The Effects, in Healthy Adults, of 'Morningness-Eveningness' on Information Processing Speeds for Visual and Auditory Input

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DEDICATION

This thesis is dedicated to my parents, Ian and Dianne Pope.
Thank you for your unwavering support and for always being there.

It is also dedicated to Missy and Larnie.
For the many hours you were by my side.

In loving memory of Missy
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ABSTRACT

The study attempted to determine whether information processing speed was influenced by morningness-eveningness preference. Prior studies have not found any ‘synchrony effect’ between a person’s chronotype and time of testing on information processing speed despite other aspects of cognition exhibiting synchrony effects. Thirty five university students aged 18 to 25 years participated in the study. Morningness-eveningness preference was determined by the Horne and Ostberg (1976) ‘Morningness-Eveningness’ Questionnaire, and information processing speed for visual and auditory stimuli was assessed by the Computerised Auditory and Visual Test of Information Processing (CAVTIP) which was developed for the present study. Participants undertook testing at two time periods, one deemed optimal and one deemed non-optimal according to chronotype (9.00 a.m. and 5.00 p.m.). Results indicated that there was an overall synchrony effect for the most complex task but not the least complex, however post-hoc analyses indicated that the synchrony effect was modality specific. For visually presented stimuli there was no advantage in the morning for any chronotype, but there was a disadvantage for morning types in the evening. For the auditory stimuli, evening types experienced an advantage in the evening. Possible implications arising from the findings are suggested.

Keywords: circadian rhythms, morningness-eveningness, chronotype, information processing speed

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CHAPTER 1

BACKGROUND

You may have wondered why some people always seem to arrive at work late then reach straight for the coffee mug before starting any work tasks. By the time they actually start working effectively, an hour or two has already passed. Are these people just very disorganised or lazy? In contrast, you may have noticed the ones who are already working flat out when you arrive, have been there for hours, and have completed a considerable amount of work. Are these people that dedicated to their job? While it is possible some people are very disorganised or lazy, and others are very dedicated to their job, there is another explanation for these extremes in behaviour.

The current study investigates differences associated with circadian rhythms on cognitive performance. Specifically it addresses the inter-individual differences observed in circadian rhythms on information processing speed.

This thesis commences with a brief discussion of what circadian rhythms are and why they are important. A summary of the protocols that are used to uncover circadian rhythmicity follows. Additionally, the influence on several biological markers of circadian rhythms will be discussed, and how they are observed to change over the day. In this section the inter-individual differences associated with the biological markers will also be reviewed. This section will conclude with a brief summary of observations of circadian rhythm (including inter-individual differences) effects on a range of cognitive abilities, and how task difficulty affects the results.

The next section reviews the literature surrounding inter-individual differences in circadian rhythm expression, with particular emphasis placed on aspects most related to the current study.

Following the second section will be a discussion of information processing generally; including what it is and how it is measured, along with factors that are known to influence how quickly information is processed.

The chapter concludes with discussion of what the current study is about, the reason for undertaking the study, and associated hypotheses derived from the literature.

Circadian Rhythms in Brief

The word 'circadian' is derived from the Latin words 'circa' and 'dies' meaning 'about' and 'a day' respectively (Dunlap, Loros, & DeCoursey, 2004) and is used to denote near 24-hour patterns (Hofstra & de Weerd, 2008; Zee & Manthena, 2007).

These near 24-hour patterns are seen in humans and other mammals, and are thought to offer some kind of selective advantage on the organism as they prepare for impending daylight or nightfall (Feillet, 2010; Merrow, Spoelstra, & Roenneberg, 2005; Sharma, 2003; Young & Bray, 2007). In humans and other mammals, circadian rhythms are controlled by the master circadian clock: the suprachiasmatic nucleus (SCN), which is located in the anterior hypothalamus (Benarroch, 2008). This structure is responsible for influencing expression of several biological processes.

The approximate 24-hour pattern is generated via electrical energy originating in the SCN which endures when environmental time cues are removed (Benarroch, 2008). In addition to maintaining periodicity in the absence of time cues, circadian rhythms are also fairly stable over a range of temperatures (Gardner & Feldman, 1981). As circadian rhythms are *near* 24-hour rhythms and do not exactly match the rotation of the earth, they must be reset on a daily basis. This resetting is known as entrainment (Hofstra & de Weerd, 2008), and is carried out by exposure to a *zeitgeber*, which is German for 'time-giver'. For humans the major zeitgeber is the light-dark cycle.

Together, the endurance in the absence of time cues, stability over a range of temperatures, and entrainment make up the three characteristics of circadian rhythms.

Eliciting Rhythmicity

Determining the periodicity of circadian rhythms has been difficult – at least in the early studies. Exposure to light masks the underlying rhythm and compels the organism to display a rhythm that is not related to the underlying intrinsic period (Mistlberger & Rusak, 2005). To help combat this issue and elicit the true periodicity of circadian rhythms, several protocols have been developed.

Constant routine. A constant routine protocol forces individuals to stay awake for more than 24-hours under constant conditions of ambient light, temperature, body posture (semi-recumbent in bed) and food intake (hourly isocaloric snacks) (Blatter & Cajochen, 2007; Schmidt, C., Collette, Cajochen, & Peigneux, 2007). Measures of physiological and behavioural factors are taken at fixed times equally distanced across the protocol period (Herman, 2005; Schmidt, C., et al., 2007). As other factors that may mask the true circadian rhythm are minimised, the underlying intrinsic period is able to be determined. Although it is useful for this purpose, constant routine protocols do not allow for the determination of the impact of sleep pressure on the circadian process (Blatter & Cajochen, 2007; Schmidt, C., et al., 2007).

Forced desynchrony. Whereas constant routine protocols require the individual to remain awake for more than 24-hours, a forced desynchrony (FD) protocol may have either *shorter* or *longer* day lengths than 24-hours (Schmidt, C., et al., 2007); from 20 minutes to 28 hours (Herman, 2005). Under a FD protocol, the individual remains isolated from external zeitgebers while under the artificial sleep/wake schedule for extended periods of time (weeks) (Schmidt, C., et al., 2007) with two thirds of their time spent awake (Herman, 2005). The intrinsic period is able to be determined due to the desynchronisation between the artificial sleep/wake cycle and the underlying intrinsic period (Herman, 2005; Schmidt, C., et al., 2007). In this state, the rhythm is said to be 'free running'. Unlike the constant routine protocol whereby the impact of sleep pressure is not able to be determined on the circadian process, the FD protocol does allow a separation between the two. However, as individuals must remain isolated, the protocol is time consuming (Schmidt, C., et al., 2007).

Chronotype a.k.a morningness-eveningness. Chronotype based protocols neither place individuals under constant conditions, nor isolate them from external stimuli. Instead, chronotype protocols centre upon the individuals 'morningness-eveningness' preference. According to this protocol, individuals undergo performance testing on tasks at a time deemed optimal, or non-optimal based upon their chronotype. The advantage of this type of protocol is the ease of implementation. However, interactions between sleep pressure and circadian processes cannot be separated (Schmidt, C., et al., 2007). This is the protocol used in the present study.

Circadian Rhythm Influence on Biological Processes

The SCN reportedly influences several physiological, endocrinological, and behavioural processes including regulation of core body temperature (CBT), secretion of the hormones cortisol, melatonin, prolactin, and growth hormone (Hofstra & de Weerd, 2008) and is responsible for sleep/wake cycles (SW) (Benarroch, 2008; Hofstra & de Weerd, 2008); all processes shown to experience 24 hour rhythmicity.

Core body temperature (CBT). Several important characteristics have been identified; shape, amplitude, and mean level. The shape of CBT under circadian control is said to be cosinor – there are peaks and troughs in the temporal distribution across 24 hours. Amplitude refers to the difference between lowest and highest temperatures in the 24 hour period, although it is sometimes measured by half the difference (Refinetti & Menaker, 1992). Dunlap et al. (2004) indicate that body temperature typically ranges between 36°C and 37.5°C with external factors such as exercise causing a larger range. Mean level of CBT is defined as the average of all temperatures over the period (Refinetti & Menaker, 1992).

Differences in the shape and amplitude have been observed depending upon what protocol has been used to measure the periodicity (Waterhouse, et al., 2005). A constant routine and conventional lifestyle approach indicates temperature minimum occurs at 5.00 a.m., and a maximum (Tmax) at 5.00 p.m. under constant routine (Krauchi & Wirz-Justice, 1994 cited in Waterhouse, et al., 2005). Monk et al. (1997) demonstrate a similar pattern. Tmax under a conventional lifestyle approach ranges between 2.00 p.m. and 8.00 p.m. The difference in timing of Tmax between the approaches is attributed to external influences under a conventional lifestyle approach.

When the morningness-eveningness aspect of circadian rhythm expression is taken into account, several differences are observed between the chronotypes. Morning types show a higher body temperature, which is accompanied by a steeper rise in the morning compared to evening types. Oral temperature of morning types peaks two hours earlier than evening types (Horne, Brass, & Pettitt, 1980; Song & Stough, 2000). The result of Lack, Bailey, Lovato, and Wright (2009) confirm this earlier (2-3 hour) peak in temperature in morning types when rectal temperature is measured under a modified 27 hour constant routine protocol. Taillard, Philip, Coste, Sagaspe, and

Bioulac (2003) have shown a smaller difference of 1.4 hours when participants were tested under normal 'workday' conditions. Conversely, the evening type shows a steady rise over the day, with a peak occurring in the middle evening. The rate of decline for both morning and evening types are comparable however (Song & Stough, 2000). Additionally, whereas Tmax has been shown to occur approximately two hours earlier in morning types, Baehr, Revelle, and Eastman (2000) have shown that Tmin also occurs approximately two hours earlier compared to evening types. Although results did not reach statistical significance, Baehr et al. (2000) have demonstrated that evening types trend toward showing greater amplitude in their temperature curves than morning types when measured rectally. They attributed this to evening types exhibiting lower nocturnal temperature than morning types.

Cortisol. Turton and Deegan (1974) have shown that in a sample of 12 male hospital patients, cortisol exhibits circadian rhythmicity. Results of the study indicated that plasma cortisol levels increased steadily from 3.00 a.m. with a peak occurring at 7.00 a.m. which corresponded to the time shortly after waking. From 11.00 a.m. levels continually decreased and reached a trough at 9.00 p.m. A more recent study by Selmaoui and Touitou (2003) corroborated the findings of Turton and Deegan (1974) that plasma cortisol levels were low during the night, with a low found at approximately 1.00 a.m. and a peak at approximately 8.00 a.m. Selmaoui and Touitou (2003) concluded that measurement of cortisol level would be an appropriate method of determining circadian phase given the observation that at both the group and individual level, cortisol secretion remained fairly stable over a six week period.

Distinct patterns of cortisol secretion expression has been shown to be evident between the chronotypes. When salivary cortisol levels are assessed, morning types show elevated levels earlier than evening types, with a higher amplitude (Bailey & Heitkemper, 2001) and the elevated levels occur within one hour after waking (Kudielka, Federenko, Hellhammer, & Wüst, 2006).

Melatonin. Along with core body temperature and cortisol, measurement of melatonin level is one of the more widely used methods of determining circadian rhythm phase (Hofstra & de Weerd, 2008). Measurement is typically of the onset of melatonin secretion under dim light conditions (DLMO) and is thought to be the most accurate measure of determining circadian phase (Pandi-Perumal, et al., 2007). Reliability of DLMO as a marker of circadian phase has been attributed to the fact that during the light hours levels are low in both plasma and saliva, with a rapid increase occurring during the night (Van Someren & Nagtegaal, 2007).

Like that of CBT, melatonin peaks 2-3 hours earlier in morning types compared to evening types when dim light melatonin onset (DLMO) is assessed (Lack, et al., 2009).

The "Synchrony Effect"

May and Hasher (1998) define the optimal time of day for performing activities based upon arousal level as the 'synchrony effect'. According to this effect, performance is best when arousal levels are high. For morning types arousal levels are highest in the morning, and evening types in the evening. This same effect has been termed 'optimality-of-testing effect' by Intons-Peterson, Rocchi, West, McLellan, and Hackney (1999). If a synchrony or optimality-of-testing effect occurs, morning types are expected to perform better in the morning, and evening types in the evening, with poorer performance at other times. Many studies investigating this 'synchrony effect' have been carried out, including early studies.

Schmidt, C., et al. (2007) cite Gates (1916) and Laird (1925) as being early studies investigating time of day effects on performance. These early studies were concerned with determining the most favourable time for teaching school children. A subsequent study by Biggers (1980) demonstrated that among school age children in grades seven through 12, peak alertness or subjective assessment of performance in the morning correlated with higher grade point averages. In individuals reporting being less alert in the morning, corresponding grade point averages were lower. This difference between groups was found to be highly significant, and was attributed to by the author as resulting from evening type students being subjected to activities that they were not capable of undertaking at that time of day. This mismatch between activity and time of day for evening types, and a match for morning types subsequently leads to an accumulation of performance difference as measured by grade point average.

The results of Gates (1916), and Laird (1925) as cited in Schmidt, C., et al. (2007), Biggers (1980), and McElroy and Mosteller (2006) investigated tasks which would be theorised to involve a number of cognitive resources. Further studies have investigated more basic aspects of cognition, specifically those targeting particular cognitive domains.

Circadian Influence on Cognition

According to O'Hara, Coman, and Butters (2006) there are seven cognitive domains: attention/working memory, visuospatial skills, language, memory, executive functions, psychomotor speed, and mood.

Studies investigating circadian effects generally, and morningness-eveningness (M-E) effects specifically on cognition, have identified several domains that are subject to these influences.

Attention/working memory. Ramirez et al. (2006) have found that working memory is influenced by circadian rhythms with Rowe, Hasher, and Turcotte (2009) indicating that a synchrony effect is evident for both younger and older adults on a Corsi Block visuospatial working memory (VSWM) task.

Language. Rosenberg, Pusch, Dietrich, and Cajochen (2009) indicate that performance on a language task using gender congruent and incongruent noun phrases was generally slower during the night, with worst performances occurring at 10.00 a.m. for the noun congruent phrases and at 7.00 a.m. for the noun incongruent phrases. When the M-E aspect is considered in relation to language, Killgore and Killgore (2007) have found a small negative correlation ($r = -0.23$, $p = 0.05$) between M-E preference and Verbal IQ as measured by the Wechsler Abbreviated Scale of Intelligence (WASI).

Memory. Extensive studies have been undertaken in the area of memory. An early study by Folkard and Monk (1980) determined that both immediate memory and delayed memory (or long-term) is influenced by circadian rhythmicity. Barbosa and Albuquerque (2008) have reported similar results in circadian rhythm effect on long term explicit memory with superior recall of word lists occurring in those who learnt the words in the afternoon compared to those who learnt in the morning. In contrast, Allen, Grabbe, McCarthy, Bush, and Wallace (2008) indicate that semantic, and episodic memory are not subject to circadian influence. When M-E preference is taken into account, long term memory access shows a synchrony effect (Anderson, Petros, Beckwith, Mitchell, & Fritz, 1991).

Executive functioning. Executive functioning refers to complex cognitive processing (Elliott, 2003) and is commonly measured using a variety of tests including the Stroop Color Word Test, the Wisconsin Card Sorting Test (O'Hara, et al., 2006) and the Controlled Oral Word Association Test (COWAT) (Bell-McGinty, Podell, Franzen, Baird, & Williams, 2002). Using the COWAT which requires the generation of words beginning with the letters *f, a,* and *s,* Bennett, Petros, Johnson, and Ferraro (2008) have found that more words generally are able to be generated at 3.00 p.m. than at 8.00 a.m. However, the authors note this difference arises from more words beginning with *s* being generated, and is not associated with either the letters *f* or *a* exhibiting differences at those times.

Psychomotor speed. Gueugneau, Mauvieux, and Papaxanthis (2009) note that performance of the motor system is circadian dependent with a peak occurring between the hours of 4.00 p.m. and 8.00 p.m. attributable to temperature maximum around this time. This finding has also been observed in a sample of cyclists by Moussay et al. (2002) whereby motor spontaneous tempo (MST) - which is a tempo specific to an individual – when measured by a finger tapping task reached peak at approximately 5.00 p.m. (4.52 p.m.). Additionally, MST increases from approximately 6.00 a.m. to 6.00 p.m., with a decrease from 6.00 p.m. to 10.00 p.m. occurring.

Mood. Positive affect as measured by a Portuguese version of the Positive Affect Negative Affect Scale (PANAS) has been shown to correlate with morningness-eveningness scores on a Portuguese version of the morningness-eveningness questionnaire (MEQ) and a visual analogue scale (VAS) using the word 'attentive'. For morning types, positive affect occurred earlier in the day when measured by the PANAS and the VAS (Porto, Duarte, & Menna-Barreto, 2006).

Depressive symptomology as measured by the Montgomery-Asberg Depression Rating Scale (MADRS) has been shown to correlate with morningness-eveningness preference on a Brazilian Portuguese version of the MEQ. Even types exhibited greater severity of depressive symptomology (Hidalgo, et al., 2009).

Task Difficulty

The preceding studies indicate that performance across a range of cognitive domains is subject to both circadian rhythms generally, and morningness-eveningness preference. However, not all studies investigating these influences have come to these same conclusions.

