THE EFFECTS OF SUSTAINED ATTENTION, WORKLOAD AND TASK-RELATED FATIGUE ON PHYSIOLOGICAL MEASURES AND PERFORMANCE DURING A TRACKING TASK

BY

CASEY DE GRAY BIRCH

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Department of Human Kinetics and Ergonomics

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ABSTRACT

Despite extensive research into the concept of mental fatigue there is as yet no “gold standard” definition or measurement technique available. Because of this a large amount of fatigue-related errors are still seen in the workplace. The complexity of the problem lies with the inability to directly measure mental processes as well as the various endogenous and exogenous factors that interact to produce the experienced fatigue. Fatigue has been divided into sleep-related and task-related fatigue; however the task-related aspect is evident both during normal waking hours as well as during periods of sleep deprivation, therefore this aspect is considered important in the understanding of fatigue in general. The concept of task-related fatigue has further been divided into active and passive fatigue states; however differentiation between the two requires careful consideration. Various physiological measures have been employed in an attempt to gain a better understanding of the mechanisms involved in the generation of fatigue, however often studies have produced dissociating results.

The current study considered the task-related fatigue elicited by a tracking task requiring sustained attention, in order to evaluate the usefulness of various cardiovascular and oculomotor measures as indicators of fatigue. A secondary aim was to determine whether the behavioural and physiological parameter responses could be used to infer the type of fatigue incurred (i.e. an active versus passive fatigue state) as well as the energetical mechanisms involved during task performance.

A simple driving simulator task was used as the main tracking task, requiring constant attention and concentration. This task was performed for approximately two hours. Three experimental groups (consisting of 14 subjects each) were used: a control group that performed the tracking task only, a group that performed a five minute auditory memory span task concurrently with the driving task after every 20 minutes of pure driving, and a group that performed a visual choice reaction task for five minutes following every 20 minute driving period. The secondary tasks were employed in order to evaluate the extent of resource allocation as well as arousal level. Performance measures included various driving performance parameters, as well as secondary task performance. Physiological measures included heart rate frequency (HR) and various time- and frequency-domain heart rate variability (HRV) parameters, pupil dilation, blink frequency and duration, fixations, and saccadic parameters as well as critical flicker fusion frequency (CFFF). The Borg CR-10 scale was used to evaluate subjective fatigue during the task, and the NASA-TLX was completed following the task.

A decline in driving performance over time was supplemented by measures such as HR, HRV and pupil dilation indicating an increase in parasympathetic activity (or a reduction in arousal). An increase in blink frequency was considered as a sign of withdrawal of attentional resources over time. Longer and faster saccades were also evident over time, coupled with shorter fixations.

With regards to the secondary task influence, the choice RT task did not affect any behavioural or physiological parameters, thereby contesting the active fatigue theory of resource depletion, as well as implying that the increase in demand for the same resources used by the primary task was insufficient to affect the state of the subjects. The increased load elicited by the memory span task improved driving performance and increased measures of HR, HRV, pupil dilation and blink frequency. Some of these measures produced opposite effects to what was expected; an attempt to explain the dissociation of the various physiological parameters was expressed in terms of arousal, effort and resource theories.

Overall, the results indicate that the fatigue and/or reduced arousal accompanying a monotonous sustained attention task can, to some degree, be alleviated through intermittent performance of a secondary task engaging mental resources other than the ones used for the primary task. The degree to which such a task is beneficial, however, requires careful consideration as while an immediate increase in arousal and primary task performance is noted, the impact of the task on general attentional resources may be detrimental in the case of reacting should an emergency situation occur.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

The role of mental workload and fatigue has become a prominent area of concern within the working world, as many occupations have transformed from a physical to a more mentally-demanding (or supervisory) role (Jorna, 1992). While the measurement of mental workload and fatigue is an important concept, there is as yet no “gold standard” definition for either workload or fatigue (Saxby *et al.,* 2007; Williamson *et al.,* 2011), as numerous aspects that can affect these, including both endogenous and exogenous factors (Thiffault and Bergeron, 2003a; Liu and Wu, 2009). While it would be ideal to consider these variables individually, various environmental, task-related and individual factors usually appear in combination to compound the situation and complicate interpretation of the actual cause of the fatigue (Sirevaag and Stern, 2000). Therefore isolation and evaluation of individual aspects of fatigue have as yet proved difficult, if not impossible. Many theories have been developed in an attempt to explain the processes relating to mental workload and fatigue. Energetical mechanisms such as arousal, activation and alertness, effort regulation, as well as resource theory have been used to explain the development of mental fatigue symptoms (De Waard, 1996; Matthews and Desmond, 2002). There is, however, often contradictory evidence and results from different studies, and therefore more research is needed in order to obtain an understanding of the underlying mechanisms.

