give will be
appreciated, even if you think it seems silly at first.

1. What sounds would make you feel negative emotion?

2. What sounds do you think would draw your attention when you're
asleep?

3. What sounds would you feel the need to investigate upon awakening?

If anyone would like to know the nature of the research project AFTER
responding, I would be happy to let them know. My contact number is EXT
2385.

THANK YOU for taking the time to respond, it is greatly appreciated!

Michelle Ball

Appendix 2: Information to participants for PILOT Experiment 1

Smoke Detector Alarm Study

INFORMATION TO PARTICIPANTS:

Researchers have found that the smoke detector alarm signal that is currently used in Australian homes fails to reliably awaken sleep deprived young adults. Added to this is information drawn from fire fatality statistics which shows that being under the influence of alcohol is the single most important risk factor for death in a fire. If you are aged between 18 and 25 years, drink alcohol on at least one night per week, and would consider yourself to be a deep sleeper, we would like to invite you to participate in a study being conducted by Professor Dorothy Bruck and PhD student Michelle Ball of Victoria University. The purpose of this study is to develop and test a new smoke detector alarm signal that is more successful in arousing people from sleep.

In order to study this we are asking that a research assistant be allowed into your home on three or four non-consecutive evenings to be arranged at your convenience. Before your usual bedtime the research assistant will apply several electrodes to the surface of your scalp and face. These electrodes will be attached by thin insulated wires to a battery operated data recorder that will send signals to a portable computer that will be monitored by the research assistant in a nearby room. The data recorder is light (300g) and compact and will be placed near the bedside, resulting in little discomfort. The purpose of the electrodes is to allow the level of activity within your brain to be monitored while you sleep. They will also allow muscle tone and eye movement to be monitored. It will be asked that you abstain from drinking alcohol on each day of testing, prior to the research conditions. It will also be asked that you are careful not to exceed your usual daily intake of caffeinated drinks (i.e. coffee, tea, soft drinks), and your usual daily consumption of cigarettes.

On all nights of testing an alarm will be sounded at between three and five separate times while you are sleeping. The signals will be the current smoke detector alarm signal, and several new and different signals. It is hoped that this will occur in the first half of the evening when you should be sleeping most deeply. Each alarm sound will begin at a low volume which will be slowly increased until it reaches a volume that awakens you, or until it has sounded at the highest level for three minutes without you responding. The highest level has been set at 95 decibels which is quite loud and may disturb the sleep of others in the home, but will not damage your hearing. On each occasion you will be required to press a button that will be placed next to your bed three times in order to signal that you are awake.

Ten participants will initially be involved in pilot testing that will measure their response to five different alarm signals. Following this, three nights of testing will take place with all participants using only 3 different alarm signals. The first night of testing will measure your response to the alarm signals without the influence of any alcohol. On the second and third nights of testing, about 30 - 60 minutes prior to your usual bedtime, you will be asked to drink some alcohol. On one of these nights you will be administered enough drinks to result in a blood alcohol content of .05 (about 2 drinks for a female, and 3 for a male), and on the other enough drinks to result in a blood alcohol content of .08 (about 3½ drinks for a female, and 4½ for a male). Your blood alcohol content will be measured using a breathalyser, and the alcohol will be administered as spirits mixed with non-alcoholic drink, for example vodka mixed with orange juice. Your blood alcohol content will also be measured using the breathalyser on each occasion if/when you awaken during the testing. In order to protect your safety it is asked that you agree not to drive or use any potentially dangerous equipment for a period of 8 hours after drinking the alcohol. For the same reason it will also be necessary to exclude from the study anyone who is taking regular medication that may interact with alcohol.

You will be paid $50.00 per night of participation in the study. Therefore, most participants will receive a total of $150.00 for taking part in testing across three nights. You may choose withdraw from the research at any time, however it should be noted that payment will be made only to those who complete the research protocol for ALL THREE NIGHTS. Payment will be made upon the completion of testing on the third night. Those who take part in the pilot testing will receive an additional $50.00 for the extra night, which may be paid to them at the completion of testing on that night. **Please contact Michelle Ball, telephone 9365-2385 to register your interest in participation or if you have any questions at all regarding the study.**

It is of vital importance for the whole community that a new smoke detector alarm signal be developed which will be more reliable in awakening those groups that are at high risk for death in a fire.

Appendix 3: Output Experiment 1 – Pilot testing.

General Linear Model

```
[DataSet1] E:\Data\Pilot testing.sav
```

Within-Subjects Factors

Measure: MEASURE_1

sound	Dependent Variable
1	eegs1
2	eegs2
3	eegs5

Descriptive Statistics

	Mean	Std. Deviation	N
Time to EEG awake - Sound 1	198.0000	172.84179	8
Time to EEG awake - Sound 2	167.0000	147.80682	8
Time to EEG awake - Sound 5	203.1250	208.85295	8

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
sound	Pillai's Trace	.617	2.417[a]	2.000	3.000	.237
	Wilks' Lambda	.383	2.417[a]	2.000	3.000	.237
	Hotelling's Trace	1.611	2.417[a]	2.000	3.000	.237
	Roy's Largest Root	1.611	2.417[a]	2.000	3.000	.237
sound * silence1	Pillai's Trace	.990	145.753[a]	2.000	3.000	.001
	Wilks' Lambda	.010	145.753[a]	2.000	3.000	.001
	Hotelling's Trace	97.168	145.753[a]	2.000	3.000	.001
	Roy's Largest Root	97.168	145.753[a]	2.000	3.000	.001
sound * silence2	Pillai's Trace	.995	309.535[a]	2.000	3.000	.000
	Wilks' Lambda	.005	309.535[a]	2.000	3.000	.000
	Hotelling's Trace	206.357	309.535[a]	2.000	3.000	.000
	Roy's Largest Root	206.357	309.535[a]	2.000	3.000	.000
sound * silence5	Pillai's Trace	.984	91.466[a]	2.000	3.000	.002
	Wilks' Lambda	.016	91.466[a]	2.000	3.000	.002
	Hotelling's Trace	60.977	91.466[a]	2.000	3.000	.002
	Roy's Largest Root	60.977	91.466[a]	2.000	3.000	.002

a. Exact statistic

b.

Design: Intercept+silence1+silence2+silence5
Within Subjects Design: sound

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
sound	.724	.967	2	.617	.784	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+silence1+silence2+silence5
Within Subjects Design: sound

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
sound	Sphericity Assumed	341.537	2	170.768	4.777	.043
	Greenhouse-Geisser	341.537	1.568	217.829	4.777	.060
	Huynh-Feldt	341.537	2.000	170.768	4.777	.043
	Lower-bound	341.537	1.000	341.537	4.777	.094
sound * silence1	Sphericity Assumed	7061.453	2	3530.726	98.772	.000
	Greenhouse-Geisser	7061.453	1.568	4503.728	98.772	.000
	Huynh-Feldt	7061.453	2.000	3530.726	98.772	.000
	Lower-bound	7061.453	1.000	7061.453	98.772	.001
sound * silence2	Sphericity Assumed	34564.031	2	17282.015	483.466	.000
	Greenhouse-Geisser	34564.031	1.568	22044.611	483.466	.000
	Huynh-Feldt	34564.031	2.000	17282.015	483.466	.000
	Lower-bound	34564.031	1.000	34564.031	483.466	.000
sound * silence5	Sphericity Assumed	7976.893	2	3988.446	111.577	.000
	Greenhouse-Geisser	7976.893	1.568	5087.587	111.577	.000
	Huynh-Feldt	7976.893	2.000	3988.446	111.577	.000
	Lower-bound	7976.893	1.000	7976.893	111.577	.000
Error(sound)	Sphericity Assumed	285.969	8	35.746		
	Greenhouse-Geisser	285.969	6.272	45.597		
	Huynh-Feldt	285.969	8.000	35.746		
	Lower-bound	285.969	4.000	71.492		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	sound	Type III Sum of Squares	df	Mean Square	F	Sig.
sound	Linear	18.437	1	18.437	.863	.405
	Quadratic	323.100	1	323.100	6.445	.064
sound * silence1	Linear	4395.694	1	4395.694	205.821	.000
	Quadratic	2665.759	1	2665.759	53.171	.002
sound * silence2	Linear	31.139	1	31.139	1.458	.294
	Quadratic	34532.891	1	34532.891	688.794	.000
sound * silence5	Linear	5125.616	1	5125.616	239.999	.000
	Quadratic	2851.277	1	2851.277	56.872	.002
Error(sound)	Linear	85.427	4	21.357		
	Quadratic	200.541	4	50.135		

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1405.673	1	1405.673	62.606	.001
silence1	3053.653	1	3053.653	136.004	.000
silence2	15298.896	1	15298.896	681.385	.000
silence5	6902.165	1	6902.165	307.410	.000
Error	89.811	4	22.453		

Estimated Marginal Means

sound

Measure: MEASURE_1

			95% Confidence Interval	
sound	Mean	Std. Error	Lower Bound	Upper Bound
1	198.000[a]	1.941	192.612	203.388
2	167.000[a]	1.717	162.233	171.767
3	203.125[a]	2.243	196.898	209.352

a. Covariates appearing in the model are evaluated at the following values: Total time of silence - Sound 1 = 92.8750, Total time of silence - Sound 2 = 77.1250, Total time of silence - Sound 5 = 97.5000.