It has been observed that task difficulty moderates the relationship between the time of day that testing is undertaken and performance on the test. On a test of simple reaction time, Ishee and Titlow (1986) found no circadian variation in performance between 9.00 a.m. 12.00 p.m., and 3.00 p.m. However, Carrier and Monk (2000) cite Folkard, Knauth, Monk and Rutenfranz (1976) as demonstrating variation in working memory performance whereby low working memory load was correlated with better performance at increased body temperature. When the cognitive load increased better performance occurred when body temperature was low. Examination of the morningness-eveningness aspects indicates these same patterns are evident.

McElroy and Mosteller (2006) observed that morning type students obtain higher grades when classes are undertaken in the morning, with the contrary being observed for evening types. Additionally, McElroy and Mosteller (2006) observed that these differences were only observed in classes with high difficulty. A further study by Bennett et al. (2008), investigated executive functioning using a variety of neuropsychological tests. A synchrony effect was detected between time of day and M-E on the most complex task, but not the simpler tasks. These findings support the findings of McElroy and Mosteller (2006) therefore leading credence to the observation that like circadian rhythm effects on tasks, observation of M-E effects are only apparent in tasks of greater complexity.

Conclusion

Circadian variation in tasks measuring a range of cognitive domains is evident. This variation may be linked to fluctuations in physiological processes including secretion of hormones, and changes in core body temperature. Several protocols have been developed to determine the true rhythmicity by removing the influence of masking factors, with each protocol offering advantages and disadvantages.

Morningness-Eveningness a.k.a Chronotype

Linked to circadian rhythms is the '*chronotype'* or morningness-eveningness (M-E) preference which is considered one of the more important of the individual differences associated with circadian rhythm expression (Adan & Natale, 2002; Chelminski, Ferraro, Petros, & Plaud, 1997; Natale, Ballardini, Schumann, Mencarelli, & Magelli, 2008; Tankova, Adan, & Buela-Casal, 1994). It refers to the preference an individual has for sleep timing (Mongrain, Carrier, & Dumont, 2006), subjective alertness evaluation, and observable differences in physiological processes (Natale, Alzani, & Cicogna, 2003) due to the circadian phase position of the sleep/wake cycle (Song & Stough, 2000).

Difference in Sleep Timing and Subjective Alertness

Research into M-E, indicates that morning types have a preference for rising earlier and sleeping earlier than their evening counterparts (Dunlap, et al., 2004) with a less variable sleep duration (Song & Stough, 2000). Morning types also report being more alert in the morning which is confirmed by the peak of the alertness curve occurring late in the morning. Conversely, evening types report being more alert in the latter part of the day, with their peak recorded in the late afternoon (Natale & Cicogna, 2002). Those identified as evening types report needing more sleep than both morning and neither types, but fail to obtain it during the work week. Therefore, to help compensate for this sleep debt accumulated during the work week, evening types sleep more than morning or evening types during the weekend (Roenneberg, Wirz-Justice, & Merrow, 2003; Taillard, Philip, & Bioulac, 1999) In comparison, morning types accumulate sleep debt during the weekend due to social pressures to remain awake in the evening and their propensity to wake early (Roenneberg, et al., 2003). Despite these differences associated with sleep debt accumulation, sleep quality of morning types has been shown to be superior to that of evening types in both shift, and non-shift workers (Chung, Chang, Yang, Kuo, & Hsu, 2009; Taillard, et al., 1999).

Whereas a morning type will be active early in the morning, both mentally and physically (Dunlap, et al., 2004), the evening type will most likely still be asleep if permitted to do so. The evening type will reach their peak activity levels later in the afternoon – a time when morning types may be beginning to feel the effects of the day and are becoming fatigued. As morning types are retiring for the day, the evening types will still be engaged in wakeful activities (McEnany & Lee, 2000).

The Genetic Basis of Morningness-Eveningness

Heritability. Research into heritability of M-E indicates it is a heritable trait, but its expression is by no means fixed; as evidenced by the observed changes during the lifetime. Heritability ranges from approximately 14% (Aguiar, da Silva & Marques, 1991 as cited in Klei, et al., 2005) to 54% of the total variability (Hur, Bouchard, & Lykken, 1998), with Klei et al. (2005) obtaining heritability estimates of 23% when the effects of age, gender and colony of residence were statistically controlled for in a population of Hutterites. Klei et al. (2005) attributes these differing estimates to variability arising from common sources among twins that have no genetic basis, with Aguiar et al. (1991) as cited in Klei et al. (2005) suggesting socio-cultural factors are important. A recent study by Hur (2007) obtained larger estimates (45%) than that of Klei et al. (2005). These (often large) discrepancies indicate that while M-E is a heritable trait, the extent to which it influences M-E preference is still debatable.

Gender. Studies investigating gender effects in morningness-eveningness reveal differences between males and females. Males tend to be more evening oriented than females (Adan & Natale, 2002; Chelminski, et al., 1997; Natale, Adan, & Chotai, 2002) with more males also being of the neither type compared to females (Adan & Natale, 2002).

Polymorphisms. While circadian rhythms have been linked to specific genes generally, so too has morningness-eveningness. Polymorphisms in several genes associated with circadian rhythms have been identified, which are thought to contribute to differences between the chronotypes.

Individuals possessing a 3111C allele in the Clock T3111 gene score lower on the MEQ which is associated with eveningness (Katzenberg, et al., 1998). In contrast, the Per3 gene is associated with morningness when a five tandem repeat allele is present, and eveningness with a four tandem repeat allele.

Changes During the Lifetime

As we age, we progress through phases of morningness-eveningness. Randler and Díaz-Morales (2007) observe that there are two shifts during a lifetime. During childhood, we are more prone to morningness (Roenneberg, et al., 2004). As we enter adolescence, we commence an eveningness phase which occurs around the age of 12 to 13 years (Ishihara, Honma, & Miyake, 1990; Kim, Dueker, Hasher, & Goldstein, 2002), and post adolescence we revert back to being more morningness oriented. This reversion back to morningness becomes particularly apparent during later years commencing around the age of 50 years (Tankova, et al., 1994), although Caci, Deschaux, Adan, and Natale (2009) found a shift towards morningness from age 25 which they attribute to a lack of participants in the middle age bracket. The results of Caci et al. (2009) supports the findings of Roenneberg et al. (2004) who suggest the shift back to morningness occurs around the age of 20. This finding was also made by Borisenkov (2010) who observed a gradual change back to morningness between the ages of 20 and 70 years. The timing of these phases appears to be associated with hormonal fluctuations that occur during these periods (Schmidt, S. & Randler, 2010).

Measurement of Morningness-Eveningness

As 'morningness-eveningness' fluctuates during the life-time, reliable and valid measures have been developed to categorise individuals. Of most note is the subjective questionnaire by Horne and Ostberg (1976), known as the 'Morningness-Eveningness Questionnaire' or MEQ.

The MEQ comprises 19 items which classifies individuals into five subtypes. The five subtypes specified by Horne and Ostberg (1976) are: definitely morning, moderately morning, neither, moderately evening, and definitely evening. Categorisation would indicate that there are distinct differences between each type and subtype, however it is recognised by Chelminski et al. (1997), and Natale and Cicogna (2002) that morningness-eveningness occurs more along a continuum, with those at the morning end of the spectrum referred to as "larks" and the evening spectrum as "owls" (Cavallera & Giudici, 2008).

One of the main criticisms of the MEQ is that it does not take into consideration activities carried out on both working and free days, and instead relies on subjective evaluation of *when* the individual believes they are at their best for particular activities. Despite these limitations, the MEQ has been validated by Horne and Ostberg (1976) against the known physiological marker of circadian rhythms - body temperature – and has shown good correlations. Duffy, Dijk, Hall, and Czeisler (1999) validated the MEQ against core body temperature and melatonin rhythms when assessment has been made under constant routine protocols. Kerkhof and Van Dongen (1996), and Taillard et al. (2003) have provided further validation against the sleep-wake cycle. One other criticism of the MEQ has been the population on which it was validated – university students. Natale and Cicogna (2002) argue that university students have a somewhat different timetable to working individuals and are relatively free to plan activities compared to someone who follows a strict working schedule. As a result, validation on a university population alone may not allow generalisations to be made regarding other populations being studied. This assessment was itself made by Horne and Ostberg (1976) who report that a bedtime of 23:30 may be more indicative of a morning type when assessing a student population, and an evening type in an older population of 40 to 60 year olds. This assumption would however presume that students were those aged less than 40 years. This limitation is evident in the study by Taillard, Philip, Chastang and Bioulac (2004) when middle-aged French workers were assessed.

Cut-off scores developed by Horne and Ostberg (1976) did not adequately identify evening types among 44 to 58 year old French workers. Modified cut-off scores developed by Taillard et al. (2004) attempted to rectify this issue. When validated against sleep characteristics of the sample i.e. time of retiring for sleep, time of waking, subjective need for sleep, and sleep duration; the new cut-off scores were better able to predict evening types in this age and occupational group.

Despite these limitations, the MEQ is the most widely used of the available measures of chronotype assessment (Caci, et al., 2009; Taillard, et al., 2004). The continued use may possibly be due to the large literature base available, the relative ease of administration, and the low cost when compared with utilising physiological measures.

The MEQ is used in the present study due to financial constraints and the fact that self report measures are less invasive than physiological measures.

Epidemiology

Distribution of M-E in the population is dependent upon which cut-off scores are used as highlighted previously. In addition, the distribution varies in relation to the population studied.

During development of the MEQ by Horne and Ostberg (1976), an original sample of 150 university students aged between 18 and 32 years was used. They were divided approximately evenly between males and females. Of the initial 150, 48 were randomly selected to undergo validation against body temperature. Results of the validation study indicated that of the 48, 18 (37.5%) were identified as moderate or definite morning types, 10 (20.8%) as neither or intermediate types, and 20 (41.6%) as moderate or definite evening types.

Chelminski et al. (1997) undertook a study to examine score distributions on the MEQ in a university student population. Of 1617 students studied with an age range of 18 to 53 years, 135 (8.3%) were identified as morning types, 473 (29.3%) were evening type and the remaining 1009 (62.4%) were neither or intermediate type.

Carrier, Monk, Buysse, & Kupfer (1997) investigated the effects of age on M-E preference. Unlike the studies of Horne and Ostberg (1976) and Chelminski et al. (1997) which studied students only, Carrier et al. (1997) used a sample of 110 adults made up of students, workers and ‘homemakers’.

When the original categories proposed by Horne and Ostberg (1976) were used, overall there was a tendency towards moderate morningness, with no definite evening types identified. When the categories were collapsed to only three (morning, neither and evening), 47 (42.7%) were identified as morning types, 24 (21.8%) as evening, and 39 (35.5%) neither type.

Further evidence in support of differences associated with cut-off scores based upon the population studied has been provided by Paine, Gander, and Travier (2006). In a large sample (N = 2526) of 30 to 49 year old adults in New Zealand, the original cut-off scores suggested by Horne and Ostberg (1976) resulted in 49.8% of the population exhibiting a preference for morningness, 44.6% as neither type, and only 5.6% as evening type. When the cut-off scores of Taillard et al. (2004) were used a better balanced distribution was seen. Twenty four point seven percent were classified as morning types, the neither type category remained approximately the same at 48.9%, with the evening category being 26.4%.

In the present study, the cut-off scores developed by Horne and Ostberg (1976) are used as the population the MEQ was validated on, and the population in the present study are similar.

Conclusion

Morningness-Eveningness is an important aspect of expression of circadian rhythms in humans, with an underlying relationship to genes responsible for expression of circadian rhythms generally. While there are links to it being a heritable trait, consensus among researchers is lacking as to what level of influence it exerts; which may be the result of heterogeneity amongst the populations studied. Measurement is able to be achieved directly via physiological responses, or subjectively by questionnaire, of which the most widely used is the Horne and Ostberg (1976) 'Morningness-Eveningness Questionnaire'.

Determination of M-E preference is imperative when tests of cognitive ability are undertaken at the individual level due to the influence exerted over a wide range of cognitive domains. This may be more important where the tests are cognitively demanding due to synchrony effects being evident on more complex tasks but not simpler tasks.

INFORMATION PROCESSING

The ability to process information is an important aspect of cognition.

Information processing is defined as the "acquisition, recording, organization, retrieval, display and dissemination of information ("Information processing", 2011). For humans, acquisition of information occurs via the senses which must then be interpreted and organised accordingly. For this to occur, information stored in memory may need to be retrieved so an appropriate action can be carried out.

As information processing encompasses a number of tasks, it makes sense that a variety of factors will have an impact.

The following section identifies a particular model associated with information processing, known factors which influence the ability to process information, and links to intelligence. Additionally, measurement of information processing will be discussed, with particular emphasis placed on several commonly used tools, and problems associated with measurement.

Speed v Accuracy

Information processing can be thought of being multi-factorial, and being broadly composed of two interacting factors. The first factor is that of speed, and the second of accuracy. It is this first factor that is the focus of the current work.

Speed of information processing is the time taken to process information (Surwillo, 1977) and is the maximum rate at which basic cognitive tasks can be performed (Kail & Salthouse, 1994) with Dickinson, Ramsey, and Gold (2007) offering a similar definition.

By decreasing accuracy on a task, an increase in speed is able to be attained and vice versa. This is referred to as the speed-accuracy trade-off (Wickelgren, 1977). Wickelgren (1977) notes that faster speeds of approximately 150 ms can be obtained when accuracy is reduced on simple perceptual tasks and up to 1,000 ms for recognition tasks. Therefore the degree to which the trade-off occurs appears to be task dependent.

Factors Affecting Information Processing Speed

Multiple factors have been linked to both increases and decreases in information processing speed (IPS) including illness such as multiple sclerosis (Demaree, DeLuca, Gaudino, & Diamond, 1999) or schizophrenia (Bachman, et al., 2010; Knowles, David, & Reichenberg, 2010), injury such as brain trauma (Johansson, Berglund, & Rönnbäck, 2009; Malojcic, Mubrin, Coric, Susnic, & Spilich, 2008), stimulants (including caffeine) and other drugs such as cigarettes (Starr, Deary, Fox, & Whalley, 2007), and age (Burgmans, et al., 2011).

Information processing speed generally increases until the 20s and then from the age of 25, there is a decline as evidenced by choice reaction time tasks of approximately 1.5 ms per year (Welford, 1977 as cited in Wickens, Braune, & Stokes, 1987).

The use of caffeine results in increased speed of information processing in both younger and older adults as demonstrated by Lorist, Snel, Mulder, and Kok (1995) when 250mg of caffeine is consumed within a 90 minute period. The duration of increased processing speed when measured by Critical Flicker Fusion (CFF) is approximately 20 minutes, with the effect occurring almost immediately upon ingestion (Hindmarch, Quinlan, Moore, & Parkin, 1998). Hindmarch et al. (1998) indicates the

CFF is a measure of central nervous system (CNS) activity. Therefore it can be implied that information processing would be influenced due to the effect on the CNS. Despite these findings of caffeine effects on IPS, there is no clear consensus as to what extent caffeine influences cognition.

In contrast, drugs such as cannabis (Kelleher, Stough, Sergejew, & Rolfe, 2004) have been shown to decrease speed of information processing of long term users in the stage prior to intoxication.

Links to Intelligence

Vernon (1983), demonstrates that more efficient processing leads to better performance on tests of intelligence, both in speeded subtests, and those which require knowledge for factual information. Performance in knowledge subtests is theorised to result from the ability of the individual to acquire *more* information over time as a result of increased information processing speed. Additionally, Kail (2000) indicates processing speed underlies other cognitive functions typically required for psychometric assessment of intelligence: working memory and reasoning. It is further suggested by Kail (2000) that where an individual has difficulties with tasks requiring working memory or reasoning, it may be that they have a deficit in the ability to process information quickly which manifests as problems in these other areas; and correction of the underlying IPS deficit should lead to improvements in these areas. It should be noted that this IPS deficit may not be regarded as a trait inherent in the individual, but rather something that is able to be altered by some form of intervention.

Measurement of Information Processing Speed

Just as there are many factors which can effect IPS, there are many methods to quantify it, including measures of reaction time, subtests of tests of intelligence such as the Multidimensional Aptitude Battery-II (MAB-II) (Sigma Assessment Systems, 1985/1999), the Digit Symbol Coding (DSC) test of the Wechsler Adult Intelligence Scale (WAIS), the Digit Symbol Substitution Test (DSST), Trail Making Test, the Paced Auditory Serial Addition Test (PASAT) (Chiaravalloti, Christodoulou, Demaree, & DeLuca, 2003), Symbol Search (Deary, Johnson, & Starr, 2010), and the Symbol Digit Modalities Test (SDMT) (Crowe, et al., 1999), with the tasks requiring various levels of cognitive resources and there being questions raised as to whether they all measure processing speed (Chiaravalloti, et al., 2003).

Problems with Measurement

Due to the number of tests available to measure processing speed, it makes sense that irrespective of whether processing speed is being measured, a variety of other cognitive abilities will also be measured. However, not all tests will measure these same other abilities and heterogeneity among results may ensue.