Appendix 4: Information to participant Experiment 2

Smoke Detector Alarm Study

INFORMATION TO PARTICIPANTS:

Researchers have found that the smoke detector alarm signal that is currently used in Australian homes fails to reliably awaken sleep deprived young adults. Added to this is information drawn from fire fatality statistics which shows that being under the influence of alcohol is the single most important risk factor for death in a fire. If you are aged between 18 and 25 years, drink alcohol on at least one night per week, and would consider yourself to be a deep sleeper, we would like to invite you to participate in a study being conducted by Associate Professor Dorothy Bruck and PhD student Michelle Ball of Victoria University. The purpose of this study is to develop and test a new smoke detector alarm signal that is more successful in arousing people from sleep.

In order to study this we are asking that a research assistant be allowed into your home on three non-consecutive evenings to be arranged at your convenience. Before your usual bedtime the research assistant will apply several electrodes to the surface of your scalp and face. These electrodes will be attached by thin insulated wires to a battery operated data recorder that will send signals to a portable computer that will be monitored by the research assistant in a nearby room. The data recorder is light (300g) and compact and will be placed near the bedside, resulting in little discomfort. The purpose of the electrodes is to allow the level of activity within your brain to be monitored while you sleep. They will also allow muscle tone and eye movement to be monitored. It will be asked that you abstain from drinking alcohol on each day of testing, prior to the research conditions. It will also be asked that you are careful not to exceed your usual daily intake of caffeinated drinks (i.e. coffee, tea, soft drinks), and your usual daily consumption of cigarettes.

On all nights of testing an alarm will be sounded at two or three separate times while you are sleeping. The signals will be the current smoke detector alarm signal, and one or two new and different signals. It is hoped that this will occur in the first half of the evening when you should be sleeping most deeply. Each alarm sound will begin at a low volume which will be slowly increased until it reaches a volume that awakens you, or until it has sounded at the highest level for ten minutes without you responding. The highest level has been set at 97 decibels which is quite loud and may disturb the sleep of others in the home, but will not damage your hearing. On each occasion you will be required to press a button that will be placed next to your bed three times in order to signal that you are awake.

The first night of testing will measure your response to the alarm signals without the influence of any alcohol. On the second and third nights of testing, about 30 - 60 minutes prior to your usual bedtime, you will be asked to drink some alcohol. On one of these nights you will be administered enough drinks to result in a blood alcohol content of .05

(about 2 drinks for a female, and 3 for a male), and on the other enough drinks to result in a blood alcohol content of .08 (about 3½ drinks for a female, and 4½ for a male). Your blood alcohol content will be measured using a breathalyser, and the alcohol will be administered as spirits mixed with non-alcoholic drink, for example vodka mixed with orange juice. Your blood alcohol content will also be measured using the breathalyser on each occasion if/when you awaken during the testing. In order to protect your safety it is asked that you agree not to drive or use any potentially dangerous equipment for a period of 8 hours after drinking the alcohol. For the same reason it will also be necessary to exclude from the study anyone who is taking regular medication that may interact with alcohol.

You will be paid a total of $150.00 for your participation across the three nights. You can choose withdraw from the research at any time, however it should be noted that full payment will be made only to those who complete the research protocol for ALL THREE NIGHTS. Payment will be made upon the completion of testing on the third night. **Please contact Michelle Ball, telephone 9365-2385 to register your interest in participation or if you have any questions at all regarding the study.**

It is of vital importance for the whole community that a new smoke detector alarm signal be developed which will be more reliable in awakening those groups that are at high risk for death in a fire.

Appendix 5: Output Experiment 2

Frequencies

[DataSet1] C:\Documents and Settings\Staff\Desktop\Michelle\Final Data\Experiment 2\dBA level final.sav

Statistics

		Sound 2 dBA sober	Sound 3 dBA sober	Sound 4 dBA sober	Sound 2 dBA .05	Sound 3 dBA .05	Sound 4 dBA .05	Sound 2 dBA .08	Sound 3 dBA .08	Sound 4 dBA .08
N	Valid	14	14	14	14	14	14	14	14	14
	Missing	6	6	6	6	6	6	6	6	6
Mean		56.4286	69.2857	57.8571	75.0000	81.0714	74.6429	75.0000	82.1429	75.7143
Median		52.5000	62.5000	60.0000	80.0000	82.5000	80.0000	75.0000	87.5000	77.5000
Mode		40.00[a]	60.00[a]	65.00	95.00	95.00	55.00[a]	70.00[a]	95.00	100.00
Std. Deviation		15.24525	17.19315	14.76929	22.53203	15.95409	20.42475	21.66174	16.25687	21.47065

a. Multiple modes exist. The smallest value is shown

Frequency Table

Sound 2 dBA sober

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	35.00	1	5.0	7.1	7.1
	40.00	3	15.0	21.4	28.6
	50.00	3	15.0	21.4	50.0
	55.00	1	5.0	7.1	57.1
	65.00	2	10.0	14.3	71.4
	70.00	2	10.0	14.3	85.7
	80.00	2	10.0	14.3	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

Sound 3 dBA sober

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	45.00	1	5.0	7.1	7.1
	50.00	1	5.0	7.1	14.3
	55.00	2	10.0	14.3	28.6
	60.00	3	15.0	21.4	50.0
	65.00	1	5.0	7.1	57.1
	80.00	3	15.0	21.4	78.6
	85.00	1	5.0	7.1	85.7
	95.00	1	5.0	7.1	92.9
	100.00	1	5.0	7.1	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

Sound 4 dBA sober

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	35.00	1	5.0	7.1	7.1
	40.00	1	5.0	7.1	14.3
	45.00	2	10.0	14.3	28.6
	50.00	2	10.0	14.3	42.9
	55.00	1	5.0	7.1	50.0
	65.00	4	20.0	28.6	78.6
	70.00	2	10.0	14.3	92.9
	90.00	1	5.0	7.1	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

Sound 2 dBA .05

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	35.00	1	5.0	7.1	7.1
	45.00	2	10.0	14.3	21.4
	60.00	1	5.0	7.1	28.6
	65.00	2	10.0	14.3	42.9
	75.00	1	5.0	7.1	50.0
	85.00	1	5.0	7.1	57.1
	90.00	1	5.0	7.1	64.3
	95.00	3	15.0	21.4	85.7
	100.00	2	10.0	14.3	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

Sound 3 dBA .05

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	40.00	1	5.0	7.1	7.1
	65.00	1	5.0	7.1	14.3
	70.00	1	5.0	7.1	21.4
	75.00	2	10.0	14.3	35.7
	80.00	2	10.0	14.3	50.0
	85.00	2	10.0	14.3	64.3
	95.00	4	20.0	28.6	92.9
	100.00	1	5.0	7.1	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

Sound 4 dBA .05

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	40.00	1	5.0	7.1	7.1
	45.00	1	5.0	7.1	14.3
	55.00	2	10.0	14.3	28.6
	65.00	2	10.0	14.3	42.9
	80.00	2	10.0	14.3	57.1
	85.00	2	10.0	14.3	71.4
	95.00	2	10.0	14.3	85.7
	100.00	2	10.0	14.3	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

Sound 2 dBA .08

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	35.00	1	5.0	7.1	7.1
	40.00	1	5.0	7.1	14.3
	50.00	1	5.0	7.1	21.4
	65.00	1	5.0	7.1	28.6
	70.00	2	10.0	14.3	42.9
	75.00	2	10.0	14.3	57.1
	90.00	2	10.0	14.3	71.4
	95.00	2	10.0	14.3	85.7
	100.00	2	10.0	14.3	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

Sound 3 dBA .08

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	55.00	1	5.0	7.1	7.1
	60.00	2	10.0	14.3	21.4
	65.00	1	5.0	7.1	28.6
	75.00	1	5.0	7.1	35.7
	80.00	1	5.0	7.1	42.9
	85.00	1	5.0	7.1	50.0
	90.00	1	5.0	7.1	57.1
	95.00	4	20.0	28.6	85.7
	100.00	2	10.0	14.3	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

Sound 4 dBA .08

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	40.00	1	5.0	7.1	7.1
	45.00	1	5.0	7.1	14.3
	55.00	2	10.0	14.3	28.6
	65.00	1	5.0	7.1	35.7
	70.00	1	5.0	7.1	42.9
	75.00	1	5.0	7.1	50.0
	80.00	2	10.0	14.3	64.3
	95.00	1	5.0	7.1	71.4
	100.00	4	20.0	28.6	100.0
	Total	14	70.0	100.0	
Missing	System	6	30.0		
Total		20	100.0		

General Linear Model

```
[DataSet2] C:\Documents and Settings\Staff\Desktop\Michelle\Final Data\Experiment 2\final data set.sav
```

Within-Subjects Factors

Measure: MEASURE_1

sound	alcohol	Dependent Variable
1	1	s205beh
	2	s208beh
	3	s2noabeh
2	1	s405beh
	2	s408beh
	3	s4noabeh
3	1	s305beh
	2	s308beh
	3	s3noabeh

Between-Subjects Factors

		Value Label	N
Sex	1.00	female	7
	2.00	male	7

Descriptive Statistics

	Sex	Mean	Std. Deviation	N
Actress .05 beh	female	201.4286	116.92285	7
	male	421.7143	216.70619	7
	Total	311.5714	202.60523	14
Actress .08 beh	female	227.1429	189.16345	7
	male	369.7143	161.95134	7
	Total	298.4286	184.64299	14
Actress no alcohol beh	female	119.4286	80.54783	7
	male	168.4286	91.94719	7
	Total	143.9286	86.84953	14
T-3 .05 beh	female	196.0000	106.04559	7
	male	341.7143	173.70925	7
	Total	268.8571	157.58702	14
T-3 .08 beh	female	195.0000	187.24761	7
	male	425.7143	166.80999	7
	Total	310.3571	208.22052	14
T-3 no alcohol beh	female	125.4286	82.35059	7
	male	174.5714	88.43049	7
	Total	150.0000	85.96153	14
Current .05 beh	female	246.1429	108.77106	7
	male	385.4286	124.80900	7
	Total	315.7857	133.69091	14
Current .08 beh	female	270.1429	156.99621	7
	male	427.5714	137.37886	7
	Total	348.8571	163.58195	14
Current no alcohol beh	female	246.0000	190.56932	7
	male	219.7143	70.15154	7
	Total	232.8571	138.63225	14

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
sound	Pillai's Trace	.548	6.670[a]	2.000	11.000	.013	.548
	Wilks' Lambda	.452	6.670[a]	2.000	11.000	.013	.548
	Hotelling's Trace	1.213	6.670[a]	2.000	11.000	.013	.548
	Roy's Largest Root	1.213	6.670[a]	2.000	11.000	.013	.548
sound * sex	Pillai's Trace	.212	1.482[a]	2.000	11.000	.269	.212
	Wilks' Lambda	.788	1.482[a]	2.000	11.000	.269	.212
	Hotelling's Trace	.269	1.482[a]	2.000	11.000	.269	.212
	Roy's Largest Root	.269	1.482[a]	2.000	11.000	.269	.212
alcohol	Pillai's Trace	.695	12.537[a]	2.000	11.000	.001	.695
	Wilks' Lambda	.305	12.537[a]	2.000	11.000	.001	.695
	Hotelling's Trace	2.279	12.537[a]	2.000	11.000	.001	.695
	Roy's Largest Root	2.279	12.537[a]	2.000	11.000	.001	.695
alcohol * sex	Pillai's Trace	.417	3.930[a]	2.000	11.000	.052	.417
	Wilks' Lambda	.583	3.930[a]	2.000	11.000	.052	.417
	Hotelling's Trace	.715	3.930[a]	2.000	11.000	.052	.417
	Roy's Largest Root	.715	3.930[a]	2.000	11.000	.052	.417
sound * alcohol	Pillai's Trace	.303	.979[a]	4.000	9.000	.465	.303
	Wilks' Lambda	.697	.979[a]	4.000	9.000	.465	.303
	Hotelling's Trace	.435	.979[a]	4.000	9.000	.465	.303
	Roy's Largest Root	.435	.979[a]	4.000	9.000	.465	.303
sound * alcohol * sex	Pillai's Trace	.134	.348[a]	4.000	9.000	.839	.134
	Wilks' Lambda	.866	.348[a]	4.000	9.000	.839	.134
	Hotelling's Trace	.155	.348[a]	4.000	9.000	.839	.134
	Roy's Largest Root	.155	.348[a]	4.000	9.000	.839	.134

a. Exact statistic

b.

Design: Intercept+sex
Within Subjects Design: sound+alcohol+sound*alcohol

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
sound	.998	.024	2	.988	.998	1.000	.500
alcohol	.958	.470	2	.791	.960	1.000	.500
sound * alcohol	.204	16.555	9	.059	.583	.792	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+sex
Within Subjects Design: sound+alcohol+sound*alcohol

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
sound	Sphericity Assumed	77067.873	2	38533.937	7.194	.004	.375
	Greenhouse-Geisser	77067.873	1.996	38617.913	7.194	.004	.375
	Huynh-Feldt	77067.873	2.000	38533.937	7.194	.004	.375
	Lower-bound	77067.873	1.000	77067.873	7.194	.020	.375
sound * sex	Sphericity Assumed	17212.000	2	8606.000	1.607	.221	.118
	Greenhouse-Geisser	17212.000	1.996	8624.755	1.607	.221	.118
	Huynh-Feldt	17212.000	2.000	8606.000	1.607	.221	.118
	Lower-bound	17212.000	1.000	17212.000	1.607	.229	.118
Error(sound)	Sphericity Assumed	128555.683	24	5356.487			
	Greenhouse-Geisser	128555.683	23.948	5368.160			
	Huynh-Feldt	128555.683	24.000	5356.487			
	Lower-bound	128555.683	12.000	10712.974			
alcohol	Sphericity Assumed	506938.159	2	253469.079	11.786	.000	.496
	Greenhouse-Geisser	506938.159	1.920	264073.122	11.786	.000	.496
	Huynh-Feldt	506938.159	2.000	253469.079	11.786	.000	.496
	Lower-bound	506938.159	1.000	506938.159	11.786	.005	.496
alcohol * sex	Sphericity Assumed	155188.762	2	77594.381	3.608	.043	.231
	Greenhouse-Geisser	155188.762	1.920	80840.592	3.608	.045	.231
	Huynh-Feldt	155188.762	2.000	77594.381	3.608	.043	.231
	Lower-bound	155188.762	1.000	155188.762	3.608	.082	.231
Error(alcohol)	Sphericity Assumed	516125.302	24	21505.221			
	Greenhouse-Geisser	516125.302	23.036	22404.906			
	Huynh-Feldt	516125.302	24.000	21505.221			
	Lower-bound	516125.302	12.000	43010.442			
sound * alcohol	Sphericity Assumed	30370.937	4	7592.734	.942	.448	.073
	Greenhouse-Geisser	30370.937	2.330	13032.110	.942	.414	.073
	Huynh-Feldt	30370.937	3.167	9588.820	.942	.434	.073
	Lower-bound	30370.937	1.000	30370.937	.942	.351	.073
sound * alcohol * sex	Sphericity Assumed	25816.238	4	6454.060	.801	.531	.063
	Greenhouse-Geisser	25816.238	2.330	11077.698	.801	.476	.063
	Huynh-Feldt	25816.238	3.167	8150.794	.801	.507	.063
	Lower-bound	25816.238	1.000	25816.238	.801	.388	.063
Error(sound*alcohol)	Sphericity Assumed	386771.937	48	8057.749			
	Greenhouse-Geisser	386771.937	[illegible]	[illegible]			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	sound	alcohol	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
sound	Level 1 vs. Level 3		32064.286	1	32064.286	8.617	.012	.418
	Level 2 vs. Level 3		44053.460	1	44053.460	12.832	.004	.517
sound * sex	Level 1 vs. Level 3		7778.571	1	7778.571	2.090	.174	.148
	Level 2 vs. Level 3		9360.286	1	9360.286	2.727	.125	.185
Error(sound)	Level 1 vs. Level 3		44652.254	12	3721.021			
	Level 2 vs. Level 3		41196.476	12	3433.040			
alcohol		Level 1 vs. Level 3	212298.286	1	212298.286	18.377	.001	.605
		Level 2 vs. Level 3	288770.032	1	288770.032	19.339	.001	.617
alcohol * sex		Level 1 vs. Level 3	73056.794	1	73056.794	6.324	.027	.345
		Level 2 vs. Level 3	81880.508	1	81880.508	5.484	.037	.314
Error(alcohol)		Level 1 vs. Level 3	138630.698	12	11552.558			
		Level 2 vs. Level 3	179183.016	12	14931.918			
sound * alcohol	Level 1 vs. Level 3	Level 1 vs. Level 3	100471.143	1	100471.143	3.944	.070	.247
		Level 2 vs. Level 3	20751.500	1	20751.500	.971	.344	.075
	Level 2 vs. Level 3	Level 1 vs. Level 3	18072.071	1	18072.071	.595	.455	.047
		Level 2 vs. Level 3	27545.786	1	27545.786	2.065	.176	.147
sound * alcohol * sex	Level 1 vs. Level 3	Level 1 vs. Level 3	114.286	1	114.286	.004	.948	.000
		Level 2 vs. Level 3	28440.071	1	28440.071	1.330	.271	.100
	Level 2 vs. Level 3	Level 1 vs. Level 3	16663.500	1	16663.500	.548	.473	.044
		Level 2 vs. Level 3	16.071	1	16.071	.001	.973	.000
Error(sound*alcohol)	Level 1 vs. Level 3	Level 1 vs. Level 3	305728.571	12	25477.381			
		Level 2 vs. Level 3	256509.429	12	21375.786			
	Level 2 vs. Level 3	Level 1 vs. Level 3	364621.429	12	30385.119			
		Level 2 vs. Level 3	160047.143	12	13337.262			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	979561.059	1	979561.059	89.615	.000	.882
sex	53033.532	1	53033.532	4.852	.048	.288
Error	131168.977	12	10930.748			