Simple reaction time. Reaction time is defined as the "interval between presentation of a stimulus and a person's response to the stimulus" (Goldstein, 2008, p. 6). In a simple reaction time task, only one stimulus is presented which must be responded to as quickly as possible to indicate that the stimulus was presented. It is typically measured by computer after the test taker presses a button or key on a keyboard (Goldstein, 2008). Components of simple reaction time (SRT) tasks are attention, and simple motor function (Chiaravalloti, et al., 2003). Simple reaction time has been described as being a ‘pure’ measure of information processing speed (Fong, Chan, Ng, & Ng, 2009, p. 166), and is considered to be a ‘simple’ measure of IPS (Chiaravalloti, et al., 2003, p. 490).

Digit Symbol Substitution Test. The DSST is a paper and pencil test, composed of tasks requiring not only attention and motor speed, but also perceptual speed, visual scanning, and memory (van Uffelen, Hopman-Rock, Chin A Paw, & van Mechelen, 2005). The test is composed of a key with nine symbols and a corresponding digit from one to nine. Rows of digits and blank spaces below the digits are presented to the test taker who must match the appropriate symbol with its corresponding digit as quickly as possible and indicate the matching on the paper. A time period of 90 seconds is allowed (van Uffelen, et al., 2005).

Digit Symbol of MAB-II and Digit Symbol Coding of WAIS. Song and Stough (2000) indicate the Digit Symbol subtest of the MAB and the Digit Symbol Coding of the WAIS-Revised (WAIS-R) are comparable, as the MAB version is a group administered version of the DSC of the WAIS-R. The Digit Symbol subtest of the MAB-II has been shown to test visual acuity, figural memory, motor skills, speed of information processing, motivation and persistence (Sigma Assessment Systems, 1985/1999). Both of these tests require the test taker to match symbols - which requires motor skills - to corresponding digits as is required for the DSST. For the Digit Symbol subtest of the MAB-II, the time limit is seven minutes (Sigma Assessment Systems, 2005-2011).

Paced Auditory Serial Addition Test. The PASAT is a test of information processing that was developed by Gronwall (1977) to measure speed of processing following concussion. In addition to testing information processing speed, it has also been reported as testing sustained attention, working memory, simultaneous performance of various other cognitive tasks (Madigan, DeLuca, Diamond, Tramontano, & Averill, 2000), concentration (Nagels, et al., 2005), and arithmetic ability (Chronicle & MacGregor, 1998). The PASAT has been reported to be an example of a "complex" (Chiaravalloti, et al., 2003, p.490-491) measure of information processing speed.

Possibly, an advantage over some other forms of testing is that the traditional PASAT does not require the use of motor functioning to undertake the test. All stimuli are presented aurally, and the test-taker makes their answer verbally. However, the fact that both stimulus presentation and response is given along an auditory pathway has lead Fos, Greve, South, Mathias, and Benefield (2000) to indicate this is a disadvantage which leads to increased difficulty of the task, particularly at faster presentation rates and for some populations.

Scoring does not specifically determine the time taken to complete the task, but rather the accuracy of scores given a fixed time interval for responses. Test takers commence testing with an inter-stimulus interval between presented digits of 2.4 s for the first trial block of 61 presented digits. Each subsequent trial block shortens by 0.4 s until an inter-stimulus interval of 1.2 s is reached, on the fourth trial block.

Since development of the PASAT, a visual form of the test has been developed known as the Paced Visual Serial Addition Test (PVSAT) (Diamond, DeLuca, Kim, & Kelley, 1997). Instead of the stimuli being delivered aurally, they are presented to the test-taker visually via computer presentation, with the test-taker giving their response verbally.

Like the PASAT, scoring is via the total number of correct answers in the fixed time interval.

The effect of practice and mathematical ability. Despite use of alternate forms, the PASAT is known to be subject to practice effects, with the greatest improvement in scores occurring between the first and second test sessions (Beglinger, et al., 2005). Additionally, Chronicle and McGregor (1998) indicate that PASAT scores are related to mathematical ability. Specifically, PASAT scores can be moderately predicted by mathematical education as indicated by a negative correlation between high mental arithmetic ability and PASAT scores. Likewise, self-rating of current arithmetic ability is also predictive of performance.

Scoring Sensitivity

As is evident from the descriptions of the tests commonly used, with the exception of reaction time tasks, sensitivity of the tests is questionable. Instead of directly measuring the *absolute* speed with which the tests can be carried out, it is the number of responses that can be made within the available time. This gives an imprecise measure of processing speed. For example, in the DSST, DSC of the WAIS, and Digit Symbol subtest of the MAB-II, processing speed would be ascertained by dividing the allowable time by the number of correct matches.

Tombaugh (2006) specifies that various scoring methods have been employed for the PASAT with the most common method being the determination of the number of correct answers within the allotted time. To determine the average response time, Gronwall (1977) suggested an alternate method of scoring. According to this method, the number of correct responses is divided by the total duration of the trial. The duration of the trial is determined by the number of inter-stimulus intervals i.e. 60, multiplied by the inter-stimulus interval. For example, for a trial block of 1.6 s, and a person scoring 30, their average response time would be 60 x 1.6 = 96/60 = 1.6 s. Tombaugh (2006) points out that this method is flawed. Instead of the average speed with which a response is made, Tombaugh (2006) specifies that the method only creates a ratio between session length and correct responses. This then leads to an improper interpretation of results. Tombaugh (2006) indicates care must to be taken to interpret the results as being the average for *correct responses* and not that for *all* responses.

Conclusion

The speed with which information can be processed is important for cognition. Multiple factors can have a detrimental or beneficial influence on the speed of information processing, including the sacrifice of accuracy to enhance speed. This can be demonstrated in the tests that are commonly used to measure IPS; which often are not good measures due to their lack of sensitivity.

The Present Study

Cognitive performance as measured by a range of tasks exhibits circadian rhythmicity with the morningness-eveningness aspect requiring consideration for many tasks. Underlying these cognitive abilities is information processing which can impact on an individuals' overall level of intelligence, with more efficient processing leading to higher scores on intelligence tests.

Two particular studies have addressed the effect of morningness-eveningness on information processing speed, with conflicting results.

The first of these studies was undertaken by Song and Stough (2000). They sought to determine whether there was a relationship between morningness-eveningness, time-of-day, speed of information processing, and intelligence. Results of the study indicated that there was no synchrony effect between morningness-eveningness preference and time-of-day for either morning or evening type, nor was there an effect of time-of-day. To ascertain information processing speed they used the digit symbol subtest of the Multidimensional Aptitude Battery.

The second study is that of Allen et al. (2008). The aim of this study was to determine whether time-of-day affected cognitive performance, including that of information processing speed as measured by the digit symbol coding subtest of the WAIS. In contrast to Song and Stough (2000), there was a significant effect of time-of-day, with increased speed being obtained in the afternoon and evening compared to the morning - irrespective of morningness-evening preference. Again, as in the Song and Stough (2000) study, no synchrony between morningness-eveningness preference and time-of-day was evident.

The current study is based upon the issues that appear to be inherent in these two prior studies:

1. As previously discussed the digit symbol subtest of the MAB, and the digit symbol coding test of the WAIS may not be sensitive tests of information processing speed due to their methods of scoring; and
2. Both the digit symbol subtest of the MAB and the digit symbol coding test of the WAIS require motor skills for completion of the test. As motor function shows circadian rhythmicity with peak performance in the afternoon/evening, this may be masking any difference associated with processing speed.

To overcome these issues the current study had the following aims:

1. To develop a test of information processing for both visual and auditory stimuli that was sensitive to changes that may occur over the day by ascertaining *absolute* speed with which the task can be performed;
2. To minimise the effects of motor functioning;
3. To determine whether there is a synchrony effect between morningness-eveningness preference and time-of-day; and
4. To determine whether a synchrony effect occurs in less complex and more complex tasks of information processing speed.

Hypotheses

Based on the fact that synchrony effects have been seen across a range of cognitive domains depending upon task complexity, the following predictions were made:

1. There will be a synchrony effect for both visual and auditory stimuli on the tasks to measure information processing speed; but
2. Only the more complex tasks will exhibit a synchrony effect, that is, no synchrony effect will be present in a simple reaction time task.

CHAPTER 2

THE COMPUTERISED AUDITORY AND VISUAL TEST OF INFORMATION PROCESSING (CAVTIP)

Overview

The Computerised Auditory and Visual Test of Information Processing (CAVTIP) was developed for the current research. It is a battery of three tasks which range in complexity and encompasses two modalities – visual and auditory. The least complex task is a simple reaction time task. The auditory component of the most complex task is based upon the Paced Auditory Serial Addition Test (PASAT) developed by Gronwall (1977) and Gronwall and Sampson (1974) to test information processing speeds in individuals suffering mild traumatic brain injury. Various versions have been developed e.g. PASAT-244 (Gronwall, 1977; Gronwall and Sampson 1974) and PASAT-200 (Levin, Benton & Grossman, 1982, as cited in Diehr, Heaton, Miller, & Grant, 1998). The visual component of the most complex task is based upon the Paced Visual Serial Addition Test (PVSAT) developed by Diamond et al. (1997) which is considered a visual analogue of the PASAT (Fos, et al., 2000).

Development

Simple Reaction Time (SRT)

Simple reaction time tasks are thought to be "pure" measures of information processing speed (Tombaugh, Rees, Stormer, Harrison, & Smith, 2007, p. 26) which place few cognitive demands on the individual. Low levels of vigilance, and simple motor responses are required (Chiaravalloti, et al., 2003). Such tests are commonly used to determine speed of information processing (Deary, et al., 2010) and task performance has been shown to exhibit circadian rhythmicity (Reinberg, et al., 1997; Shub, Ashkenazi, & Reinberg, 1997).

The visual stimuli comprised numbers ranging from one to 18. These were presented in white coloured, Times New Roman font, on a black background and when presented on the monitor were 35mm high.

Auditory stimuli were numbers ranging from one to 18, delivered by a male voice with an American accent.

Two versions of the task were developed - one version for the visual modality and the other for the auditory modality. Timing of stimuli presentation was random with a range of 1000 to 3000 ms, with each stimulus presented for 550 ms for the visual modality. Auditory stimuli were presented for the length of time taken to articulate the numbers, which on average was approximately 560 ms.

Each version of the task comprised a trial block of 20 trials, with each number from one to 18 being presented at least once.

Input Reaction Time (IRT)

Motor functioning exhibits circadian rhythmicity with peak performance generally occurring between the hours of 4.00 p.m. and 8.00 p.m. (Gueugneau, et al., 2009). A tempo which is specific to an individual is known as the Motor Spontaneous Tempo (MST). MST arises internally and exhibits a maximum and minimum at approximately 6.00 p.m. and 6.00 a.m. respectively when measured by a finger tapping task; that is more taps are completed at 6.00 p.m. than 6.00 a.m. (Moussay, et al., 2002).

The IRT task was designed to measure motor function so as to act as a control for the speed with which individual responses could be made.

Five versions of the task were developed – two versions for each of the visual and auditory modalities and a practice version which was identical in both visual and auditory modality. Excluding the practice version, two versions were created then reverse ordered to give two versions for each of the modalities. There were six options for inter-stimulus intervals. These were: 1.2 s, 1.6 s, 2.0 s, 2.4 s, user defined, or incremental increase and decrease depending upon whether the previous answer was correct. The visual stimuli were presented for 550 ms. Auditory stimuli were presented for the length of the stimuli which was on average approximately 560 ms. These presentation times were encompassed by the chosen interstimulus interval.

The practice version consisted of a block of 10 trials, and each of the other versions contained 20 trials in each block. The practice version contained five single digit numbers i.e. one to nine, and five double digit numbers i.e. 10 to 18. Each of the other four versions contained 10 single digit numbers, and 10 double digit numbers.

Complex Reaction Time (CRT)

For the purposes of the current research, 'PASAT' will refer to all versions of the task, excluding the PVSAT, with mention of the specific versions where they differ from each other.

The PASAT-244 consists of a series of 61 numbers ranging from one to nine, presented at fixed intervals of 2.4 s, 2.0 s, 1.6 s, and 1.2 s (Diehr, et al., 1998) Completion of the test requires the addition of two consecutive numbers to obtain a sum of those numbers (Tombaugh, 2006).

> "For example, if the digits '3', '6' and '2' were presented, the participant would respond with the correct sums, which are '9' and then '8'." (Tombaugh, 2006, p. 54)

The PASAT-200 is a shorter version of the PASAT-244, with only 50 numbers being delivered, although the procedure is the same (Diehr, et al., 1998).

Although the PASAT is a commonly used measure of information processing speed (Chiaravalloti, et al., 2003), it is not without its critics. In particular the PASAT-244 is prone to practice effects due to the same sequence of numbers being used at each time interval (Brittain, La Marche, Reeder, Roth, & Boll, 1991). Furthermore the PASAT-200 uses different number sequences in an attempt to overcome practice effects, but no psychometric data is available to determine whether each version is equivalent (Diehr, et al., 1998). It has also been determined that the PASAT is sensitive to mathematical ability (Tombaugh, 2006). This is evidenced by the fact that faster reaction times on a mathematical verification task, and higher mathematical grades obtained in the education setting, correlate positively with increased scores on the PASAT (Chronicle & MacGregor, 1998). Another criticism relates to fact that the PASAT is delivered aurally, with responses made verbally (Gronwall & Sampson, 1974). This leads to increased difficulty due to increased interference from the competing tasks particularly when the rate of presentation is increased (Fos, et al., 2000). Finally, inter-stimulus intervals for the various versions of PASAT are not clearly defined. Diehr et al. (1998) report that early descriptions of the PASAT do not clearly specify whether the presentation rates are inter-stimulus intervals, or whether the stimuli themselves were included. This has lead to variation between the different versions. The CRT task of the CAVTIP was developed for the current research in an attempt to address these criticisms. A description of the development of the CRT deals with these problems and is set out below.

Practice Effects

To help overcome the effect of practice due to repeated administration of the same number sequences as occurs in the PASAT-244, the CRT, like the PASAT-200, used different sequences at each administration. Two number sequences were developed then reverse ordered, resulting in four number sequences in total. The number sequences used had very similar numbers of single and double digit sums, 28 and 32 respectively. Additionally, the frequency of each sum e.g. three, eight etc. appeared approximately the same number of times. A practice version of the test comprising 10 sums (11 numbers are presented) was also developed. This was designed to allow participants to gain familiarity with the task prior to undertaking the main trials.

Test Equivalency

As information for the PASAT-200 as to equivalency of test forms is unavailable this will be addressed in the main analysis for the current study. Correlation will be determined among test forms for the CAVTIP.

Mathematical Ability

A number of researchers (Royan, Tombaugh, Rees, & Francis, 2004; Tombaugh, Rees, Baird, & Kost, 2004) have determined that number lists where the sum is between two and 10 - rather than two and 18 – reduces the effect of mathematical ability. The CRT of the CAVTIP does not implement the recommended reduction in the sum of numbers because, within the repeated measures design used in the study, each person acts as their own control. Additionally, a reduction in available sums would make it difficult to attain number lists whereby approximately equal numbers of single and double digit numbers appear and each sum appeared an approximately equal number of times.

Mode of Presentation and Recording of Responses

Auditory and visual modes of presentation were developed for the current research to allow both auditory and visual processing speeds to be investigated.

To address interference associated with the aurally presented stimuli, participants' answers were recorded by direct input to a computer for both auditory and visual stimuli. Reaction times for entering both the first and second digit (where the sum was a double digit number) were recorded by the computer.

Inter-stimulus Interval/Presentation Rate

Presentation rates for the CRT of the CAVTIP were based upon those used in the PASAT, that is, 2.4 s, 2.0 s, 1.6 s, and 1.2 s. Additional functionality was included in the CAVTIP to allow presentation rate to be selected by the researcher, and for the rate to increase or decrease depending upon whether the previous answer was correct. The inter-stimulus interval was defined as the presentation rate minus the on-time of the stimulus. For the visual tasks, the stimuli were presented for 550 ms. The auditory stimuli were presented for approximately 560 ms on average.

Pilot Study

The CAVTIP program was piloted prior to its use in the main study. The aims of the pilot were to refine the presentation format, and to determine appropriate procedures for its use, and finally implement those suggestions under test conditions.

Method

Participants. Five volunteers (2 male and 3 females) agreed to participate. Initially two participants (1 male and 1 female) undertook testing and gave general feedback as to the format and general procedures for the use of the program. Subsequently the remaining three participants (1 male and 2 female) undertook testing of the program modified in response to the initial suggestions, and according to the proposed procedures that would be used in the main study.

Materials and apparatus. The first two participants used only the CAVTIP program by means of a standard computer keyboard and computer speakers. The remaining three participants used both the CAVTIP program and the Morningness-Eveningness Questionnaire (MEQ) developed by Horne and Ostberg (1976). The standard computer keyboard was replaced with a Genius 20 key USB Numpad, and the speakers were replaced with Transonic Hi Fi Stereo Headphones, model number TC993DH. The USB Numpad and headphones were not available for the initial two participants due to their geographic location.

Procedure. The initial two participants were supplied with a copy of the CAVTIP program and asked to undertake the tasks. They were not in the presence of the researcher due to geographic location of researcher and participants. The participants were free to choose presentation rate, and other than a directive to not look at the keys on the keyboard, participants were free to undertake the tasks as they saw fit so as to provide general feedback. The subsequent three participants undertook the tasks in the presence of the researcher. The tasks were completed using the notebook computer, headphones, and USB Numpad, and in the envisaged order of what would take place in the main study.