Estimated Marginal Means

1. Sex

Measure: MEASURE_1

Sex	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
female	202.968	39.516	116.870	289.067
male	326.063	39.516	239.965	412.162

2. sound

Measure: MEASURE_1

sound	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	251.310	30.758	184.293	318.326
2	243.071	28.230	181.564	304.579
3	299.167	29.230	235.480	362.853

3. alcohol

Measure: MEASURE_1

alcohol	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	298.738	32.168	228.651	368.826
2	319.214	41.930	227.857	410.572
3	175.595	23.947	123.418	227.772

4. Sex * sound

Measure: MEASURE_1

Sex	sound	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
female	1	182.667	43.498	87.892	277.442
	2	172.143	39.923	85.158	259.128
	3	254.095	41.337	164.029	344.162
male	1	319.952	43.498	225.177	414.727
	2	314.000	39.923	227.015	400.985
	3	344.238	41.337	254.172	434.304

5. Sex * alcohol

Measure: MEASURE_1

Sex	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
female	1	214.524	45.492	115.405	313.643
	2	230.762	59.298	101.563	359.961
	3	163.619	33.867	89.830	237.408
male	1	382.952	45.492	283.834	482.071
	2	407.667	59.298	278.468	536.866
	3	187.571	33.867	113.782	261.361

6. sound * alcohol

Measure: MEASURE_1

sound	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	311.571	46.534	210.182	412.961
	2	298.429	47.060	195.893	400.964
	3	143.929	23.101	93.596	194.261
2	1	268.857	38.462	185.056	352.658
	2	310.357	47.392	207.100	413.615
	3	150.000	22.836	100.245	199.755
3	1	315.786	31.287	247.617	383.954
	2	348.857	39.425	262.958	434.756
	3	232.857	38.377	149.241	316.473

7. Sex * sound * alcohol

Measure: MEASURE_1

Sex	sound	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
female	1	1	201.429	65.810	58.042	344.815
		2	227.143	66.553	82.135	372.150
		3	119.429	32.670	48.248	190.610
	2	1	196.000	54.393	77.488	314.512
		2	195.000	67.022	48.972	341.028
		3	125.429	32.295	55.064	195.793
	3	1	246.143	44.246	149.738	342.548
		2	270.143	55.755	148.663	391.623
		3	246.000	54.273	127.749	364.251
male	1	1	421.714	65.810	278.328	565.101
		2	369.714	66.553	224.707	514.722
		3	168.429	32.670	97.248	239.610
	2	1	341.714	54.393	223.202	460.227
		2	425.714	67.022	279.686	571.743
		3	174.571	32.295	104.207	244.936
	3	1	385.429	44.246	289.024	481.833
		2	427.571	55.755	306.092	549.051
		3	219.714	54.273	101.463	337.965

General Linear Model

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[DataSet2] C:\Documents and Settings\Staff\Desktop\Michelle\Final Data\Experiment 2\final data set.sav
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Within-Subjects Factors

Measure: MEASURE_1

sound	alcohol	Dependent Variable
1	1	s4noabeh
	2	s405beh
	3	s408beh
2	1	s3noabeh
	2	s305beh
	3	s308beh
3	1	s2noabeh
	2	s205beh
	3	s208beh

Between-Subjects Factors

		Value Label	N
Sex	1.00	female	7
	2.00	male	7

Descriptive Statistics

	Sex	Mean	Std. Deviation	N
T-3 no alcohol beh	female	125.4286	82.35059	7
	male	174.5714	88.43049	7
	Total	150.0000	85.96153	14
T-3 .05 beh	female	196.0000	106.04559	7
	male	341.7143	173.70925	7
	Total	268.8571	157.58702	14
T-3 .08 beh	female	195.0000	187.24761	7
	male	425.7143	166.80999	7
	Total	310.3571	208.22052	14
Current no alcohol beh	female	246.0000	190.56932	7
	male	219.7143	70.15154	7
	Total	232.8571	138.63225	14
Current .05 beh	female	246.1429	108.77106	7
	male	385.4286	124.80900	7
	Total	315.7857	133.69091	14
Current .08 beh	female	270.1429	156.99621	7
	male	427.5714	137.37886	7
	Total	348.8571	163.58195	14
Actress no alcohol beh	female	119.4286	80.54783	7
	male	168.4286	91.94719	7
	Total	143.9286	86.84953	14
Actress .05 beh	female	201.4286	116.92285	7
	male	421.7143	216.70619	7
	Total	311.5714	202.60523	14
Actress .08 beh	female	227.1429	189.16345	7
	male	369.7143	161.95134	7
	Total	298.4286	184.64299	14

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
sound	Pillai's Trace	.548	6.670[a]	2.000	11.000	.013	.548
	Wilks' Lambda	.452	6.670[a]	2.000	11.000	.013	.548
	Hotelling's Trace	1.213	6.670[a]	2.000	11.000	.013	.548
	Roy's Largest Root	1.213	6.670[a]	2.000	11.000	.013	.548
sound * sex	Pillai's Trace	.212	1.482[a]	2.000	11.000	.269	.212
	Wilks' Lambda	.788	1.482[a]	2.000	11.000	.269	.212
	Hotelling's Trace	.269	1.482[a]	2.000	11.000	.269	.212
	Roy's Largest Root	.269	1.482[a]	2.000	11.000	.269	.212
alcohol	Pillai's Trace	.695	12.537[a]	2.000	11.000	.001	.695
	Wilks' Lambda	.305	12.537[a]	2.000	11.000	.001	.695
	Hotelling's Trace	2.279	12.537[a]	2.000	11.000	.001	.695
	Roy's Largest Root	2.279	12.537[a]	2.000	11.000	.001	.695
alcohol * sex	Pillai's Trace	.417	3.930[a]	2.000	11.000	.052	.417
	Wilks' Lambda	.583	3.930[a]	2.000	11.000	.052	.417
	Hotelling's Trace	.715	3.930[a]	2.000	11.000	.052	.417
	Roy's Largest Root	.715	3.930[a]	2.000	11.000	.052	.417
sound * alcohol	Pillai's Trace	.303	.979[a]	4.000	9.000	.465	.303
	Wilks' Lambda	.697	.979[a]	4.000	9.000	.465	.303
	Hotelling's Trace	.435	.979[a]	4.000	9.000	.465	.303
	Roy's Largest Root	.435	.979[a]	4.000	9.000	.465	.303
sound * alcohol * sex	Pillai's Trace	.134	.348[a]	4.000	9.000	.839	.134
	Wilks' Lambda	.866	.348[a]	4.000	9.000	.839	.134
	Hotelling's Trace	.155	.348[a]	4.000	9.000	.839	.134
	Roy's Largest Root	.155	.348[a]	4.000	9.000	.839	.134

a. Exact statistic

b.

Design: Intercept+sex
Within Subjects Design: sound+alcohol+sound*alcohol

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
sound	.998	.024	2	.988	.998	1.000	.500
alcohol	.958	.470	2	.791	.960	1.000	.500
sound * alcohol	.204	16.555	9	.059	.583	.792	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+sex
Within Subjects Design: sound+alcohol+sound*alcohol