Outcome of Pilot Testing

Feedback obtained from the initial two participants highlighted several issues.

When auditory stimuli were presented the screen was black. One participant indicated that this was disturbing in combination with the voice presenting the stimuli. It therefore was decided to include a fixation point (X) on the screen that could be looked at rather than the black screen. The initial fixation point was deemed too large and "intimidating", therefore the fixation point was reduced to 50% of the original size. Further feedback indicated that despite the initial suggestion to include a fixation point, continued use of the CAVTIP program resulted in the participants not looking at the screen when the auditory stimuli were delivered. The fixation point was therefore removed due to it being redundant, and in light of the fact that during the main study participants would not be required to look at the screen during this phase of the study.

Of the initial two participants, one participant found the auditory stimuli to be clear and understandable, whereas the other participant did not. For example, when the number "16" was presented, it was reported to sound like "15". To overcome this issue, the male voice was replaced with a female voice (still retaining the American accent). Following this alteration, additional feedback indicated that the female voice was clearer and easier to understand than the male voice. The stimuli were downloaded as a file from the internet and sound clips were made of the required individual numbers using the software program Audacity version 1.3 Beta.

Another issue that arose was the inputting of the answers. Due to unfamiliarity with the numeric keypad on the keyboard, and when using the preset presentation rates, the participants found it difficult to enter their answers in the available time. It was decided that participants would be permitted to look at the keypad when entering responses to reduce incorrect answers resulting from inadvertently wrongly entered answers. Despite allowing the participants to look at the keypad for inputting their answers, even at the longest preset presentation rate of 2.4 s the rate was considered too fast to consistently provide an answer in the time available. A presentation rate of 3.0 s was therefore selected using the additional functionality in the program. Although several issues were highlighted, the participants advised that the written instructions regarding how to undertake the tasks were clear and understandable.

The aim of the second part of the pilot using the three subsequent participants was to determine the approximate time to complete one testing session, and to verify in a sample unfamiliar with the CAVTIP program that the alterations made were appropriate. The feedback received indicated that the 3.0 s presentation rate was adequate to comfortably enter the correct responses, and one of the participants advised that a time greater than 3.0 s may make remembering the first number presented in the pair of the complex reaction time task difficult. Observations made by the researcher during the completion of the visual task indicated that participants looked at the Numpad when entering their responses. For the auditory stimuli participants did not look at the screen but focused on the Numpad throughout the tasks. The two female participants indicated that they used the number keypad on their standard keyboard on a daily basis, and although they were familiar with the layout, still found themselves looking at the Numpad when entering a response. They attributed this to making sure they were being accurate with their answers while still maintaining speed. Like that of the first two participants, the subsequent three participants indicated that there was no difficulty understanding the task instructions.

Implications for Main Study

Based on the feedback and observations made in the pilot study, it was determined that the written instructions to participants were adequate for understanding the tasks and no alterations would be required. As the presentation rate of 2.4 s was deemed too fast to comfortably enter a response, and more than 3.0 s may be too long, it was decided that the presentation rate would be 3.0 s in the main study. As accuracy was maintained when participants were able to look at the keys when entering their responses (while maintaining speed) it was decided that restrictions would not be placed on where the participant was required to look when entering their response. To do so would make compliance difficult to control. Although the sample size for the pilot study was small, agreement particularly among the latter three participants suggested that the feedback was relatively reliable and the procedures could be implemented in the main study.

Despite the instructions to participants being deemed adequate, it was envisaged some participants in the main study would not read the instructions properly and would not carry out the tasks as required. If this occurred, the instructions would be clarified verbally to the participant. It was also anticipated that 3.0 s would not be an adequate time for *some* answers to be entered, but based on the comments received that 3.0 s was adequate for participants in the pilot, and that more than 3.0 s may be too long, only correct responses would be included in the analyses to ensure both speed and accuracy.

CHAPTER 3

METHODOLOGY

Experimental Approach to the Problem

The study was designed to measure M-E influences on the performance of tasks of information processing speed using tasks that differed in complexity. The study used a quasi-experimental within-between subjects design. Participants were required to undertake testing at two times of the day, a morning (9.00 a.m.) and an evening (5.00 p.m.) session.

The research was approved by the Massey University Human Ethics Committee (MUHEC – Northern approval number 10/005).

Participant Characteristics

To be eligible for the study, participants were required to meet the following criteria: (a) 18 – 25 years of age; (b) English as the first language; (c) no diagnosed history of traumatic brain injury – including concussion; (d) no diagnosed history of psychological illness; (e) a willingness not to consume alcohol or drugs in the 24-hours prior to participation in a session (caffeine was not restricted); and (f) current or prior university education.

English as the first language was operationally defined as English as the first language, as well as if participants had resided in New Zealand since young and used English on a daily basis both inside and outside their home environments.

Sampling Procedure

Participants were recruited from a large tertiary institution in New Zealand. Recruitment of participants was by four methods: (a) in-class addresses made to students at the beginning or end of lectures at the campus where the research was being conducted, with recruitment notices left to be taken by students; (b) placement of recruitment notices on notice-boards and in bathrooms at the campus where the research was being conducted; (c) snowball sampling; and (d) mass email to psychology graduates students via a university mailing list. A total of 56 potential participants initiated contact with the researcher to indicate a willingness to participate in the research, and were provided with an information sheet outlining the study requirements. Potential participants were required to confirm they met the study criteria prior to scheduling experimental sessions. Of the 56 participants who made contact, 36 agreed to participate in the research and met eligibility criteria (a 64% conversion rate). Indications from participants at the time of testing show that the majority were recruited via in-class addresses ($n = 26$), followed by placement of notices ($n = 6$), and snowball sampling ($n = 4$). Of the 36 participants who agreed to participate, only the results of 35 were included in the analyses due to one participant not completing both the required experimental sessions. Participants who completed both required experimental sessions received a $20.00 grocery or petrol voucher as compensation for their time and/or travel. The recruitment notice and information provided to participants is included in Appendices A-1 and A-2.

Apparatus and Measures

All data were collected on an ASUS notebook with Intel Core Duo T2390 processor and three gigabytes of memory. The operating system was Windows Vista

Home Premium. Antivirus was disabled. The notebook was connected to a Viewsonic E653 monitor with screen resolution set to 1024 x 768 (32 bit). The monitor was raised 80 millimetres from the desk surface.

Data input was via a Genius 20 key USB Numpad which was tilted to an angle of approximately 20 degrees towards the participant and placed by the participant in a comfortable position on the desk in front of them. A halogen desk lamp with GE JC64 lamp (12V, 20w) was used to light the Numpad and was placed 15 centimetres to the right of it with the shade pointed straight down at a height of 18 centimetres from the desk surface. Other than this lighting, the room was in darkness during the testing. This was to avoid the use of the main lights which were fluorescent and had the potential to cause headaches and visual discomfort (Stone, 1992).

Auditory stimuli were presented via Transonic hi-fi stereo headphones (model # TC993DH) at a volume of 30 as set through the notebook's operating system.

Ambient temperature of the room was set to 25 degrees Celsius on a Panasonic heat-pump (Model # R410A). It became apparent during the testing of the final three participants that the reliability of the temperature for all prior participants may have been in doubt.

Morningness-Eveningness. Morningness-Eveningness (M-E) preference (chronotype) was assessed using the Morningness-Eveningness Questionnaire (MEQ) (Horne & Ostberg, 1976). The questionnaire consists of 19 items assessing a person's perceived best time for undertaking physical and mental activity. The questionnaire was developed (*N* = 150) and validated (*n* = 48) on a sample of students undertaking tertiary level education ranging in age from 18 to 32 years (Horne & Ostberg, 1976). The MEQ is the most widely used subjective measure of chronotype (Jones, et al., 2007;

Porto, et al., 2006) and has been validated against body temperature (Horne & Ostberg, 1976; Neubauer, 1992) and melatonin (Griefahn, 2002) which are known circadian markers (Benloucif, et al., 2005; Lewy, Cutler, & Sack, 1999). Research by Neubauer (1992) using a German version of the MEQ with undergraduate students aged 18 to 47 years (N = 93), indicates the MEQ to exhibit high internal consistency (Cronbach's alpha = 0.86) and high 2-month test-retest reliability (r = 0.89).

Scoring of the MEQ can be by several methods as proposed by several authors including Horne and Ostberg (1976), Natale and Cicogna (2002), and Taillard et al. (2004). The present study used the cut-off scores determined by Horne and Ostberg (1976) due to the similarities in the populations between the development and validation of the MEQ, and the present study. A higher score indicates a propensity towards morningness, whereas a lower score indicates eveningness.

Information processing speed. Assessment of information processing speed was via the Computerised Auditory and Visual Test of Information Processing (CAVTIP). The CAVTIP is a computer program developed for the present research which measures response times in milliseconds for both visual and auditory stimuli. As response times are measured in milliseconds, the program is sensitive to small changes which may occur as a result of circadian factors. Although sensitive to small changes, accuracy of timing is not able to be completely determined. Accuracy is based upon the hardware and other applications currently in use by the computer. To help reduce variations due to hardware and software, computer apparatuses used were plugged into the same input/output ports for all sessions and antivirus and wireless internet connection were stopped.

The CAVTIP program comprised three tasks differing in complexity: simple reaction time (SRT), input reaction time (IRT), and complex reaction time (CRT). Two alternate trial blocks were available for the SRT task; for simplicity they will be referred to as ‘SRT 1’, and ‘SRT 2’. The IRT and CRT tasks were made up of one practice trial block and four alternate trial blocks each. These will be referred to as ‘IRT practice’, ‘IRT 1’, ‘IRT 2’, ‘IRT 3, ‘IRT 4’, ‘CRT practice’, ‘CRT 1’, ‘CRT2’, ‘CRT 3’, and ‘CRT 4’. A discussion of the development of the program appears in the previous chapter.

Demographic and health questionnaire. Demographic and health information was obtained on age, years at university (if participants were in their first year this was counted as one), gender, history of traumatic brain injury (including concussion), history of psychological problems, smoking behaviour generally and just prior to testing, consumption of food/drink prior to testing, and caffeine consumption prior to testing. Two forms of the questionnaire were used during the study (Appendices B-1 and B-2). The initial questionnaire did not contain items specifically relating to caffeine consumption (Question 8a and 8b updated questionnaire). Instead, participants were *verbally* advised to list foods/beverages consumed during the day (7(a)), and question 7(b) was used to record when they had last consumed *caffeine*. The updated questionnaire was implemented for ease of administration and to ensure clarity to participants. Version one was used by 19 participants, and version two by 17 participants.

Procedure

Testing was undertaken over two sessions. One session was scheduled for 9.00 a.m., and the other at 5.00 p.m. All participants commenced testing within 20 minutes of the scheduled start time, and each session lasted approximately 30 minutes. The two sessions were not required to be completed on the same day, and participants were free to choose which session time they attended first, with the aim of having equal numbers of participants tested first in the morning and first in the evening.

At each session participants were asked to sit in the seat in front of the monitor. Prior to the start of testing at each session, participants were asked whether they had consumed alcohol or drugs in the 24 hours prior to the session. No participant indicated they had done so, so no rescheduling was necessary. At the first session, a paper copy of the information sheet was given to the participant that was in addition to the electronic version already received to ensure participants had the opportunity to read and understand the requirements of the study and were able to ask questions. Upon acceptance of the contents of the information sheet participants signed a consent form (Appendix B-3). In addition to obtaining the participant's consent for the study, the consent form allowed the participant to indicate whether they wished to receive a summary of the study, and of their own results. After completion, the desk lamp was switched on and the main lights were switched off.

The participant then completed the MEQ to determine M-E preference. Completion of the MEQ took approximately five minutes. During this time the Numpad and headphones were cleaned in view of the participant with alcohol wipes. It was envisaged this may allay any hygiene fears. Following completion of the questionnaire, participants were placed face on to the monitor with their eyes at a distance of 55 centimetres from the screen – this distance allowed comfortable viewing and resulted in a visual angle of approximately 3.6°. At this time the participant was instructed the Numpad was to be used for their responses and to place it in a comfortable position. The desk lamp was placed at a distance of 15 centimetres to the right of the Numpad with the shade facing down at a height of 18 centimetres from the desk surface.

Participants were instructed that both visual and auditory stimuli were to be presented, with the visual stimuli being presented first – this order of modalities was the same for all participants and for both sessions. During both sessions, tasks were presented in the following order: simple reaction time (SRT), input reaction time (IRT), and complex reaction time (CRT). The instructions for these tasks appear in Appendices C-1 to C10.

During the first session, testing with the CAVTIP program commenced in the visual modality with SRT 1, followed by IRT practice, IRT 1, then CRT practice which was carried out three times to allow familiarity to be gained, and CRT 1. Testing in the visual modality lasted approximately 10 minutes. After completion of the visual tasks, an approximate five minute break was given in which time the participants completed the Demographic and Health Questionnaire. Once the Demographic and Health Questionnaire was completed, the auditory stimuli were presented to the participants via the headphones in the following order: SRT 2, IRT practice, IRT 2, CRT practice, and CRT 2. At the conclusion of testing, the participants were asked which type of compensation (either a petrol or grocery voucher) they would like to receive at the end of their second session. A note was made of this.

At the second session, in lieu of the completion of the consent form and questionnaire which had been completed at the first session, the desk lamp was switched on and the main lights switched off. As the completion of the MEQ had taken approximately five minutes during the first session, the participants sat in the darkened room for approximately five minutes to allow their eyes to adjust to the light level. During this time the Numpad and headphones were cleaned, and the participants and researcher made conversation. The participants were advised that the sequence of tasks would be the same as the first session, with alternate versions of the tests being used (although the practice trials were the same). The participants were again placed facing the monitor at a distance of 55 centimetres, and the Numpad and desk lamp positioned as in session one. The sequence of tasks (and number of practice trial blocks) on the CAVTIP were the same as the first session and commenced with the visual modality, but comprised SRT 1, IRT practice, IRT 3, and CRT 3. Following the visual modality, the Demographic and Health Questionnaire was completed for a second time to ascertain consumption of cigarettes, food and drink prior to the second session. Upon completion, the auditory stimuli were presented via the headphones, comprising SRT 2, IRT practice, IRT 4, CRT practice, and CRT 4. At the conclusion of the second session of testing, participants were presented with their choice of voucher, and were asked to sign a receipt acknowledging they had received the compensation.

During both sessions the researcher was seated approximately two metres behind and to the left of the participant at an angle of approximately 45 degrees in order to make the participants feel more at ease and to monitor compliance with instructions while the CAVTIP program was in use.

CHAPTER 4
RESULTS

Approach to Data Analysis

When both within and between subject factors are to be analysed by parametric methods, mixed-design analysis of variance (ANOVA) is an appropriate statistical tool. For the current research a mixed-design ANOVA was employed. Like other forms of ANOVA, assumptions must be met to ensure the statistical test is appropriate for analysing the data. Mixed-design ANOVAs rely on assumptions related to both between and within subjects (repeated measures) ANOVA. The extent to which these assumptions were met will be discussed.

All data were analysed using PASW 17.0.

Data Handling

Paper-Based Data

Morningness-Eveningness Preference/Chronotype. Participant chronotype was assessed using the Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976). Possible scores range between 16 and 86 with lower scores indicating a preference for eveningness, and higher scores for morningness. Cut-off scores developed by Horne and Ostberg (1976) were used to categorise participants into one of the five categories proposed by Horne and Ostberg (1976). These five categories were collapsed to form three categories corresponding to 'Morning', 'Neither', and 'Evening' chronotype.

Demographic and health. Demographic and health questionnaires were completed at both experimental sessions and the data entered into PASW. Included were data that potentially altered between sessions e.g. consumption of caffeine and smoking behaviour.

Electronic Data

Scores on CAVTIP. The CAVTIP software recorded participant reaction time (ms) for each task undertaken. Data from .txt files was imported into Microsoft Office Excel 2007 and accuracy of participant scores was assessed manually. Where the participant gave an incorrect answer or failed to provide an answer, the reaction time associated with that trial was deleted. The reaction times for the remaining correct trials were transferred into PASW.

Preliminary Data Analysis

Data Screening

Accuracy of input. All data entered into PASW was checked against the paper-based and/or electronic sources from which it had been transferred.

Missing data. Missing value analyses were conducted to determine the existence of missing data. Missing data accounted for 2.8% of the total cases. This was attributed to attrition of one participant who did not complete both required experimental sessions. No other missing data were detected. While it may be problematic to remove cases due to missing data (Tabachnick & Fidell, 2007), O'Connell and McCoach (2004) specify that repeated measures require balanced data across time points. Myrtveit, Stensrud, and Olsson (2001), report that the simplest method of handling missing data is to ignore the data via listwise deletion which is the default in most statistical programs, including PASW. Additionally, it may be an adequate method of dealing with missing data when the amount of missing data is small, although if a large proportion of data is missing, it can significantly reduce the availability of data for analysis (Myrtveit, et al., 2001). Therefore, to balance the data between participants, and given the small number of cases affected, the participant with missing data was excluded from all further analyses. This resulted in analyses being carried out on 35 participants.