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
sound	Sphericity Assumed	77067.873	2	38533.937	7.194	.004	.375
	Greenhouse-Geisser	77067.873	1.996	38617.913	7.194	.004	.375
	Huynh-Feldt	77067.873	2.000	38533.937	7.194	.004	.375
	Lower-bound	77067.873	1.000	77067.873	7.194	.020	.375
sound * sex	Sphericity Assumed	17212.000	2	8606.000	1.607	.221	.118
	Greenhouse-Geisser	17212.000	1.996	8624.755	1.607	.221	.118
	Huynh-Feldt	17212.000	2.000	8606.000	1.607	.221	.118
	Lower-bound	17212.000	1.000	17212.000	1.607	.229	.118
Error(sound)	Sphericity Assumed	128555.683	24	5356.487			
	Greenhouse-Geisser	128555.683	23.948	5368.160			
	Huynh-Feldt	128555.683	24.000	5356.487			
	Lower-bound	128555.683	12.000	10712.974			
alcohol	Sphericity Assumed	506938.159	2	253469.079	11.786	.000	.496
	Greenhouse-Geisser	506938.159	1.920	264073.122	11.786	.000	.496
	Huynh-Feldt	506938.159	2.000	253469.079	11.786	.000	.496
	Lower-bound	506938.159	1.000	506938.159	11.786	.005	.496
alcohol * sex	Sphericity Assumed	155188.762	2	77594.381	3.608	.043	.231
	Greenhouse-Geisser	155188.762	1.920	80840.592	3.608	.045	.231
	Huynh-Feldt	155188.762	2.000	77594.381	3.608	.043	.231
	Lower-bound	155188.762	1.000	155188.762	3.608	.082	.231
Error(alcohol)	Sphericity Assumed	516125.302	24	21505.221			
	Greenhouse-Geisser	516125.302	23.036	22404.906			
	Huynh-Feldt	516125.302	24.000	21505.221			
	Lower-bound	516125.302	12.000	43010.442			
sound * alcohol	Sphericity Assumed	30370.937	4	7592.734	.942	.448	.073
	Greenhouse-Geisser	30370.937	2.330	13032.110	.942	.414	.073
	Huynh-Feldt	30370.937	3.167	9588.820	.942	.434	.073
	Lower-bound	30370.937	1.000	30370.937	.942	.351	.073
sound * alcohol * sex	Sphericity Assumed	25816.238	4	6454.060	.801	.531	.063
	Greenhouse-Geisser	25816.238	2.330	11077.698	.801	.476	.063
	Huynh-Feldt	25816.238	3.167	8150.794	.801	.507	.063
	Lower-bound	25816.238	1.000	25816.238	.801	.388	.063
Error(sound*alcohol)	Sphericity Assumed	386771.937	48	8057.749			
	Greenhouse-Geisser	386771.937	27.966	13830.358			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	sound	alcohol	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
sound	Level 1 vs. Level 3		950.127	1	950.127	.267	.615	.022
	Level 2 vs. Level 3		32064.286	1	32064.286	8.617	.012	.418
sound * sex	Level 1 vs. Level 3		73.143	1	73.143	.021	.888	.002
	Level 2 vs. Level 3		7778.571	1	7778.571	2.090	.174	.148
Error(sound)	Level 1 vs. Level 3		42706.952	12	3558.913			
	Level 2 vs. Level 3		44652.254	12	3721.021			
alcohol		Level 1 vs. Level 3	288770.032	1	288770.032	19.339	.001	.617
		Level 2 vs. Level 3	5869.841	1	5869.841	.355	.562	.029
alcohol * sex		Level 1 vs. Level 3	81880.508	1	81880.508	5.484	.037	.314
		Level 2 vs. Level 3	251.460	1	251.460	.015	.904	.001
Error(alcohol)		Level 1 vs. Level 3	179183.016	12	14931.918			
		Level 2 vs. Level 3	198311.587	12	16525.966			
sound * alcohol	Level 1 vs. Level 3	Level 1 vs. Level 3	480.286	1	480.286	.017	.898	.001
		Level 2 vs. Level 3	41801.786	1	41801.786	.586	.459	.047
	Level 2 vs. Level 3	Level 1 vs. Level 3	20751.500	1	20751.500	.971	.344	.075
		Level 2 vs. Level 3	29900.643	1	29900.643	.702	.418	.055
sound * alcohol * sex	Level 1 vs. Level 3	Level 1 vs. Level 3	27104.000	1	27104.000	.967	.345	.075
		Level 2 vs. Level 3	92665.786	1	92665.786	1.299	.277	.098
	Level 2 vs. Level 3	Level 1 vs. Level 3	28440.071	1	28440.071	1.330	.271	.100
		Level 2 vs. Level 3	32160.071	1	32160.071	.755	.402	.059
Error(sound*alcohol)	Level 1 vs. Level 3	Level 1 vs. Level 3	336335.714	12	28027.976			
		Level 2 vs. Level 3	856075.429	12	71339.619			
	Level 2 vs. Level 3	Level 1 vs. Level 3	256509.429	12	21375.786			
		Level 2 vs. Level 3	510862.286	12	42571.857			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	979561.059	1	979561.059	89.615	.000	.882
sex	53033.532	1	53033.532	4.852	.048	.288
Error	131168.977	12	10930.748			

Estimated Marginal Means

1. Sex

Measure: MEASURE_1

Sex	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
female	202.968	39.516	116.870	289.067
male	326.063	39.516	239.965	412.162

2. sound

Measure: MEASURE_1

sound	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	243.071	28.230	181.564	304.579
2	299.167	29.230	235.480	362.853
3	251.310	30.758	184.293	318.326

3. alcohol

Measure: MEASURE_1

alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	175.595	23.947	123.418	227.772
2	298.738	32.168	228.651	368.826
3	319.214	41.930	227.857	410.572

4. Sex * sound

Measure: MEASURE_1

Sex	sound	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
female	1	172.143	39.923	85.158	259.128
	2	254.095	41.337	164.029	344.162
	3	182.667	43.498	87.892	277.442
male	1	314.000	39.923	227.015	400.985
	2	344.238	41.337	254.172	434.304
	3	319.952	43.498	225.177	414.727

5. Sex * alcohol

Measure: MEASURE_1

Sex	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
female	1	163.619	33.867	89.830	237.408
	2	214.524	45.492	115.405	313.643
	3	230.762	59.298	101.563	359.961
male	1	187.571	33.867	113.782	261.361
	2	382.952	45.492	283.834	482.071
	3	407.667	59.298	278.468	536.866

6. sound * alcohol

Measure: MEASURE_1

sound	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	150.000	22.836	100.245	199.755
	2	268.857	38.462	185.056	352.658
	3	310.357	47.392	207.100	413.615
2	1	232.857	38.377	149.241	316.473
	2	315.786	31.287	247.617	383.954
	3	348.857	39.425	262.958	434.756
3	1	143.929	23.101	93.596	194.261
	2	311.571	46.534	210.182	412.961
	3	298.429	47.060	195.893	400.964

7. Sex * sound * alcohol

Measure: MEASURE_1

Sex	sound	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
female	1	1	125.429	32.295	55.064	195.793
		2	196.000	54.393	77.488	314.512
		3	195.000	67.022	48.972	341.028
	2	1	246.000	54.273	127.749	364.251
		2	246.143	44.246	149.738	342.548
		3	270.143	55.755	148.663	391.623
	3	1	119.429	32.670	48.248	190.610
		2	201.429	65.810	58.042	344.815
		3	227.143	66.553	82.135	372.150
male	1	1	174.571	32.295	104.207	244.936
		2	341.714	54.393	223.202	460.227
		3	425.714	67.022	279.686	571.743
	2	1	219.714	54.273	101.463	337.965
		2	385.429	44.246	289.024	481.833
		3	427.571	55.755	306.092	549.051
	3	1	168.429	32.670	97.248	239.610
		2	421.714	65.810	278.328	565.101
		3	369.714	66.553	224.707	514.722

Appendix 6: Output for Fisher Exact Test for Exp 3.

NPar Tests

```
[DataSet1] E:\stick\belfast\full data1.sav
```

alarm signal * woke up? Crosstabulation

			woke up?		Total
			no, did not wake	yes, woke	
alarm signal	mother's voice	Count	*0*	*19*	*19*
		% within alarm signal	*.0%*	*100.0%*	*100.0%*
		% within woke up?	*.0%*	*24.1%*	*20.4%*
	actor's voice	Count	*1*	*18*	*19*
		% within alarm signal	*5.3%*	*94.7%*	*100.0%*
		% within woke up?	*7.1%*	*22.8%*	*20.4%*
	standard alarm	Count	*12*	*16*	*28*
		% within alarm signal	*42.9%*	*57.1%*	*100.0%*
		% within woke up?	*85.7%*	*20.3%*	*30.1%*
	low pitch T-3	Count	*1*	*26*	*27*
		% within alarm signal	*3.7%*	*96.3%*	*100.0%*
		% within woke up?	*7.1%*	*32.9%*	*29.0%*
Total		Count	*14*	*79*	*93*
		% within alarm signal	*15.1%*	*84.9%*	*100.0%*
		% within woke up?	*100.0%*	*100.0%*	*100.0%*

Frequencies

alarm signal

	Observed N	Expected N	Residual
mother's voice	*19*	*23.3*	*-4.3*
actor's voice	*19*	*23.3*	*-4.3*
standard alarm	*28*	*23.3*	*4.8*
low pitch T-3	*27*	*23.3*	*3.8*
Total	*93*		

woke up?

	Observed N	Expected N	Residual
no, did not wake	*14*	*46.5*	*-32.5*
yes, woke	*79*	*46.5*	*32.5*
Total	*93*		

Test Statistics

	alarm signal	woke up?
Chi-Square[a,b]	*3.129*	*45.430*
df	*3*	*1*
Asymp. Sig.	*.372*	*.000*
Exact Sig.	*.383*	*.000*
Point Probability	*.011*	*.000*

a. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 23.3.

b. 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 46.5.