Outlier and normality assessment. The presence of extreme outliers in a data set can have a profound effect on the normality distribution by causing significant skew (Tabachnick & Fidell, 2007) which in turn may increase type I (Crawford, Garthwaite, Azzalini, Howell, & Laws, 2006; Tabachnick & Fidell, 2007; Trachtman, Giambalvo, & Dippner, 1978) and type II error (Tabachnick & Fidell, 2007; Trachtman, et al., 1978).

According to Tabachnick and Fidell (2007) where group analyses such as ANOVA are to be conducted, outlier detection should be undertaken at the group level.

Data were divided into three groups according to the **Chronotype** variable which corresponded to the collapsed chronotype categories. Normality was assessed using Z-scores. Tabachnick and Fidell (2007) advise using a significance level of p =.001 corresponding to a Z-score of ±3.29. Values greater than this indicate non-normal data. As ANOVA analyses are considered extremely robust to departures of normality (Schmider, Ziegler, Danay, Beyer, & Buhner, 2010), variables with Z-scores less than ±3.29 were considered to meet the normality assumption.

Tabachnick and Fidell (2007) recommend that where non-normal data are detected or outliers are present, transformation of data is preferable to other methods of increasing normality. However, they do advise that transformation can make interpretation of data more difficult and therefore transformation may not always be a suitable option. As scores on the CAVTIP tasks were recorded using a meaningful scale, that is, reaction times measured in milliseconds, transformation does not appear to be an appropriate method of increasing normality for non-normal data. Instead, removal of outliers may be a more appropriate method, particularly where only a small number of outliers are detected, thereby not substantially reducing the sample size.

Normality of the morning, neither, and evening groups was assessed for skewness and kurtosis using Z-scores at the $p = .001$ level. Normality was found to be within the acceptable range for all items. One outlier in the ‘morning’ group, and two outliers in the ‘neither’ group were detected. They were not removed from the analyses on the basis that normality was within acceptable limits, and removal would decrease the power of the analyses – particularly in the ‘morning’ group.

Main Data Analysis

The main analysis is predominantly focussed on the computed variables where the effects of motor functioning have been attempted to be controlled. These variables are designed to determine whether the effects of morningness-eveningness (chronotype) influence the cognitive aspect of information processing speed while reducing the influence of motor functioning on performance. The results for these variables are presented first. The influence of morningness-eveningness on the simple reaction time tasks will also be examined. Where appropriate, statistical control of factors identified in the preliminary analysis as having an influence on CAVTIP tasks will be undertaken. Unless otherwise advised the following analyses were conducted at the $p = .05$ level (two-tailed).

Both visual and auditory variables to ascertain information processing speed were computed using variables recorded via the CAVTIP program. Difference scores between the most complex task (Complex Reaction Time (CRT)) and the task designed to record motor function (Input Reaction Time (IRT)) were computed to arrive at a measure of information processing speed with a minimisation of motor function effect –

that is, an attempt at experimental control of motor functioning was carried out and analysed. This is referred to as Final Reaction Time (FRT). Simple reaction time (SRT) was recorded directly by the CAVTIP program as an alternative measure of information processing speed.

For the CRT and IRT tasks, the required response was either a single digit or double digit number between 2 and 18. If the required response was a single digit number, the CAVTIP program recorded the time taken to enter the single digit. Where the required response was a double digit number, the CAVTIP program recorded each digit entered separately so that a time was recorded for each. Reported results refer to ‘Digit 1’ or ‘first digit’ as being the first digit entered, that is, it is the only digit required to be entered for a single digit response, or the first digit entered where a double digit response is required. ‘Digit 2’ or ‘second digit’ refers to the time taken to enter the required response for the second digit of a double digit response.

Participant Characteristics

Major participant characteristics of the 35 participants appear in Table 4.1.

Distribution of Morningness-Eveningness

The distribution of morningness-eveningness in the sample appears in Table 4.2, according to the original five categories proposed by Horne and Ostberg (1976).

Table 4.1

Major Participant Characteristics

	n (% of total sample)	*M*	*SD*	*Minimum*	*Maximum*	*Median*
Age	-	20.11	2.10	18	25	19
Gender						
Male	6 (17.1)	-	-	-	-	-
Female	29 (82.9)	-	-	-	-	-
Years of university study[a]	-	2.14	1.44	1	7	2
Days between test sessions	-	4.91	12.63	0	71	1
Consumed caffeine a.m.	-					
Yes	9 (25.7)	-	-	-	-	-
No	26 (74.3)	-	-	-	-	-
Consumed caffeine p.m.						
Yes	15 (42.9)	-	-	-	-	-
No	20 (57.1)	-	-	-	-	-
Smoked a.m.						
Yes	1 (2.9)	-	-	-	-	-
No	34 (97.1)	-	-	-	-	-
Smoked p.m.						
Yes	1 (2.9)	-	-	-	-	-
No	34 (97.1)	-	-	-	-	-

[a] Where participant in first year of study this is taken to be “1”

Table 4.2

Distribution of Morningness-Eveningness

	Morning		Neither	Evening	
	Definitely	Moderately		Moderately	Definitely
n	0	5	23	7	0
% of total sample	0.0	14.3	65.7	20	0.0

Information Processing Speed for Final Reaction Time (FRT) Scores – Visual and Auditory

A 3 (Chronotype) x 2 (Time) mixed-design analysis of variance (ANOVA) was conducted to determine whether morningness-eveningness (chronotype) influenced information processing speed for visual and auditory stimuli.

A univariate approach was undertaken using the GLM procedure in PASW. As there were only two levels for the within-subjects factor, that is, participants were tested at only two session times, there can be no violation of the sphericity assumption as tested by Mauchley's Test of Sphericity. Levene's Test of Homogeneity of Variance were carried out to determine whether the error variance of each repeated measures dependent variable was the same across levels of the between-subjects factor (chronotype).

FRT (visual and auditory). The means and standard deviations for the FRT task in each of the modalities for the 9.00 a.m. and 5.00 p.m. test sessions appear in Table 4.3 below.

Table 4.3

Means and Standard Deviations for Final Reaction Time (Visual and Auditory Modalities) by Chronotype During the 9.00 a.m. and 5.00 p.m. Test Sessions

Visual – Digit 1

	AM session				PM session		
Chronotype	*n*	*M*	*SD*		*n*	*M*	SD
Morning	5	600.68	124.36	Morning	5	745.29	106.66
Neither	23	635.42	194.56	Neither	23	591.11	168.33
Evening	7	650.43	197.52	Evening	7	623.75	237.76

Visual - Digit 2

	AM session				PM session		
Chronotype	*n*	*M*	*SD*		*n*	*M*	SD
Morning	5	752.88	150.47	Morning	5	967.38	116.24
Neither	23	774.03	270.88	Neither	23	758.48	196.80
Evening	7	809.27	203.95	Evening	7	755.51	254.78

Auditory – Digit 1

	AM session				PM session		
Chronotype	*n*	*M*	*SD*		*n*	*M*	SD
Morning	5	778.15	236.77	Morning	5	859.55	142.06
Neither	23	668.09	193.80	Neither	23	696.24	195.48
Evening	7	671.91	197.33	Evening	7	568.14	124.20

Auditory - Digit 2

	AM Session				PM Session		
Chronotype	*n*	*M*	*SD*		*n*	*M*	SD
Morning	5	937.36	217.38	Morning	5	1030.20	41.43
Neither	23	790.89	204.94	Neither	23	853.58	230.35
Evening	7	803.59	219.89	Evening	7	634.46	179.55

For the first digit of the visual stimuli, results of the analysis indicate that there was no significant difference in reaction time scores between the 9.00 a.m. and 5.00 p.m. test times [$F(1,32) = 0.819$, $p = .372$, $\eta_p^2 = .025$]. There was also no significant difference in reaction time scores between the morning, neither, and evening chronotypes [$F(2,32) = 0.268$, $p = .766$, $\eta_p^2 = .016$]. A significant Chronotype x Time interaction was present [$F(2,32) = 4.320$, $p = .022$, $\eta_p^2 = .213$]. This is illustrated in Figure 4.1. Morning types exhibited lower scores (faster times) in the morning compared to the neither and evening types who showed faster times in the evening. Whereas both neither and evening types became slightly faster between the morning and evening test session, the morning types got considerably slower. During both the morning and evening test times, the neither types exhibited slightly faster times than the evening types.

Post hoc comparisons using the Bonferroni Correction indicated that the mean score for the morning chronotype in the morning was significantly different than the morning chronotype in the evening ($p = .019$). The neither chronotype did not differ significantly between the morning and evening test sessions ($p = .114$), nor did the evening chronotype ($p = .593$).

Figure 4.1. Interaction of Time of Test and Chronotype for Visual Stimuli for the First Digit Entered

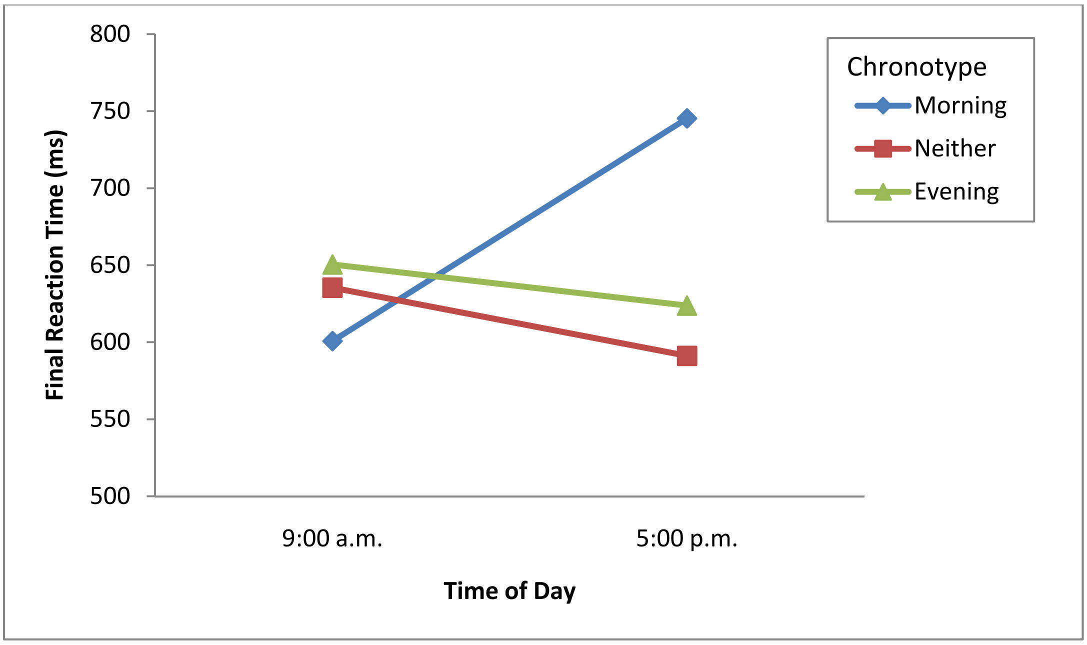

Figure 4.1. Interaction of time and chronotype on the computed first digit FRT score for visual stimuli on the CAVTIP

Like that for the first digit in the visual modality, there was no significant difference in reaction time scores for the second digit entered between the 9.00 a.m. and 5.00 p.m. test times [$F(1,32) = 2.032$, $p = .164$, $\eta_p^2 = .060$]. Nor was there a significant difference in reaction time scores between the morning, neither, and evening chronotypes [$F(2,32) = 0.411$, $p = .667$, $\eta_p^2 = .025$]. There was a significant Chronotype x Time interaction present [$F(2,32) = 4.703$, $p = .016$, $\eta_p^2 = 0.227$] with morning types showing faster times in the morning than either the neither and evening types. Whereas the evening types got slighter faster in the evening, and the neither types remained relatively stable across the day, the morning types became considerably slower in the evening. The neither types started the day slightly faster than the evening types, but by the evening, there was very little difference in reaction times between the neither and evening types. This interaction is shown in Figure 4.2.

Post hoc comparisons using the Bonferroni Correction indicated that the mean score for the morning chronotype in the morning was significantly different than the morning chronotype in the evening (p = .006). The neither chronotype did not differ significantly between the morning and evening test sessions (p = .652), nor did the evening chronotype (p = .392).

Figure 4.2. Interaction of Time of Test and Chronotype for Visual Stimuli for the Second Digit Entered

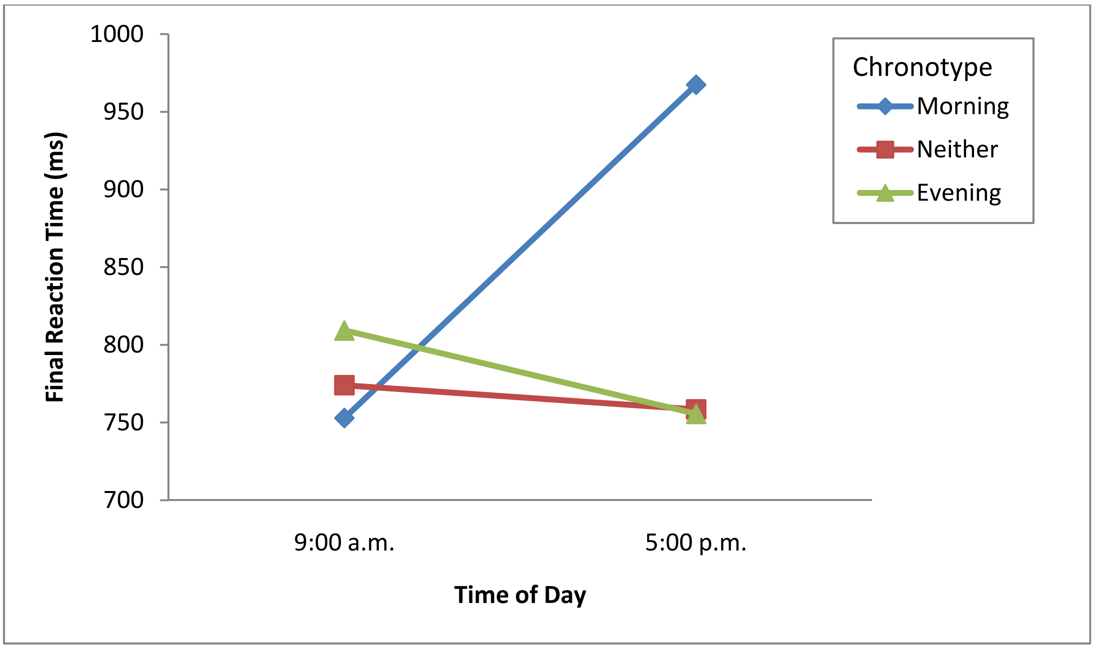

Figure 4.2. Interaction of time and chronotype on the computed second digit FRT score for visual stimuli on the CAVTIP

A similar pattern to the visual modality was exhibited by the auditory modality. There was no significant difference between reaction time scores for the first digit between the 9.00 a.m. and 5.00 p.m. test times [$F(1,32) = 0.005$, $p = .943$, $\eta_p^2 = .000$], nor for the morning, neither, and evening chronotypes [$F(2,32) = 1.868$, $p = .171$, $\eta_p^2 = .105$]. There was however a significant Chronotype x Time interaction [$F(2,32) = 3.730$, $p = .035$, $\eta_p^2 = .189$]. The morning types became slightly slower throughout the day, while the neither types showed a fairly stable pattern across the day. The neither types began the day with reaction times very similar to the evening types - who became considerably faster throughout the day. The interaction is shown in Figure 4.3.

Post hoc comparisons using the Bonferroni Correction indicated that the mean score for the evening chronotype in the morning was significantly different than the evening chronotype in the evening (p = .041). The morning chronotype did not differ significantly between the morning and evening test sessions (p = .167), nor did the neither chronotype (p = .302).