Appendix 7: Output Experiment 4

Frequencies

```
[DataSet2] C:\Documents and Settings\Staff\Desktop\Michelle\Final Data\Experiment 2\sound and light
fixed.sav
```

Statistics

		snd200	snd205	snd208	snd300	snd305	snd308	snd400	snd405	snd408	snd600	snd608	snd700	snd708
N	Valid	10	10	10	10	10	10	10	10	10	10	10	10	10
	Missing	8	8	8	8	8	8	8	8	8	8	8	8	8
Mean		169.2000	347.6000	352.1000	243.0000	312.8000	400.7000	176.6000	280.3000	372.8000	122.5000	314.3000	167.6000	273.4000
Median		198.0000	327.5000	338.0000	283.5000	322.0000	426.5000	188.0000	283.0000	442.5000	78.0000	333.5000	182.5000	239.5000
Mode		44.00[a]	600.00	338.00[a]	306.00	402.00	600.00	333.00	286.00	600.00	24.00[a]	132.00[a]	39.00[a]	133.00[a]
Std. Deviation		102.94961	217.10069	186.55857	89.41663	149.97837	194.52566	97.43967	166.60069	247.93404	104.17747	138.48068	60.44134	137.17807

a. Multiple modes exist. The smallest value is shown

Frequency Table

snd200

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	30.00	1	5.6	10.0	10.0
	44.00	2	11.1	20.0	30.0
	117.00	1	5.6	10.0	40.0
	182.00	1	5.6	10.0	50.0
	214.00	1	5.6	10.0	60.0
	219.00	1	5.6	10.0	70.0
	278.00	1	5.6	10.0	80.0
	282.00	2	11.1	20.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd205

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	17.00	1	5.6	10.0	10.0
	74.00	1	5.6	10.0	20.0
	208.00	1	5.6	10.0	30.0
	243.00	1	5.6	10.0	40.0
	313.00	1	5.6	10.0	50.0
	342.00	1	5.6	10.0	60.0
	479.00	1	5.6	10.0	70.0
	600.00	3	16.7	30.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd208

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	19.00	1	5.6	10.0	10.0
	197.00	1	5.6	10.0	20.0
	225.00	1	5.6	10.0	30.0
	259.00	1	5.6	10.0	40.0
	338.00	2	11.1	20.0	60.0
	449.00	1	5.6	10.0	70.0
	496.00	1	5.6	10.0	80.0
	600.00	2	11.1	20.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd300

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	103.00	1	5.6	10.0	10.0
	129.00	1	5.6	10.0	20.0
	164.00	1	5.6	10.0	30.0
	192.00	1	5.6	10.0	40.0
	280.00	1	5.6	10.0	50.0
	287.00	1	5.6	10.0	60.0
	289.00	1	5.6	10.0	70.0
	306.00	2	11.1	20.0	90.0
	374.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd305

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	52.00	1	5.6	10.0	10.0
	191.00	1	5.6	10.0	20.0
	195.00	1	5.6	10.0	30.0
	262.00	1	5.6	10.0	40.0
	317.00	1	5.6	10.0	50.0
	327.00	1	5.6	10.0	60.0
	380.00	1	5.6	10.0	70.0
	402.00	2	11.1	20.0	90.0
	600.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd308

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	124.00	1	5.6	10.0	10.0
	179.00	1	5.6	10.0	20.0
	192.00	1	5.6	10.0	30.0
	289.00	1	5.6	10.0	40.0
	357.00	1	5.6	10.0	50.0
	496.00	1	5.6	10.0	60.0
	570.00	1	5.6	10.0	70.0
	600.00	3	16.7	30.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd400

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	52.00	1	5.6	10.0	10.0
	84.00	1	5.6	10.0	20.0
	100.00	1	5.6	10.0	30.0
	101.00	1	5.6	10.0	40.0
	187.00	1	5.6	10.0	50.0
	189.00	1	5.6	10.0	60.0
	191.00	1	5.6	10.0	70.0
	196.00	1	5.6	10.0	80.0
	333.00	2	11.1	20.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd405

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	30.00	1	5.6	10.0	10.0
	135.00	1	5.6	10.0	20.0
	189.00	1	5.6	10.0	30.0
	207.00	1	5.6	10.0	40.0
	282.00	1	5.6	10.0	50.0
	284.00	1	5.6	10.0	60.0
	286.00	2	11.1	20.0	80.0
	504.00	1	5.6	10.0	90.0
	600.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd408

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	41.00	1	5.6	10.0	10.0
	85.00	1	5.6	10.0	20.0
	122.00	1	5.6	10.0	30.0
	195.00	1	5.6	10.0	40.0
	285.00	1	5.6	10.0	50.0
	600.00	5	27.8	50.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd600

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	24.00	1	5.6	10.0	10.0
	44.00	1	5.6	10.0	20.0
	47.00	1	5.6	10.0	30.0
	59.00	1	5.6	10.0	40.0
	71.00	1	5.6	10.0	50.0
	85.00	1	5.6	10.0	60.0
	143.00	1	5.6	10.0	70.0
	190.00	1	5.6	10.0	80.0
	201.00	1	5.6	10.0	90.0
	361.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd608

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	132.00	1	5.6	10.0	10.0
	178.00	1	5.6	10.0	20.0
	199.00	1	5.6	10.0	30.0
	225.00	1	5.6	10.0	40.0
	330.00	1	5.6	10.0	50.0
	337.00	1	5.6	10.0	60.0
	348.00	1	5.6	10.0	70.0
	363.00	1	5.6	10.0	80.0
	431.00	1	5.6	10.0	90.0
	600.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd700

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	39.00	1	5.6	10.0	10.0
	99.00	1	5.6	10.0	20.0
	137.00	1	5.6	10.0	30.0
	165.00	1	5.6	10.0	40.0
	178.00	1	5.6	10.0	50.0
	187.00	1	5.6	10.0	60.0
	211.00	1	5.6	10.0	70.0
	214.00	1	5.6	10.0	80.0
	219.00	1	5.6	10.0	90.0
	227.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd708

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	133.00	1	5.6	10.0	10.0
	167.00	1	5.6	10.0	20.0
	170.00	1	5.6	10.0	30.0
	199.00	1	5.6	10.0	40.0
	227.00	1	5.6	10.0	50.0
	252.00	1	5.6	10.0	60.0
	282.00	1	5.6	10.0	70.0
	338.00	1	5.6	10.0	80.0
	366.00	1	5.6	10.0	90.0
	600.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

General Linear Model

```
[DataSet1] C:\Documents and Settings\Staff\Desktop\Michelle\Final Data\Experiment 2\sound and light no
05.sav
```

Within-Subjects Factors

Measure: MEASURE_1

sound	alcohol	Dependent Variable
1	1	snd200
	2	snd208
2	1	snd300
	2	snd308
3	1	snd400
	2	snd408
4	1	snd700
	2	snd708
5	1	snd600
	2	snd608

Between-Subjects Factors

		Value Label	N
sex	1.00	male	5
	2.00	female	5

Descriptive Statistics

	sex	Mean	Std. Deviation	N
snd200	male	221.0000	102.49878	5
	female	117.4000	81.44200	5
	Total	169.2000	102.94961	10
snd208	male	444.2000	111.28432	5
	female	260.0000	211.46867	5
	Total	352.1000	186.55857	10
snd300	male	274.2000	47.37299	5
	female	211.8000	115.37634	5
	Total	243.0000	89.41663	10
snd308	male	530.6000	106.98505	5
	female	270.8000	177.50972	5
	Total	400.7000	194.52566	10
snd400	male	227.4000	106.27464	5
	female	125.8000	60.13901	5
	Total	176.6000	97.43967	10
snd408	male	537.0000	140.87228	5
	female	208.6000	225.96748	5
	Total	372.8000	247.93404	10
snd700	male	168.0000	42.07137	5
	female	167.2000	80.30691	5
	Total	167.6000	60.44134	10
snd708	male	334.8000	161.36511	5
	female	212.0000	82.92466	5
	Total	273.4000	137.17807	10
snd600	male	162.2000	127.78576	5
	female	82.8000	64.41817	5
	Total	122.5000	104.17747	10
snd608	male	381.6000	147.71019	5
	female	247.0000	100.03249	5
	Total	314.3000	138.48068	10

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
sound	Pillai's Trace	.674	2.581[a]	4.000	5.000	.163	.674
	Wilks' Lambda	.326	2.581[a]	4.000	5.000	.163	.674
	Hotelling's Trace	2.065	2.581[a]	4.000	5.000	.163	.674
	Roy's Largest Root	2.065	2.581[a]	4.000	5.000	.163	.674
sound * sex	Pillai's Trace	.637	2.189[a]	4.000	5.000	.206	.637
	Wilks' Lambda	.363	2.189[a]	4.000	5.000	.206	.637
	Hotelling's Trace	1.751	2.189[a]	4.000	5.000	.206	.637
	Roy's Largest Root	1.751	2.189[a]	4.000	5.000	.206	.637
alcohol	Pillai's Trace	.910	81.148[a]	1.000	8.000	.000	.910
	Wilks' Lambda	.090	81.148[a]	1.000	8.000	.000	.910
	Hotelling's Trace	10.144	81.148[a]	1.000	8.000	.000	.910
	Roy's Largest Root	10.144	81.148[a]	1.000	8.000	.000	.910
alcohol * sex	Pillai's Trace	.629	13.553[a]	1.000	8.000	.006	.629
	Wilks' Lambda	.371	13.553[a]	1.000	8.000	.006	.629
	Hotelling's Trace	1.694	13.553[a]	1.000	8.000	.006	.629
	Roy's Largest Root	1.694	13.553[a]	1.000	8.000	.006	.629
sound * alcohol	Pillai's Trace	.501	1.255[a]	4.000	5.000	.396	.501
	Wilks' Lambda	.499	1.255[a]	4.000	5.000	.396	.501
	Hotelling's Trace	1.004	1.255[a]	4.000	5.000	.396	.501
	Roy's Largest Root	1.004	1.255[a]	4.000	5.000	.396	.501
sound * alcohol * sex	Pillai's Trace	.293	.519[a]	4.000	5.000	.728	.293
	Wilks' Lambda	.707	.519[a]	4.000	5.000	.728	.293
	Hotelling's Trace	.415	.519[a]	4.000	5.000	.728	.293
	Roy's Largest Root	.415	.519[a]	4.000	5.000	.728	.293

a. Exact statistic

b.