Figure 4.3. Interaction of Time of Test and Chronotype for Auditory Stimuli for the First Digit Entered

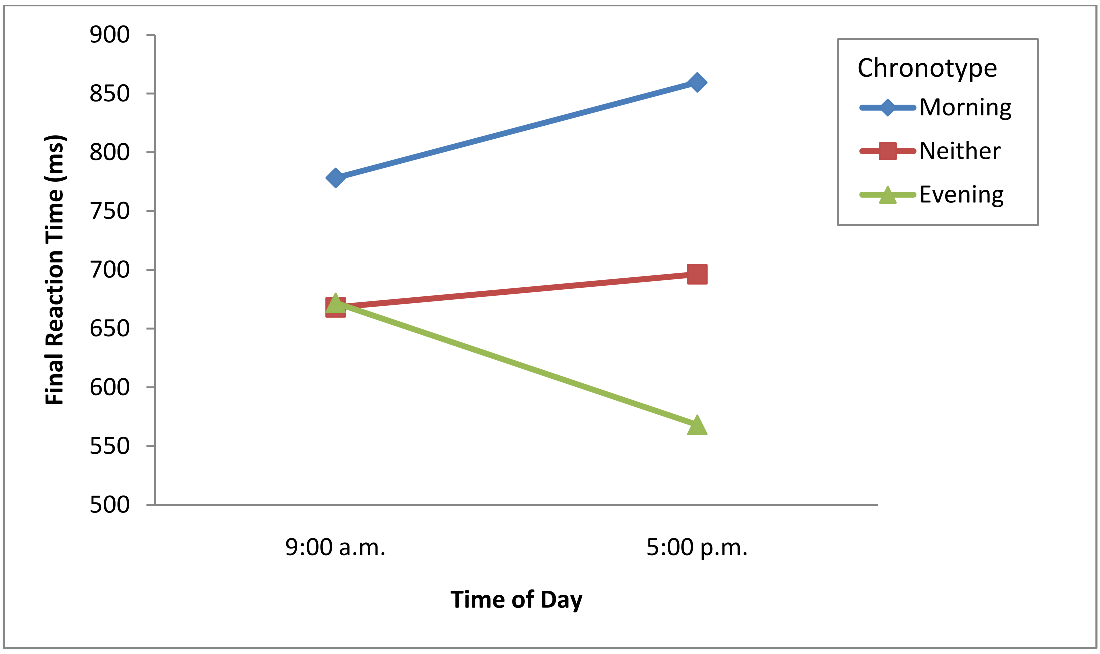

Figure 4.3. Interaction of time and chronotype on the computed first digit FRT score for auditory stimuli on the CAVTIP

Again the second digit entered showed similar results as the first digit in the auditory modality. There was no difference in reaction times between the 9.00 a.m. and

5.00 p.m. test times [$F(1,32) = 0.017$, $p = .896$, $\eta_p^2 = .001$], and no difference between the morning, neither, and evening chronotypes [$F(2,32) = 2.819$, $p = .075$, $\eta_p^2 = .15$]. There was a Chronotype x Time interaction [$F(2,32) = 5.726$, $p = .007$, $\eta_p^2 = .264$] as shown in Figure 4.4, with an almost identical pattern as the first digit exhibited. That is morning types became slightly slower during the day, whereas the evening types became considerably faster. The neither types showed a slight slowing between the morning and evening test times, and like the first digit in the auditory modality started the day with very similar reaction times to the evening types.

Post hoc comparisons using the Bonferroni Correction indicated that the mean score for the evening chronotype in the morning was significantly different than the evening chronotype in the evening ($p = .011$). The morning chronotype did not differ significantly between the morning and evening test sessions ($p = .222$), nor did the neither chronotype ($p = .081$).

Figure 4.4. Interaction of Time of Test and Chronotype for Auditory Stimuli for the Second Digit Entered

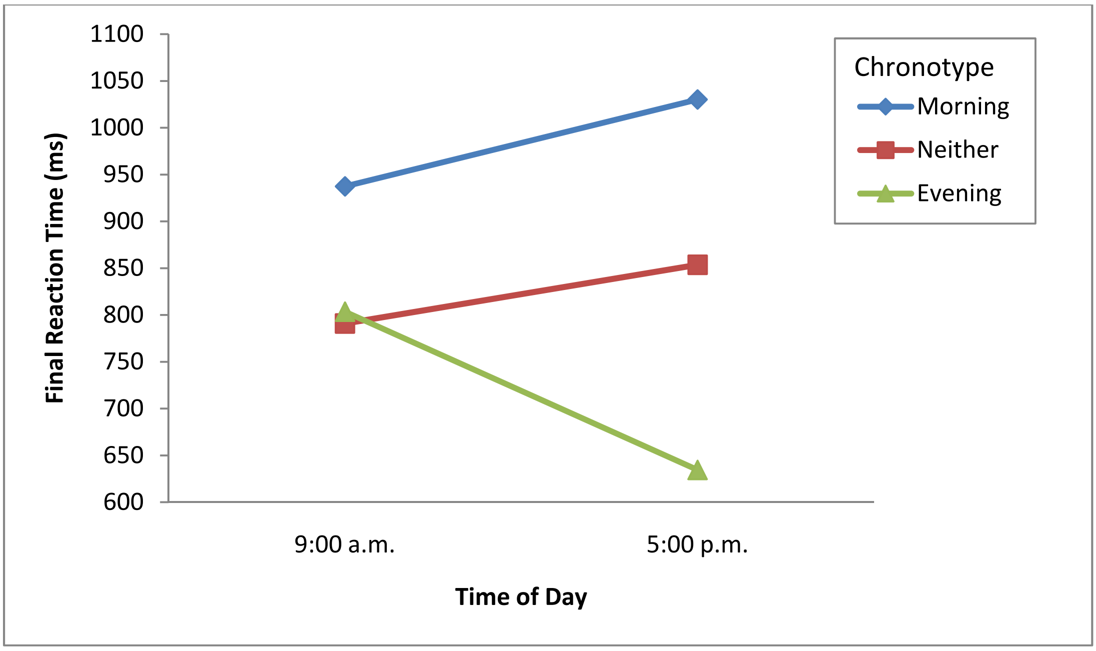

Figure 4.4. Interaction of time and chronotype on the computed second digit FRT score for auditory stimuli on the CAVTIP

For both the first and second digits in both visual and auditory modalities, the Levene's test indicated that the error variances were not significantly different.

SRT (Visual and Auditory)

As an alternative measure of information processing speed simple reaction time was analysed.

A 3 (Chronotype) x 2 (Time) mixed-design analysis of variance (ANOVA) was conducted for both visual and auditory stimuli. The means and standard deviations for each of the modalities appear in Table 4.4 below.

Table 4.4

Means and Standard Deviations for Simple Reaction Time (Visual and Auditory Modalities) by Chronotype During the 9.00 a.m. and 5.00 p.m. Test Sessions

Visual		AM				PM	
Chronotype	*n*	*M*	*SD*		*N*	*M*	SD
Morning	5	294.51	33.85	Morning	5	307.70	44.83
Neither	23	301.56	48.92	Neither	23	315.11	54.99
Evening	7	305.02	51.00	Evening	7	303.84	60.53
Auditory		**AM**				**PM**	
Chronotype	*n*	*M*	*SD*		*N*	*M*	SD
Morning	5	341.14	63.38	Morning	5	485.31	243.35
Neither	23	460.70	178.76	Neither	23	464.32	176.76
Evening	7	435.62	149.60	Evening	7	437.74	216.50

For the visual stimuli there was no difference in reaction times between the 9.00 a.m. and 5.00 p.m. test sessions [$F(1,32) = 0.406$, $p = .528$, $\eta_p^2 = 0.013$], or morning, neither, and evening chronotype [$F(2,32) = 0.079$, $p = .924$, $\eta_p^2 = 0.005$]. A Time x Chronotype interaction effect was not present [$F(2,32) = 0.145$, $p = .866$, $\eta_p^2 = 0.009$]. Likewise, for the auditory stimuli there was not a significant difference in reaction time between the 9.00 a.m. and 5.00 p.m. test sessions [$F(1,32) = 1.817$, $p = .19$, $\eta_p^2 = 0.054$], or morning, neither, and evening chronotype [$F(2,32) = 0.240$, $p = .788$, $\eta_p^2 = 0.015$]. There was no interaction Time x Chronotype present [$F(2,32) = 1.329$, $p = .279$, $\eta_p^2 = 0.077$].

Levene's test indicated error differences were not significantly different in either the visual or auditory modality.

Supplemental Analyses

Test Equivalency

Prior to the main analyses, equivalency of the CAVTIP test forms was analysed via paired sample t-tests at the $p < .05$ level (two-tailed). Normality of the difference scores were analysed for each pair of variables using Shapiro-Wilks statistic. Normality was within the acceptable range.

Order effects associated with the time of day testing was undertaken were reduced by the test forms being administered in the same order, and approximately half the participants undertaking each test form in the a.m. session first *(n* = 19) and the remainder in the p.m. session first *(n*= 16).

Paired sample t-tests on the items on the CAVTIP showed there were no significant differences in the means between versions of the visual simple reaction time task (SRT_Visual) [*t* (34) = -0.993, *p* = .328, *d* = -.168], nor for the auditory simple reaction time task (SRT_Auditory) [*t* (34) = -0.766, *p* = .449, *d* = -.13]. As the test forms used for the visual stimuli were identical at the a.m. and p.m. sessions, likewise for the auditory stimuli, it would be expected that there would be no difference in scores. The means and standard deviations are shown in Table 4.5.

Table 4.5

Means and Standard Deviations for Simple Reaction Time (Visual and Auditory Modalities) at 9.00 a.m. and 5.00 p.m. Test Sessions

	AM session			PM session		
	n	*M*	*SD*	*n*	*M*	*SD*
Visual	35	301.25	46.39	35	311.80	53.50
Auditory	35	438.61	163.79	35	462.00	188.64

As the Final Reaction Time (FRT) was composed of the results obtained from the IRT and CRT tasks, these were inspected to determine whether they were from equivalent forms. For the Input Reaction Time task (IRT), there was no difference between means for the visual task [*t* (34) = -0.090, *p* = .929, *d* = -.016] for the first digit entered, nor the second digit entered [*t* (34) = 0.679, *p* = .502, *d* = .125] between test versions. This same pattern was seen for the means of the auditory task for both the first digit [*t* (34) = 1.082, *p* = .287, *d* = .183] and the second digit entered [*t* (34) = 1.469, *p* = .151, *d* = .253] between test versions. Means and standard deviations of the IRT tasks appear in Table 4.6.

Table 4.6

Means and Standard Deviations for Input Reaction Time (Visual and Auditory Modalities) at 9.00 a.m. and 5.00 p.m. Test Sessions

Visual	AM session			PM session		
	n	*M*	*SD*	*n*	*M*	*SD*
Digit 1	35	657.33	140.17	35	658.44	114.85
Digit 2	35	866.27	194.5	35	852.78	145.24
Auditory	AM session			PM session		
	n	*M*	*SD*	*n*	*M*	*SD*
Digit 1	35	774.62	96.02	35	762.58	97.46
Digit 2	35	970.14	121.78	35	946.02	140.62

On the Complex Reaction Time task (CRT), there was no difference between means for the visual task [*t* (34) = 0.791, *p* = .435, *d* = .134] for the first digit entered, nor the second digit entered [*t* (34) = 0.417, *p* = .679, *d* = .071] between test versions. There was no difference between means for the auditory task [*t* (34) = 0.090, *p* = .929, *d* = .015] for the first digit entered, nor the second digit entered [*t* (34) = 0.289, *p* = .774, *d* = .049] between test versions. Means and standard deviations for the CRT tasks appear in Table 4.7

Table 4.7

Means and Standard Deviations for Complex Reaction Time (Visual and Auditory Modalities) at 9.00 a.m. and 5.00 p.m. Test Sessions

Visual	AM session			PM session		
	n	*M*	*SD*	*n*	*M*	*SD*
Digit 1	35	1290.79	199.69	35	1271.82	207.78
Digit 2	35	1644.33	261.91	35	1631.64	243.33
Auditory	**AM session**			**PM session**		
	n	*M*	*SD*	*n*	*M*	*SD*
Digit 1	35	1459.19	216.37	35	1456.82	213.25
Digit 2	35	1784.50	231.17	35	1775.60	239.47

Test equivalency was deemed adequate between the versions administered.

Effects of Caffeine

The effect of caffeine was assessed to determine whether it influenced performance on CAVTIP items during the different session times. The means, standard deviations and *t* values for each of the tasks appear in Table 4.8.

AM session. Of the 35 participants analysed, 9 consumed caffeine within 2 hours of the morning session test time. Independent samples t-tests carried out to determine whether caffeine influenced reaction times on the CAVTIP tasks indicated that there was no difference between participants who consumed caffeine (n = 9) and those who did not consume caffeine (n = 26) on the SRT and FRT tasks.

PM session. 15 of the 35 participants analysed consumed caffeine within two hours of the evening session test time. Independent samples t-tests indicated that there was no difference in reaction times recorded between those who consumed caffeine (n = 15) and those who did not consume caffeine (n = 20) on the SRT and FRT tasks.

Table 4.8

Means, Standard Deviations, and t values for the SRT and FRT Tasks (Visual and Auditory) when Caffeine is Consumed or Not Consumed

AM session		Caffeine			No caffeine		
SRT	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*
Visual	9	295.23	39.09	26	303.33	49.20	0.446
Auditory	9	467.97	198.45	26	428.44	153.18	-0.062
FRT							
Visual							
Digit 1	9	613.77	263.45	26	640.27	151.82	0.370
Digit 2	9	750.11	336.22	26	787.73	205.04	0.400
Auditory							
Digit 1	9	613.69	240.50	26	709.11	180.19	1.255
Digit 2	9	731.19	250.64	26	843.15	190.36	1.401

PM session		Caffeine			No caffeine		
SRT	*n*	*M*	*SD*	*n*	*M*	*SD*	*t*
Visual	15	301.28	50.24	20	319.68	55.77	1.007
Auditory	15	403.31	125.26	20	506.02	217.62	1.633
FRT							
Visual							
Digit 1	15	622.32	176.31	20	617.67	187.85	-0.074
Digit 2	15	798.86	203.99	20	779.38	217.41	-0.269
Auditory							
Digit 1	15	658.73	183.41	20	720.36	199.81	0.935
Digit 2	15	810.74	213.67	20	853.17	250.58	0.527

* $p < .05$ ** $p < .01$ *** $p < .001$

Effects of Smoking

As only one of the 35 participants smoked prior to either the first or second test session, the effect of smoking was not analysed.

Effects of Practice

The effect of practice was assessed to determine whether it influenced performance on SRT and FRT tasks during the different session times. It is hypothesised that if a practice effect was evident, participants would show lower scores (faster times) on the tasks at their second session compared to the first session as they became more competent at the tasks.

Of the 35 participants analysed, $n = 19$ undertook their first session in the morning, with the remaining $n = 16$ in the evening.

Independent samples t-tests indicate significant differences for the SRT task in both modalities, as well as the computed 'final reaction time' task in the visual modality for the first digit. Results of statistically significant differences appear below, with the means, standard deviations and *t* values of all SRT and FRT tasks appearing in Appendix D-1.

For the simple reaction time task in the visual modality, quicker reaction times were recorded in the morning ($M = 287.61$, $SD = 43.27$) compared to the evening ($M = 340.52$, $SD = 51.19$) when the first session had taken place in the evening, $t\ (33) = 0.\text{-}3.316$, $p = .002$, $d = 0.132$. The auditory modality showed the same pattern as that of the visual modality. That is, quicker reaction times were recorded in the morning ($M = 382.88$, $SD = 155.80$) compared to the evening ($M = 555.96$, $SD = 184.89$) when the first session had taken place in the evening, $t\ (33) = -3.007$, $p = .005$, $d = 0.864$.

For the first digit of the FRT task in the visual modality, a practice effect was evident when the first test time occurred in the morning. Significantly quicker reaction times were recorded in the evening ($M = 566.35$, $SD = 129.32$) than the morning ($M = 689.97$, $SD = 204.48$), $t\ (33) = 2.089$, $p = .044$, $d = 0.517$.

FRT (Practice Controlled)

When the effect of practice was controlled for the first digit of the FRT task in the visual modality, similar results were obtained as when practice was not controlled. That is there was no significant difference in reaction time scores between the 9.00 a.m. and 5.00 p.m. session times [$F(1,29) = .720$, $p = .403$, $\eta p^2 = .024$], nor was there a significant difference between the morning, neither, and evening chronotypes [$F(2,29) = .336$, $p = .717$, $\eta p^2 = .023$]. The Time x Chronotype interaction remained significantly different [$F(2,29) = 3.421$, $p = .046$, $\eta p^2 = .191$].

Post hoc comparisons using the Bonferroni Correction indicated that the mean score for the morning chronotype in the morning was significantly different than the morning chronotype in the evening ($p = .040$). The neither chronotype did not differ significantly between the morning and evening test sessions ($p = .126$), nor did the evening chronotype ($p = .811$).

The estimated marginal means and standard errors appear in Table 4.9.

Table 4.9
Estimated Marginal Means and Standard Errors for the First Digit FRT Task (Visual) When Practice is Controlled at 9.00 a.m. and 5.00 p.m. Test Sessions

Visual- Digit 1						
	AM session			PM session		
Chronotype	*n*	*EMM*	*SE*	*n*	*EMM*	*SE*
Morning	5	613.60	84.45	5	743.14	83.24
Neither	23	633.15	38.62	23	589.87	38.06
Evening	7	609.11	77.4	7	595.81	76.29

SRT (Practice Controlled)

Like that of the first digit of the FRT task in the visual modality, when the effect of practice was controlled, similar results were obtained for both the visual and auditory modality as when practice was not controlled. There was no significant difference in reaction time scores between the 9.00 a.m. and 5.00 p.m. session times for either the visual [F(1,29) = .922, p = .345, ηp^2 = .031], or auditory modality [F(1,29) = 2.485, p = .126, ηp^2 = .079]. Additionally there was no significant difference between the morning, neither, and evening chronotypes for either the visual [F(2,32) = .343, p = .712, ηp^2 = .023], or auditory modality [F(2,29) = .961, p = .394, ηp^2 = .062]. There was also no Time x Chronotype interaction for either the visual [F(2,29) = .116, p = .891, ηp^2 = .008], or auditory modality [F(2,29) = .990, p = .384, ηp^2 = .064]. The estimated marginal means and standard errors appear in Table 4.10 and Table 4.11.

Table 4.10

Estimated Marginal Means and Standard Errors for the SRT Task (Visual) When Practice is Controlled at 9.00 a.m. and 5.00 p.m. Test Sessions

Visual						
	AM session			AM session		
Chronotype	*n*	*EMM*	*SE*	*n*	*EMM*	*SE*
Morning	5	299.96	20.32	5	302.99	21.92
Neither	23	300.68	9.29	23	316.02	10.03
Evening	7	313.68	18.62	7	327.25	20.09

Note: EMM (Estimated Marginal Means)

Table 4.11

Estimated Marginal Means and Standard Errors for the SRT Task (Auditory) When Practice is Controlled at 9.00 a.m. and 5.00 p.m. Test Sessions

Auditory						
	AM session			PM session		
Chronotype	*n*	*EMM*	*SE*	*n*	*EMM*	*SE*
Morning	5	337.18	69.40	5	454	74.71
Neither	23	458.35	31.73	23	466.05	34.16
Evening	7	496.02	63.61	7	531.24	68.47

Note: EMM (Estimated Marginal Means)

CHAPTER 5

DISCUSSION

Overview

Prior studies investigating the effects of morningness-eveningness (M-E) on information processing speed across the day have failed to find any significant differences. This is despite other studies that have shown a synchrony effect occurs between the time of day and a person's chronotype across a range of cognitive abilities. May and Hasher (1998) define the synchrony effect as superior performance at the optimal time of day based on chronotype.

It was theorised that the failure to identify a synchrony effect resulted from two limitations in the previous studies. The first relates to the measures used, with the second being attributed to the effects of motor function not being controlled.

To overcome the limitations in the previous studies, a measure of information processing speed was developed for the present study.

The Computerised Auditory and Visual Test of Information Processing (CAVTIP)

One limitation of the previous studies attempting to determine whether a synchrony effect is evident for information processing speed related to the measures used. This researcher deemed the measures inadequate to detect small changes that may be occurring across test times. To overcome this limitation the CAVTIP was developed. Whereas the other measures relied on determining the number of correct matches of letters and symbols in a specified period of time to determine information processing speed, the CAVTIP recorded actual response times in milliseconds. This made the CAVTIP highly sensitive to changes in information processing speed that may occur over time. Results of the CAVTIP's sensitivity could be observed from looking at raw scores for participants with vast differences often being apparent both within and between participants. Additionally, mean scores attained across the time-of-day and chronotype factors indicated differences of up to 400 ms.

The other limitation resulting from the measures used in the previous studies was the possible effects that motor function may have been exerting on the results. As motor function is known to exhibit circadian rhythmicity (Gueugneau, et al., 2009) with superior performance occurring in the evening, it was possible the uncontrolled effects were masking any differences. This limitation was able to be overcome by utilising a task in the CAVTIP which allowed control of motor function in the present study.

Other research investigating the effects of morningness-eveningness on aspects of cognition have shown that whether a synchrony effect is observed depends upon task complexity. Therefore to address this question more complex and less complex tasks were able to assessed using the CAVTIP.

The CAVTIP was also developed so that the effects of morningness-eveningness could be determined across both visual and auditory modalities. This is in contrast to the previous studies which focussed on visual processing only.

Based upon the prior literature investigating synchrony effects in cognition and in conjunction with use of the CAVTIP the following hypotheses were made:

1. There will be a synchrony effect for both visual and auditory stimuli on the tasks to measure information processing speed; but
2. Only the more complex tasks will exhibit a synchrony effect.

The Effect of Morningness-Eveningness on Information Processing Speed

"***Hypothesis 1 - There will be a synchrony effect for both visual and auditory stimuli on the tasks to measure information processing speed"***

The results of the present research indicate that morningness-eveningness *does* influence information processing speed.

There was no indication that either chronotype or time-of-day influenced information processing speed individually as evidenced by non-significant findings. However, chronotype and time-of-day interacted, and was in the predicted direction; that is, superior performance was observed for morning types in the morning, with evening types exhibiting superior performance in the evening.

Closer inspection of this relationship revealed interesting findings which were dependent on the modality of the presented stimuli.

When visual stimuli were presented, results indicated that at the morning test session the different chronotypes (morning, neither, and evening) showed similar performance; although the morning type showed slightly better performance than the neither and evening types. At the evening test session there was a slight improvement in performance for the neither and evening types (although not significant) from the morning test session. However, the morning types showed a significant decrease in performance.

For the auditory stimuli it was shown that the morning types showed slightly worse performance in the morning than both the neither and evening types. This difference was not significant however. The neither and evening types showed very similar (within 15ms) performances in the morning. This similarity in performance was not seen at the evening test session however. Instead the neither type's performance decreased slightly between the morning and evening test sessions, as did the morning type. In contrast the evening types became significantly faster.

It should be noted that for the visual stimuli the neither type's performance between the morning and evening test sessions was intermediate to the morning and evening types. In contrast, for the auditory stimuli with the exception of the similarities with the evening types in the morning, the neither types generally showed superior performance to both the morning and evening types – that is, their performance was not intermediate to the morning and evening types.

While it may seem counterintuitive that the neither type would show performance that was not intermediate to the morning and evening types, the observed relationship is not unique. Adan (1991) and Almirall (1993) have shown relationships whereby neither types showed either superior, or inferior performance.

Although no specific hypothesis was made regarding differences that may occur between the modalities - rather it was hypothesised that synchrony effects would occur in each modality - this finding is interesting and requires further investigation. As it was not the intention of the study to investigate an effect such as was observed, it is difficult to determine what mechanism may be responsible for this difference between modalities. However, as the present study has shown that morningness-eveningness influences information processing speed depending upon time-of-day and chronotype, it is possible that an interaction occurs between time-of-day and chronotype for brain activity along the visual and auditory pathways. Investigations using event related potentials (ERP) could be undertaken to uncover any differences. As there are many components e.g. N1 (Taylor, Roberts, Downing, & Thierry, 2010), N2 (Folstein & Van Petten, 2008), and P300 (Higuchi, Liu, Yuasa, Maeda, & Motohashi, 2000) that make up ERPs, and considering research that indicates some components exhibit circadian rhythmicity in amplitude and latency (Higuchi, et al., 2000) whereas others have not (Kubová, Kremláček, Szanyi, Chlubnová, & Kuba, 2002) this explanation warrants further investigation.

The effects of chronotype and time-of-day. Although the present study demonstrated that there was a synchrony effect between chronotype and time-of-day for information processing speed on the most complex task; no main effects of chronotype or time-of-day were observed for either the least complex or most complex task. These findings support those of Song and Stough (2000) and in part contrast with those of Allen et al. (2008). It is possible that as Allen et al. (2008) observed a time-of-day difference in performance on the DSST with better performance in the evening irrespective of chronotype, this difference resulted from improved motor function occurring in the evening compared to the morning and not from the cognitive aspect of information processing speed per se. As the present study sought to control for the effect of motor functioning, this may explain the finding that time-of-day did not influence information processing speed.

With regards to the effect of chronotype, neither Song and Stough (2000), nor Allen et al. (2008) observed significant differences between the chronotypes under investigation. This is in contrast to findings of May, Hasher, and Stoltzfus (1993), May and Hasher (1998), and Intons-Peterson, Rocchi, West, McLellan, and Hackney (1998) who observed differences between chronotypes on cognition. Allen et al. (2008) indicate a possible explanation for the non-significant differences between the chronotypes as being that in the May et al. (1993), and Intons-Peterson et al. (1998) studies, 'extreme' chronotypes were included in the samples. That is, there were participants in the 'definitely morning' and 'definitely evening' categories. The sample used by May and Hasher (1998) also included participants in the extreme categories. Results of the present study indicate that for each of the morning and neither groups there were no participants in the extreme categories (a more thorough discussion of morningness-eveningness distribution follows). Additionally, as the sample was composed of only five participants in the morning group, and seven in the evening group, these small sub-samples may have been too small and therefore under-powered to make adequate comparisons between the groups.

The effects of practice. When the FRT was computed and analysed it became apparent that a practice effect had occurred, likewise for the SRT task in both modalities.

This was despite attempts at reducing the effects of practice by having an approximately equal number of participants undertake testing in the morning first, with the remainder in the evening (counterbalancing test session times). For the FRT task this practice effect was only observed in one of the computed variables, but was seen for both visual and auditory SRT.

As only one of the four computed FRT variables exhibited a practice effect it is likely that the counterbalancing of test session times did reduce the effects of practice, possibly in combination with the three practice trial blocks carried out for each of the CRT tasks from which the FRT's were computed.

As the FRT variables were computed from the CRT tasks, it was no surprise a practice effect existed. This results from the CRT task being based upon the PASAT (Gronwall, 1977) which is known to be subject to practice effects with the greatest improvement in scores occurring between the first and second test sessions (Beglinger, et al., 2005). Use of the three practice trial blocks may have decreased this effect, but as the practice trial blocks were the same each time, this decrease may have been limited as participants may have relied on memory to complete the practice trial blocks rather than becoming more familiar with the task per se.

During development of the CAVTIP it was anticipated that use of identical trial blocks may not entirely control for practice effects. However, it was decided that as correct responses were required for the analyses, feedback should be given to participants after each practice trial block with an opportunity to improve on the previous score. This further allowed participants to become more confident that they were undertaking the tasks correctly.

Caffeine and smoking effects. The use of caffeine (Hindmarch, et al., 1998; Lorist, et al., 1995) and smoking (Starr, et al., 2007) are factors known to influence information processing speed. It was decided that rather than risk withdrawal effects (Sigmon, Herning, Better, Cadet, & Griffiths, 2009) which may themselves influence performance on the tasks of information processing speed, use of caffeine and smoking would be recorded and any effect statistically controlled. Consumption of tea, coffee, cola, or smoking within two hours of a test session constituted use of the substance. Outside of this time frame was associated with no use of the substance.

Analyses indicated that scores on the computed FRT, and SRT variables were not influenced by the consumption of caffeine. Therefore statistical control was not required when analysis of the effect of morningness-eveningness on information processing speed for the FRT and SRT variables was undertaken.

As only one participant was identified as smoking within the two hour period, further analysis was not out carried as it was likely any effect the one participant had on the overall result would be minimal.

"Hypothesis 2 – Only the more complex tasks will exhibit a synchrony effect"

Despite the overall finding that morningness-eveningness influences information processing speed, this does not hold across levels of task difficulty. Consistent with the results of McElroy and Mosteller (2006), and Bennett et al. (2008), a synchrony effect was only observed in the more complex task, and not in the less complex task.

McElroy and Mosteller (2006) attribute their findings to that of cognitive demand. According to McElroy and Mosteller (2006), low complexity tasks are less sensitive to any advantage or disadvantage that is offered by undertaking the task at either an optimal or non-optimal time of day.

As no synchrony effect was seen in the least complex task (SRT), the explanation offered by McElroy and Mosteller (2006) appears to be relevant in the present study. This finding seems to be corroborated by the differences in effect sizes seen between the least complex (maximum partial eta squared = 0.077) and most complex (minimum partial eta squared = 0.189) tasks.

Quantification of Information Processing Speed

By developing the CAVTIP to be a sensitive measure of information processing speed for both visual and auditory stimuli (and allowing control of motor function), quantification of information processing speed was possible.

For the most complex task, single and double digit responses were recorded, and it is arguable that the double digit responses increased task complexity beyond what was achieved with the single digit responses.

The results (see Table 4.3 and Table 4.9) indicated that for the visually presented stimuli, the time required to process a single digit, or the first digit of a double digit number, is in the vicinity of 600 ms, with the time to process the second digit approximately 200 ms more. For the auditory stimuli, the first digit was processed in approximately 700 ms, with the second digit taking approximately an additional 150 ms.

It must be remembered however that as the CAVTIP was developed for the present study, reliability and validity of the measure is undetermined. Validation against a physiological measure such as ERPs may be an appropriate method of determining accuracy of the measurements. While the obtained results may not be entirely accurate, they do give an approximate indication of information processing speed when the effects of motor function have been controlled. This is in addition to the determination of differences between the chronotypes at different time periods.

Chronotype Distribution

As Horne and Ostberg (1976), Carrier et al. (1997), Chelminski et al. (1997), May et al. (1993), May and Hasher (1998), and Paine et al. (2006) demonstrate, distribution of chronotype in a population depends on the population studied.

The present study indicates that in a population of 18 to 25 year old university students the majority (65.7%) identify as being of the neither type. The next highest chronotype is that of the evening type (20.0%), with the morning type making up the minority (14.3%). When this distribution is compared to that of the other researchers, the present study's distribution is closest to that of Chelminski et al. (1997). In both the Chelminski et al. (1997) and the present study the median age of participants was 19.0 years, although the age ranges were considerably different; 18 to 53 years in the Chelminski et al. (1997), and 18 to 25 years in the present study.

This finding is interesting when the age ranges and populations of interest are taken into account. As the cut-off scores used were those suggested by Horne and Ostberg (1976), it would be expected that the present study would be more similar to that of Horne and Ostberg (1976) who like Chelminski et al. (1997) used university students, but more like the present study used a narrower age range of 18 to 32 year olds. According to the Horne and Ostberg (1976) study, the morning and evening types combined made up the majority (37.5%) and (41.6%) respectively with the neither type making up the minority of 20.8%.

The discrepancy between the distributions is unclear. However, it may relate to the use of the MEQ for classification. As the MEQ is a subjective measure, it is possible participants incorrectly answered the questions. The MEQ is designed to ascertain the *preferred* time that individuals would undertake tasks if free to do so. Instead, it is possible that participants answered the questions based on when they *currently* undertook activities due to time constraints surrounding study and other commitments.

It should be noted that while Horne and Ostberg (1976) obtained good correlations between scores on the MEQ and core body temperature using the cut-off scores developed 35 years ago, these same cut-off scores may no longer be applicable in a population of university students of a similar age range today. This may arise due to different demands placed on students to perhaps not only be students, but also workers, and parents. Accordingly, comparable responses may no longer be made on the MEQ by the participants, and new cut-off scores may need to be developed. Use of the Horne and Ostberg (1976) cut-off scores may have resulted in the neither types being over-represented in the sample compared to the Horne and Ostberg (1976) findings.

Visual v Auditory Simple Reaction Time

While it was not the intention to compare visual and auditory processing speed, but rather to determine whether morningness-eveningness influences information processing speed for visual and auditory stimuli, an interesting finding was observed betweens the means of the SRT tasks.

Shelton and Kumar (2010) indicate that SRTs for auditory stimuli are faster than that for visual stimuli. Typically SRTs for auditory stimuli is approximately 284 ms, whereas visual stimuli are 331ms. Findings of the present study indicate an opposite trend.

Visual stimuli were found to be faster (305 ms) than auditory stimuli (437 ms) on average (determined by averaging across a.m. and p.m. sessions - Table 4.4).

Two possible explanations for these finding are that as the auditory stimuli were numbers, participants delayed their response until they had heard the presentation of the entire stimulus. In contrast the visual stimuli may have been presented almost immediately in their entirety, thereby allowing the participants to respond at a quicker rate.

The alternate explanation is that the auditory stimuli may have required a longer processing time by the computer before the stimuli were delivered to the participants via the headphones. Whereas for the visual stimuli the computer presented the stimuli on-screen, processing by the computer's soundcard *may* have increased processing time. This may have increased the duration from the time the computer registered the onset of the stimulus to the time taken by the participant to register a response.

Both explanations seem plausible considering duration of the visual and auditory stimuli were comparable (550 ms) and (560 ms on average) respectively.

Practical Implications

The present study indicates that a synchrony effect does occur for the time-of-day and chronotype on information processing speed. However, it must be kept in mind that this effect appears to be modality dependent. It is questionable whether the slight advantages for the evening types in the evening for visually presented stimuli, or the slight advantage in the morning for morning types for auditory stimuli is of practical importance. What may be of more importance is the disadvantage that occurs for morning types in the evening compared to the morning for visually presented stimuli, and the advantage for the evening types in the evening for auditory stimuli.

As Kail (2000) indicates deficits in memory and reasoning may result from difficulties in efficient information processing, it is possible that by allowing individuals (based on their chronotype) to undertake tasks that require these areas of cognition at a time deemed optimal, performance on the tasks will improve. Additionally, by undertaking the tasks at an optimal time compared to a non-optimal time there may be overall increases in results on intelligence tests due to a more efficient accumulation of knowledge generally over time, and more efficient processing at the time of testing.

As the results indicate the synchrony effect is only apparent for more complex tasks, it is possible that tailoring work schedules for jobs requiring high levels of cognition may result in improved productivity and less work-place accidents.

As the study was carried out on adults it is not clear whether the same patterns would be seen in children. However as chronotype can be measured it is probable they would be. Therefore, it is possible that allowing children to learn at an optimal time of day based on their chronotype may lead to long term benefits as knowledge is potentially more easily gained. School schedules could be tailored to a child's chronotype with the schedule changing as required.

One other area that may benefit from the results of the present study is that of neuropsychology. Although the present study was carried out on healthy adults, it is possible that when assessments are undertaken on patients, their performance may vary across time periods. This may be not as a result of any deficit arising from illness or injury, but from the patient undertaking the tasks at what may be an optimal or non-optimal time of day depending on their chronotype. Therefore neuropsychological assessments could be carried out at the same time of day to eliminate any advantage or disadvantage that may be obtained with varying times of day.

Study Limitations and Future Directions

Several limitations are inherent in the present study. The first such limitation surrounds the population sampled. The present sample was restricted to healthy adults aged 18 to 25 years. Although information processing speed is shown to depend upon time-of-day and a person's chronotype (which is able to be determined), it appears this same finding would be made across other age groups. However, testing of other age groups should be undertaken to determine whether the findings are able to be replicated outside this age group.