Design: Intercept+sex
Within Subjects Design: sound+alcohol+sound*alcohol

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
sound	.242	9.101	9	.443	.618	1.000	.250
alcohol	1.000	.000	0	.	1.000	1.000	1.000
sound * alcohol	.038	21.049	9	.015	.478	.703	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept+sex
Within Subjects Design: sound+alcohol+sound*alcohol

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
sound	Sphericity Assumed	146594.060	4	36648.515	3.821	.012	.323
	Greenhouse-Geisser	146594.060	2.473	59284.855	3.821	.032	.323
	Huynh-Feldt	146594.060	4.000	36648.515	3.821	.012	.323
	Lower-bound	146594.060	1.000	146594.060	3.821	.086	.323
sound * sex	Sphericity Assumed	66322.860	4	16580.715	1.729	.168	.178
	Greenhouse-Geisser	66322.860	2.473	26821.968	1.729	.199	.178
	Huynh-Feldt	66322.860	4.000	16580.715	1.729	.168	.178
	Lower-bound	66322.860	1.000	66322.860	1.729	.225	.178
Error(sound)	Sphericity Assumed	306892.280	32	9590.384			
	Greenhouse-Geisser	306892.280	19.782	15513.985			
	Huynh-Feldt	306892.280	32.000	9590.384			
	Lower-bound	306892.280	8.000	38361.535			
alcohol	Sphericity Assumed	696223.360	1	696223.360	81.148	.000	.910
	Greenhouse-Geisser	696223.360	1.000	696223.360	81.148	.000	.910
	Huynh-Feldt	696223.360	1.000	696223.360	81.148	.000	.910
	Lower-bound	696223.360	1.000	696223.360	81.148	.000	.910
alcohol * sex	Sphericity Assumed	116281.000	1	116281.000	13.553	.006	.629
	Greenhouse-Geisser	116281.000	1.000	116281.000	13.553	.006	.629
	Huynh-Feldt	116281.000	1.000	116281.000	13.553	.006	.629
	Lower-bound	116281.000	1.000	116281.000	13.553	.006	.629
Error(alcohol)	Sphericity Assumed	68637.040	8	8579.630			
	Greenhouse-Geisser	68637.040	8.000	8579.630			
	Huynh-Feldt	68637.040	8.000	8579.630			
	Lower-bound	68637.040	8.000	8579.630			
sound * alcohol	Sphericity Assumed	27761.740	4	6940.435	.547	.703	.064
	Greenhouse-Geisser	27761.740	1.911	14527.231	.547	.582	.064
	Huynh-Feldt	27761.740	2.810	9879.572	.547	.644	.064
	Lower-bound	27761.740	1.000	27761.740	.547	.481	.064
sound * alcohol * sex	Sphericity Assumed	27259.500	4	6814.875	.537	.710	.063
	Greenhouse-Geisser	27259.500	1.911	14264.417	.537	.587	.063
	Huynh-Feldt	27259.500	2.810	9700.840	.537	.651	.063
	Lower-bound	27259.500	1.000	27259.500	.537	.485	.063
Error(sound*alcohol)	Sphericity Assumed	406246.360	32	12695.199			
	Greenhouse-Geisser	406246.360	15.288	26573.698			

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	sound	alcohol	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
sound	Level 1 vs. Level 5		17850.625	1	17850.625	1.452	.263	.154
	Level 2 vs. Level 5		107019.025	1	107019.025	7.868	.023	.496
	Level 3 vs. Level 5		31696.900	1	31696.900	1.693	.229	.175
	Level 4 vs. Level 5		44.100	1	44.100	.006	.941	.001
sound * sex	Level 1 vs. Level 5		3404.025	1	3404.025	.277	.613	.033
	Level 2 vs. Level 5		7317.025	1	7317.025	.538	.484	.063
	Level 3 vs. Level 5		29160.000	1	29160.000	1.557	.247	.163
	Level 4 vs. Level 5		5107.600	1	5107.600	.686	.432	.079
Error(sound)	Level 1 vs. Level 5		98360.600	8	12295.075			
	Level 2 vs. Level 5		108810.200	8	13601.275			
	Level 3 vs. Level 5		149815.100	8	18726.888			
	Level 4 vs. Level 5		59568.800	8	7446.100			
alcohol		Level 1 vs. Level 2	278489.344	1	278489.344	81.148	.000	.910
alcohol * sex		Level 1 vs. Level 2	46512.400	1	46512.400	13.553	.006	.629
Error(alcohol)		Level 1 vs. Level 2	27454.816	8	3431.852			
sound * alcohol	Level 1 vs. Level 5	Level 1 vs. Level 2	792.100	1	792.100	.009	.926	.001
	Level 2 vs. Level 5	Level 1 vs. Level 2	11628.100	1	11628.100	.202	.665	.025
	Level 3 vs. Level 5	Level 1 vs. Level 2	193.600	1	193.600	.002	.965	.000
	Level 4 vs. Level 5	Level 1 vs. Level 2	73960.000	1	73960.000	3.680	.091	.315
sound * alcohol * sex	Level 1 vs. Level 5	Level 1 vs. Level 2	1612.900	1	1612.900	.019	.894	.002
	Level 2 vs. Level 5	Level 1 vs. Level 2	50552.100	1	50552.100	.879	.376	.099
	Level 3 vs. Level 5	Level 1 vs. Level 2	73616.400	1	73616.400	.796	.398	.091
	Level 4 vs. Level 5	Level 1 vs. Level 2	11155.600	1	11155.600	.555	.478	.065
Error(sound*alcohol)	Level 1 vs. Level 5	Level 1 vs. Level 2	682492.000	8	85311.500			
	Level 2 vs. Level 5	Level 1 vs. Level 2	459940.800	8	57492.600			
	Level 3 vs. Level 5	Level 1 vs. Level 2	739402.000	8	92425.250			
	Level 4 vs. Level 5	Level 1 vs. Level 2	160782.400	8	20097.800			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	671950.084	1	671950.084	115.292	.000	.935
sex	47444.544	1	47444.544	8.140	.021	.504
Error	46625.952	8	5828.244			

Estimated Marginal Means

1. sex

Measure: MEASURE_1

sex	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
male	328.100	34.142	249.369	406.831
female	190.340	34.142	111.609	269.071

2. sound

Measure: MEASURE_1

sound	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	260.650	33.550	183.283	338.017
2	321.850	34.238	242.897	400.803
3	274.700	37.014	189.345	360.055
4	220.500	21.476	170.976	270.024
5	218.400	26.515	157.257	279.543

3. alcohol

Measure: MEASURE_1

alcohol	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	175.780	17.540	135.333	216.227
2	342.660	32.087	268.666	416.654

4. sex * sound

Measure: MEASURE_1

sex	sound	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
male	1	332.600	47.447	223.186	442.014
	2	402.400	48.420	290.743	514.057
	3	382.200	52.346	261.489	502.911
	4	251.400	30.372	181.362	321.438
	5	271.900	37.497	185.431	358.369
female	1	188.700	47.447	79.286	298.114
	2	241.300	48.420	129.643	352.957
	3	167.200	52.346	46.489	287.911
	4	189.600	30.372	119.562	259.638
	5	164.900	37.497	78.431	251.369

5. sex * alcohol

Measure: MEASURE_1

sex	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
male	1	210.560	24.805	153.360	267.760
	2	445.640	45.378	340.997	550.283
female	1	141.000	24.805	83.800	198.200
	2	239.680	45.378	135.037	344.323

6. sound * alcohol

Measure: MEASURE_1

sound	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	169.200	29.274	101.695	236.705
	2	352.100	53.434	228.882	475.318
2	1	243.000	27.889	178.688	307.312
	2	400.700	46.344	293.830	507.570
3	1	176.600	27.305	113.635	239.565
	2	372.800	59.543	235.495	510.105
4	1	167.600	20.272	120.852	214.348
	2	273.400	40.568	179.850	366.950
5	1	122.500	31.999	48.710	196.290
	2	314.300	39.890	222.313	406.287

7. sex * sound * alcohol

Measure: MEASURE_1

sex	sound	alcohol	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
male	1	1	221.000	41.399	125.534	316.466
		2	444.200	75.567	269.943	618.457
	2	1	274.200	39.441	183.249	365.151
		2	530.600	65.540	379.463	681.737
	3	1	227.400	38.615	138.354	316.446
		2	537.000	84.206	342.821	731.179
	4	1	168.000	28.669	101.889	234.111
		2	334.800	57.372	202.500	467.100
	5	1	162.200	45.254	57.845	266.555
		2	381.600	56.413	251.510	511.690
female	1	1	117.400	41.399	21.934	212.866
		2	260.000	75.567	85.743	434.257
	2	1	211.800	39.441	120.849	302.751
		2	270.800	65.540	119.663	421.937
	3	1	125.800	38.615	36.754	214.846
		2	208.600	84.206	14.421	402.779
	4	1	167.200	28.669	101.089	233.311
		2	212.000	57.372	79.700	344.300
	5	1	82.800	45.254	-21.555	187.155
		2	247.000	56.413	116.910	377.090

Appendix 8: Output Experiment 5

Frequencies

[DataSet2] C:\Documents and Settings\Staff\Desktop\Michelle\Final Data\Experiment 2\sound and light fixed.sav

Statistics

		snd100s2	snd108s2	light00	light08	s1lig00	s1lig08
N	Valid	10	9	10	9	10	9
	Missing	8	9	8	9	8	9
Mean		62.5000	175.2222	257.6000	541.6667	53.8000	140.2222
Median		33.0000	197.0000	65.0000	600.0000	27.5000	128.0000
Mode		33.00	47.00[a]	600.00	600.00	8.00	16.00[a]
Std. Deviation		69.13955	92.33333	295.46694	175.00000	56.84247	100.39768

a. Multiple modes exist. The smallest value is shown

Frequency Table

snd100s2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10.00	1	5.6	10.0	10.0
	14.00	1	5.6	10.0	20.0
	20.00	1	5.6	10.0	30.0
	28.00	1	5.6	10.0	40.0
	33.00	2	11.1	20.0	60.0
	45.00	1	5.6	10.0	70.0
	63.00	1	5.6	10.0	80.0
	172.00	1	5.6	10.0	90.0
	207.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

snd108s2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	47.00	1	5.6	11.1	11.1
	62.00	1	5.6	11.1	22.2
	63.00	1	5.6	11.1	33.3
	191.00	1	5.6	11.1	44.4
	197.00	1	5.6	11.1	55.6
	237.00	1	5.6	11.1	66.7
	250.00	1	5.6	11.1	77.8
	258.00	1	5.6	11.1	88.9
	272.00	1	5.6	11.1	100.0
	Total	9	50.0	100.0	
Missing	System	9	50.0		
Total		18	100.0		

light00

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	7.00	1	5.6	10.0	10.0
	8.00	1	5.6	10.0	20.0
	11.00	1	5.6	10.0	30.0
	20.00	1	5.6	10.0	40.0
	55.00	1	5.6	10.0	50.0
	75.00	1	5.6	10.0	60.0
	600.00	4	22.2	40.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

light08

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	75.00	1	5.6	11.1	11.1
	600.00	8	44.4	88.9	100.0
	Total	9	50.0	100.0	
Missing	System	9	50.0		
Total		18	100.0		

s1lig00

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	8.00	2	11.1	20.0	20.0
	10.00	1	5.6	10.0	30.0
	13.00	1	5.6	10.0	40.0
	20.00	1	5.6	10.0	50.0
	35.00	1	5.6	10.0	60.0
	61.00	1	5.6	10.0	70.0
	83.00	1	5.6	10.0	80.0
	136.00	1	5.6	10.0	90.0
	164.00	1	5.6	10.0	100.0
	Total	10	55.6	100.0	
Missing	System	8	44.4		
Total		18	100.0		

s1lig08

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	16.00	1	5.6	11.1	11.1
	20.00	1	5.6	11.1	22.2
	71.00	1	5.6	11.1	33.3
	101.00	1	5.6	11.1	44.4
	128.00	1	5.6	11.1	55.6
	190.00	1	5.6	11.1	66.7
	196.00	1	5.6	11.1	77.8
	220.00	1	5.6	11.1	88.9
	320.00	1	5.6	11.1	100.0
	Total	9	50.0	100.0	
Missing	System	9	50.0		
Total		18	100.0		

General Linear Model

[DataSet2] C:\Documents and Settings\Staff\Desktop\Michelle\Final Data\Experiment 2\sound and light fixed.sav

Within-Subjects Factors

Measure: MEASURE_1

Stimulus	alcohol	Dependent Variable
1	1	snd100s2
	2	snd108s2
2	1	light00
	2	light08
3	1	s1lig00
	2	s1lig08

Descriptive Statistics

	Mean	Std. Deviation	N
snd100s2	68.3333	70.67531	9
snd108s2	175.2222	92.33333	9
light00	284.0000	300.62019	9
light08	541.6667	175.00000	9
s1lig00	58.8889	57.82397	9
s1lig08	140.2222	100.39768	9

Multivariate Tests[b]

Effect		Value	F	Hypothesis df	Error df	Sig.
Stimulus	Pillai's Trace	.871	23.555[a]	2.000	7.000	.001
	Wilks' Lambda	.129	23.555[a]	2.000	7.000	.001
	Hotelling's Trace	6.730	23.555[a]	2.000	7.000	.001
	Roy's Largest Root	6.730	23.555[a]	2.000	7.000	.001
alcohol	Pillai's Trace	.677	16.749[a]	1.000	8.000	.003
	Wilks' Lambda	.323	16.749[a]	1.000	8.000	.003
	Hotelling's Trace	2.094	16.749[a]	1.000	8.000	.003
	Roy's Largest Root	2.094	16.749[a]	1.000	8.000	.003
Stimulus * alcohol	Pillai's Trace	.273	1.315[a]	2.000	7.000	.327
	Wilks' Lambda	.727	1.315[a]	2.000	7.000	.327
	Hotelling's Trace	.376	1.315[a]	2.000	7.000	.327
	Roy's Largest Root	.376	1.315[a]	2.000	7.000	.327

a. Exact statistic

b.

Design: Intercept
Within Subjects Design: Stimulus+alcohol+Stimulus*alcohol

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Stimulus	.298	8.469	2	.014	.588	.628	.500
alcohol	1.000	.000	0	.	1.000	1.000	1.000
Stimulus * alcohol	.109	15.495	2	.000	.529	.542	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept
Within Subjects Design: Stimulus+alcohol+Stimulus*alcohol

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Stimulus	Sphericity Assumed	1100100.778	2	550050.389	40.142	.000
	Greenhouse-Geisser	1100100.778	1.175	936047.138	40.142	.000
	Huynh-Feldt	1100100.778	1.257	875315.940	40.142	.000
	Lower-bound	1100100.778	1.000	1100100.778	40.142	.000
Error(Stimulus)	Sphericity Assumed	219239.556	16	13702.472		
	Greenhouse-Geisser	219239.556	9.402	23318.154		
	Huynh-Feldt	219239.556	10.054	21805.261		
	Lower-bound	219239.556	8.000	27404.944		
alcohol	Sphericity Assumed	298225.352	1	298225.352	16.749	.003
	Greenhouse-Geisser	298225.352	1.000	298225.352	16.749	.003
	Huynh-Feldt	298225.352	1.000	298225.352	16.749	.003
	Lower-bound	298225.352	1.000	298225.352	16.749	.003
Error(alcohol)	Sphericity Assumed	142444.148	8	17805.519		
	Greenhouse-Geisser	142444.148	8.000	17805.519		
	Huynh-Feldt	142444.148	8.000	17805.519		
	Lower-bound	142444.148	8.000	17805.519		
Stimulus * alcohol	Sphericity Assumed	81720.704	2	40860.352	2.189	.144
	Greenhouse-Geisser	81720.704	1.058	77254.205	2.189	.176
	Huynh-Feldt	81720.704	1.083	75438.100	2.189	.175
	Lower-bound	81720.704	1.000	81720.704	2.189	.177
Error(Stimulus*alcohol)	Sphericity Assumed	298710.296	16	18669.394		
	Greenhouse-Geisser	298710.296	8.463	35298.011		
	Huynh-Feldt	298710.296	8.666	34468.220		
	Lower-bound	298710.296	8.000	37338.787		

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	Stimulus	alcohol	Type III Sum of Squares	df	Mean Square	F	Sig.
Stimulus	Level 1 vs. Level 3		4444.444	1	4444.444	1.854	.210
	Level 2 vs. Level 3		883286.694	1	883286.694	50.090	.000
Error(Stimulus)	Level 1 vs. Level 3		19177.556	8	2397.194		
	Level 2 vs. Level 3		141072.556	8	17634.069		
alcohol		Level 1 vs. Level 2	198816.901	1	198816.901	16.749	.003
Error(alcohol)		Level 1 vs. Level 2	94962.765	8	11870.346		
Stimulus * alcohol	Level 1 vs. Level 3	Level 1 vs. Level 2	5877.778	1	5877.778	1.346	.279
	Level 2 vs. Level 3	Level 1 vs. Level 2	279841.000	1	279841.000	2.454	.156
Error(Stimulus*alcohol)	Level 1 vs. Level 3	Level 1 vs. Level 2	34938.222	8	4367.278		
	Level 2 vs. Level 3	Level 1 vs. Level 2	912320.000	8	114040.000		

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	402167.361	1	402167.361	36.901	.000
Error	87189.333	8	10898.667		

Estimated Marginal Means

1. Stimulus

Measure: MEASURE_1

Stimulus	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	121.778	21.237	72.804	170.751
2	412.833	64.211	264.763	560.904
3	99.556	24.111	43.956	155.155

2. alcohol

Measure: MEASURE_1

alcohol	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	137.074	43.759	36.165	237.984
2	285.704	34.154	206.944	364.463

3. Stimulus * alcohol

Measure: MEASURE_1

Stimulus	alcohol	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	68.333	23.558	14.007	122.659
	2	175.222	30.778	104.249	246.196
2	1	284.000	100.207	52.923	515.077
	2	541.667	58.333	407.150	676.184
3	1	58.889	19.275	14.441	103.336
	2	140.222	33.466	63.050	217.395