Another limitation surrounds the cut-off scores for classification of morningness-eveningness preference. The present research used cut-off scores deemed to be most appropriate in the sampled population – that of Horne and Ostberg (1976). As no physiological measures of morningness-eveningness were undertaken it is possible the cut-off scores used were not the most appropriate despite indications by Horne and Ostberg (1976) that the cut-off scores devised correlate well with core body temperature in a comparable sample. This is a likely possibility considering the discrepancy in distributions between the Horne and Ostberg (1976) study and the present study. Accordingly, the results obtained are dependent on correct classification being undertaken.

As the distribution of morningness-eveningness preference in the sample indicated approximately two thirds were in the ‘neither’ type category, it would have been preferable to undertake the study in two parts. The first part would entail testing a larger sample to determine their chronotype. A random sample in each of the morning, neither, and evening categories would then be contacted for part two to undertake testing of information processing speed. The advantage of this method would be to ensure an approximately equal number of participants were in each chronotype group, and participants could be identified in the extremes and included. Each group would then undertake testing in a counterbalanced order thereby ensuring practice effects were balanced across chronotype. This is in contrast to the present study whereby counterbalancing was across participants rather than across chronotype.

As no satisfactory explanation can be made by the present study as to the differences highlighted by post-hoc analyses between the modalities this is an area which requires further investigation. The same study could be carried out on another sample - using the same controls and suggestions made previously regarding chronotype distribution - but measurements could also be made of ERPs to ascertain amplitude and latency distributions during testing between the chronotypes.

Conclusion

To this researchers knowledge this is the first study to demonstrate a synchrony effect between chronotype and time-of-day on information processing speed for visual and auditory stimuli despite previous studies investigating this relationship. It is unknown why the present study obtained conflicting results to the previous studies, but it is thought it may relate to using a measure of information processing speed sensitive to small changes, and by controlling for motor function which is known to exhibit circadian rhythmicity. It appears that for visually presented stimuli there is no advantage for any chronotype in the morning, but a clear disadvantage for morning types in the evening. In contrast for auditory stimuli there is a clear advantage for evening types in the evening. The present study supported the findings of McElroy and Mosteller (2006), and Bennett et al. (2008) by demonstrating that a synchrony effect only occurs in more complex tasks and not less complex tasks. Additionally, by using a measure capable of detecting small changes in information processing speed an estimate of speed across the day was able to be attained.

While implications of this finding are currently unknown, it is possible such implications may be wide reaching and applicable to a vast age range including children and adults alike - although this needs further investigation and in light of the limitations of the present study.

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APPENDIX A-1

Recruitment Notice

MASSEY UNIVERSITY
COLLEGE OF HUMANITIES AND SOCIAL SCIENCES
TE KURA PŪKENGA TANGATA

Research Participants Required

The effects, in healthy adults, of 'morningness-eveningness' on information processing speeds for visual and auditory input

- Are you 18 – 25 years of age?
- Is English your first language?
- Do you have **NO** history of diagnosed traumatic brain injury (including concussion)?
- Do you have **NO** history of psychological illness?
- Are you willing to **NOT** consume alcohol/drugs during the 24 hours before and during participation?
- Are you a student, or staff member of Massey University (with some university education)?
- Do you have 2 hours of time available?
- Do you want to find out at what time of day (morning/evening) you are at your peak mentally?

If you answered **"YES"** to the above questions I would appreciate your help in undertaking the research for my MSc thesis.

In return for your help you will receive:

- An individualised report (if requested)
- The knowledge that you have made a contribution in the field of psychology
- Compensation for your time and travel in the form of a grocery or fuel voucher (your choice to the value of $20)

If you would like to participate, or if you require more information, please contact the researcher or supervisor:

Researcher: Denyse Pope **Email: denyse.pope.1@uni.massey.ac.nz**

Supervisor: Dr Jennifer Stillman **Telephone: (09) 414 0800 ext 41218**
Email: j.a.stillman@massey.ac.nz

APPENDIX A-2

Information Sheet

MASSEY UNIVERSITY
COLLEGE OF HUMANITIES
AND SOCIAL SCIENCES
TE KURA PŪKENGA TANGATA

The effects, in healthy adults, of 'morningness-eveningness' on information processing speeds for visual and auditory input

INFORMATION SHEET

My name is Denyse Pope and I am a student at Massey University. I am currently working towards my Master of Science (MSc) in Psychology. My supervisor for this research is Dr. Jennifer Stillman of Massey University, Albany.

What is this research about?

Most people have heard of the term "larks" and "owls", This term relates to whether an individual has a preference to arising early, or going to bed late, and may influence how effective people are at working at various times of the day. This research will look at how rapidly people can process information at different times of day and whether this depends on their "morning" or "evening" type.

The study involves completing two paper-and-pencil questionnaires, and three computerised tasks. The computerised tasks involve responding to visual and auditory stimuli presented at timed intervals. Some of these tasks are quite difficult for most people. It is unlikely that this will give rise to stress or anxiety, but if this does arise it is usually brief and occurs only during the task. If you continue to experience anxiety after the task ends, please talk to the researcher or contact the Massey University Health and Counselling Centre on 443 9973 or Building 100, Gate 5, Oteha Rohe**.**

The research takes place in two sessions of approximately 1 hour each – one session will start at 9am, and the second session at 5pm.

Who can participate?

I would like to invite you to take part in the study. You would need to be between the ages of 18 and 25 years, and have English as your first language, no diagnosed history of traumatic brain injury (including concussion) or psychological illness. Participants will need to avoid consuming alcohol and drugs for the day of testing and in the 24 hours immediately before testing.

Participants who complete both sessions will receive their choice of either a $20 petrol voucher or grocery voucher.

You can also receive an individualised report indicating whether you are a 'morning' or an 'evening' type, and your results on the computerised tasks. If you would like to receive a summary of findings you can enter your email address on the consent form.

Your rights

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study before the conclusion of both sessions;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it is concluded.

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Private Bag 102904, North Shore Mail Centre, Auckland 0745, New Zealand T +64 9 414 0800 extn 41244 F +64 9 414 0831
www.massey.ac.nz

Project Contacts

If you have any questions regarding this research please contact me or my supervisor for further information.

Researcher:

Denyse Pope
Email: denyse.pope.1@uni.massey.ac.nz

Supervisor:

Dr. Jennifer Stillman,
Telephone (09) 414 0800 ext. 41218,
Email: j.a.stillman@massey.ac.nz

This project has been reviewed and approved by the Massey University Human Ethics Committee: Northern, Application **10/005**. If you have any concerns about the conduct of this research, please contact Dr Denise Wilson, Chair, Massey University Human Ethics Committee: Northern, telephone 09 414 0800 x9070, email humanethicsnorth@massey.ac.nz.

APPENDIX B-1

Demographic and Health Questionnaire (Version 1)

The effects, in healthy adults, of 'morningness-eveningness' on information processing speeds for visual and auditory input

DEMOGRAPHIC INFORMATION AND HEALTH QUESTIONNAIRE

Important: Please inform the researcher if you have consumed any alcohol/drugs during the last 24 hours, in which case an alternative time may be made for you to complete the required tasks.

Please answer the following questions (you may decline to answer any particular question)

1. Age: ____________________

2. Years at University: ____________________

3. Gender: (please tick)

Male ☐
Female ☐

4. Have you ever suffered a traumatic brain injury (including concussion)?

Yes ☐
No ☐

5. Do you have a history of psychological problems?

Yes ☐
No ☐

6 a. Do you smoke cigarettes?

Yes ☐
No ☐

If your answer to question 6 a. was "Yes" please answer this question.

6 b. How long before testing commenced did you smoke a cigarette?

0-30 mins ☐
31-60 mins ☐
61-90 mins ☐
91-120 mins ☐
120+ mins ☐

Continued over

7 a. Have you eaten/had a drink today?

Yes	
No	

If yes, please specify: ……………………………………………………….

If your answer to question 7 a. was "Yes" please answer this question.

7 b. How long before testing commenced did you eat/drink?

0-30 mins	
31-60 mins	
61-90 mins	
91-120 mins	
120+ mins	

APPENDIX B-2

Demographic and Health Questionnaire (Version 2)

The effects, in healthy adults, of 'morningness-eveningness' on information processing speeds for visual and auditory input

DEMOGRAPHIC INFORMATION AND HEALTH QUESTIONNAIRE

Important: Please inform the researcher if you have consumed any alcohol/drugs during the last 24 hours, in which case an alternative time may be made for you to complete the required tasks.

Please answer the following questions (you may decline to answer any particular question)

6. Age: ______________________

7. Years at University: ______________________

8. Gender: (please tick)

Male ☐
Female ☐

9. Have you ever suffered a traumatic brain injury (including concussion)?

Yes ☐
No ☐

10. Do you have a history of psychological problems?

Yes ☐
No ☐

6 a. Do you smoke cigarettes?

Yes ☐
No ☐

If your answer to question 6 a. was "Yes" please answer this question.

6 b. How long before testing commenced did you smoke a cigarette?

0-30 mins ☐
31-60 mins ☐
61-90 mins ☐
91-120 mins ☐
120+ mins ☐

Continued over

7 a. **Have you eaten/had a drink today?**

Yes	☐
No	☐

If yes, please specify: …………………………………………………….

If your answer to question 7 a. was "Yes" please answer this question.

7 b. **How long before testing commenced did you eat/drink?**

0-30 mins	☐
31-60 mins	☐
61-90 mins	☐
91-120 mins	☐
120+ mins	☐

8 a. **Have you consumed caffeine today?**

Yes	☐
No	☐

If yes, please specify: …………………………………………………….

If your answer to question 8 a. was "Yes" please answer this question.

8 b. **How long before testing commenced did you consume caffeine?**

0-30 mins	☐
31-60 mins	☐
61-90 mins	☐
91-120 mins	☐
120+ mins	☐

APPENDIX B-3

Sample Consent Form

MASSEY UNIVERSITY
COLLEGE OF HUMANITIES AND SOCIAL SCIENCES
TE KURA PŪKENGA TANGATA

The effects, in healthy adults, of 'morningness-eveningness' on information processing speeds for visual and auditory input

PARTICIPANT CONSENT FORM - INDIVIDUAL

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

- I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: .... **Date:** ....

Full Name - printed ....

- I would like to receive a summary of the results of the study **Yes / No**
- I would like to receive an individualised report of my own results **Yes / No**

If you answered "Yes" to either of the above, please clearly enter your name and email address below.

<u>Please write clearly</u>

Name - printed ....

Email ....

APPENDIX C-1

SRT Visual Instructions

Simple Reaction Time Visual Instructions

You will be presented with a series of 20 numbers that appear briefly on screen at random intervals.
When you see a number, please press “1” on the keypad.

Press Enter To Continue

APPENDIX C-2

SRT Auditory Instructions

Simple Reaction Time Audio Instructions

You will be presented with a series of 20 numbers delivered through the speakers at random intervals.
When you hear a number, please press "1" on the keypad.

Press Enter To Continue

APPENDIX C-3

IRT Visual Instructions (Practice)

Input Reaction Time Visual Instructions

You will be presented with a series of 10 numbers which appear briefly on the screen.

When you see a number, enter the number you saw on the keypad.

You will have only one opportunity to enter the correct number,
which must be entered in the allocated time.

If you do not enter your answer before the next number is presented,
ignore that trial and move on to the next.

Press Enter To Continue

APPENDIX C-4

IRT Visual Instructions

Input Reaction Time Visual Instructions

You will be presented with a series of 20 numbers which appear briefly on the screen.

When you see a number, enter the number you saw on the keypad.

You will have only one opportunity to enter the correct number,
which must be entered in the allocated time.

If you do not enter your answer before the next number is presented,
ignore that trial and move on to the next.

Press Enter To Continue

APPENDIX C-5

IRT Auditory Instructions (Practice)

Input Reaction Time Audio Instructions

You will be presented with a series of 10 numbers presented through the speakers.

When you hear a number, enter the number you heard on the keypad.

You will have only one opportunity to enter the correct number,
which must be entered in the allocated time.

If you do not enter your answer before the next number is presented,
ignore that trial and move on to the next.

Press Enter To Continue

APPENDIX C-6

IRT Auditory Instructions

Input Reaction Time Audio Instructions

You will be presented with a series of 20 numbers presented through the speakers.

When you hear a number, enter the number you heard on the keypad.

You will have only one opportunity to enter the correct number,
which must be entered in the allocated time.

If you do not enter your answer before the next number is presented,
ignore that trial and move on to the next.

Press Enter To Continue

APPENDIX C-7

CRT Visual Instructions (Practice)

Complex Reaction Time Visual Instructions

You will be presented with a series of 11 numbers ranging between 1 and 9 that appear briefly on the screen.

You are required to add the first two numbers together, and enter the sum on the keypad.

When you see the next number add it to the previous number you saw, and enter the sum on the keypad.

For example, if the numbers “3” then “7” then “1” are presented, you would enter “10” then “8”.

You are **not** required to keep a running total of the numbers presented - only the sum of the two previous numbers you saw is required.

This is a challenging task.

If you lose your place, wait until you see two numbers in a row then enter your response.

You will have only one opportunity to enter the correct number, which must be entered in the allocated time.

If you do not enter your answer before the next number is presented, ignore that sum and move onto the next one.

Press Enter To Continue

APPENDIX C-8

CRT Visual Instructions

Complex Reaction Time Visual Instructions

You will be presented with a series of 61 numbers ranging between 1 and 9 that appear briefly on the screen.

You are required to add the first two numbers together, and enter the sum on the keypad.

When you see the next number add it to the previous number you saw, and enter the sum on the keypad.

For example, if the numbers “3” then “7” then “1” are presented, you would enter “10” then “8”.

You are **not** required to keep a running total of the numbers presented - only the sum of the two previous numbers you saw is required.

This is a challenging task.

If you lose your place, wait until you see two numbers in a row then enter your response.

You will have only one opportunity to enter the correct number, which must be entered in the allocated time.

If you do not enter your answer before the next number is presented, ignore that sum and move onto the next one.

Press Enter To Continue

APPENDIX C-9

CRT Auditory Instructions (Practice)

Complex Reaction Time Audio Instructions

You will be presented with a series of 11 numbers ranging between 1 and 9 delivered through the speakers.

You are required to add the first two numbers together, and enter the sum on the keypad.

When you hear the next number add it to the previous number you heard, and enter the sum on the keypad.

For example, if the numbers “3” then “7” then “1” are presented, you would enter “10” then “8”.

You are **not** required to keep a running total of the numbers presented - only the sum of the two previous numbers you heard is required.

This is a challenging task.

If you lose your place, wait until you hear two numbers in a row then enter your response.

You will have only one opportunity to enter the correct number, which must be entered in the allocated time.

If you do not enter your answer before the next number is presented, ignore that sum and move onto the next one.

Press Enter To Continue

APPENDIX C-10

CRT Auditory Instructions

Complex Reaction Time Audio Instructions

You will be presented with a series of 61 numbers ranging between 1 and 9 delivered through the speakers.

You are required to add the first two numbers together, and enter the sum on the keypad.

When you hear the next number add it to the previous number you heard, and enter the sum on the keypad.

For example, if the numbers “3” then “7” then “1” are presented, you would enter “10” then “8”.

You are **not** required to keep a running total of the numbers presented - only the sum of the two previous numbers you heard is required.

This is a challenging task.

If you lose your place, wait until you hear two numbers in a row then enter your response.

You will have only one opportunity to enter the correct number, which must be entered in the allocated time.

If you do not enter your answer before the next number is presented, ignore that sum and move onto the next one.

APPENDIX D-1

Means, Standard Deviations, and t values for the SRT and FRT Tasks (Visual and Auditory) According to Time of First Test Session

Table Appendix D-1.

Means, Standard Deviations, and t values for the SRT and FRT Tasks (Visual and Auditory) According to Time of First Test Session

	First session						
	Morning			Evening			
	n	*M*	*SD*	*n*	*M*	*SD*	*t*
AM session							
SRT							
Visual	19	314.43	53.00	16	285.60	32.03	1.900
Auditory	19	450.58	183.07	16	424.38	142.11	0.466
FRT							
Visual							
Digit 1	19	689.97	204.48	16	566.35	129.32	2.089*
Digit 2	19	844.84	283.14	16	698.73	149.76	1.854
Auditory							
Digit 1	19	733.51	233.01	16	626.46	131.26	1.707[a]
Digit 2	19	845.18	247.94	16	777.76	151.95	0.947

	Second session						
	Morning			Evening			
	n	*M*	*SD*	*n*	*M*	*SD*	*t*
PM session							
SRT							
Visual	19	287.61	43.27	16	340.52	51.19	-3.316*
Auditory	19	382.88	155.80	16	555.96	184.89	-3.007*
FRT							
Visual							
Digit 1	19	641.62	217.98	16	593.59	123.97	0.780
Digit 2	19	810.00	254.51	16	761.28	140.78	.715[a]
Auditory							
Digit 1	19	677.37	216.28	16	713.64	165.05	-0.549
Digit 2	19	832.73	245.98	16	837.66	224.83	-0.061

[a] *t* value when Significant Levene's Test Obtained (Equal Variances not Assumed Used)
* $p < .05$ ** $p < .01$ *** $p < .001$