Mental fatigue has been divided into two different types, namely sleep-related fatigue, and task-related fatigue (Desmond and Hancock, 2001; May and Baldwin, 2009). Sleep-related fatigue is affected mainly by endogenous factors such as circadian rhythm and sleep debt incurred (May and Baldwin, 2009; Williamson and Friswell, 2011), while task-related fatigue considers the exogenous effects of workload induced by the task itself (Desmond and Hancock, 2001).

While both sleep-related and task-related influences are important in our understanding of mental fatigue as a whole, the aim of this study was to negate the sleep-related aspects and to analyse only effects of task-related fatigue. Desmond and Hancock (2001) further divided task-related fatigue into active and passive fatigue - active fatigue ensues from tasks requiring continuous high perceptual-motor adjustment, while passive fatigue considers a less-demanding situation where few or no perceptual-motor responses are required. Vigilance and the act of sustained attention have been associated with the concept of passive fatigue; however other researchers have argued that the mere act of maintaining attention during a monotonous task could be considered as having a similar effect to a high workload condition (i.e. active fatigue) rather than an underload condition (Grandjean, 1979; Hancock and Verwey, 1997; van der Hulst *et al.,* 2001). Some authors have therefore considered tasks such as monotonous driving as being an integration of both active and passive fatigue (Schmidt *et al.,* 2009).

Performance deterioration is commonly linked to mental fatigue (Lal and Craig, 2001), and therefore performance measures are one of the most widely used methods of measurement in mental fatigue research. It has been noted, however, that performance deterioration often only occurs once fatigue is already severe (Mascord and Heath, 1992; Lal and Craig, 2001). The difficulty in determining when fatigue becomes apparent is due to the fact that an individual is able to apply various physiological mechanisms or coping strategies in order to maintain an optimal energetical state and prevent excessive fatigue and/or performance decrements (Hockey, 1997; Oron-Gilad and Hancock, 2005).

Due to the physiological changes that occur during mental processes, physiological measures are considered the most “natural” type of workload index (Brookhuis and de Waard, 2010) and are thought to be more sensitive measures of task demand than performance measures (Wang *et al.,* 2010). Attention to physiological measures is increasing, as it is considered that these variables will depict changes in mental state earlier than performance measures, and therefore provide an indication of impending fatigue before it becomes detrimental (Russo *et al.,* 2005). Numerous measures have been suggested, such as electroencephalography, cardiorespiratory measures, and oculometric measures. Again, conflicting results with regard to the reaction of these physiological measures to mental workload and fatigue are common, but it is possible that this is due to methodological differences (Matthews and Desmond, 2002). More research is therefore necessary in order to ascertain which measures are most reliable for use in mental fatigue research, as well as how they are expected to react in certain circumstances.

Subjective measures are also often used in such research, as the subjective component of workload and fatigue is considered very important (Lal and Craig, 2001). However, real-time collection of subjective data is intrusive and can add to an individual's mental workload, while validity and accuracy of subjective measures taken after a task tend to lose some of their validity (Rokicki, 1995). Miyake (2001) also found that while subjective assessment of workload is an important factor, it is greatly affected by factors such as task results and feelings of achievement. Brown (1994) noted the discrepancy between subjective feelings of fatigue and performance: he noted that it is possible for an individual's performance to deteriorate without any subjective feelings of fatigue, as well as for an individual to report feelings of fatigue with no concomitant performance decrement. Lal and Craig (2001) therefore suggest that if subjective measures are the main objective, they should be accompanied by objective measures in order to verify the results.

Due to the complicated and compounded nature of mental fatigue, this study has considered only a small portion of the problem in the hopes of clarifying some of the questions put forward in previous works. A simplistic and monotonous driving scenario is considered, in order to determine the fatigue induced by a task requiring vigilance and sustained attention over a prolonged period. In an attempt to answer the question of whether such a task is related to active or passive fatigue, secondary tasks are introduced intermittently and their effect on performance is considered in terms of the resource theory and its grounding in mental workload.

The main aim of this study is to assess the effect of such a task on physiological measures in order to ascertain which measures are best able to depict the changes in mental state over time, as well as the changes that inclusion of a secondary task would induce. Some studies, for example, have considered the inclusion of a secondary task during a prolonged monotonous driving situation in order to increase task engagement and possibly reduce the effects of monotony on performance (Oron-Gilad *et al.,* 2008; Gershon *et al.,* 2009; Atchley and Chan, 2011). These studies have used a variety of performance, subjective and objective measures. It is hoped that the combination of performance and physiological data obtained can be related to previous research on mental workload and some light can be shed on the questions relating to this type of mental fatigue.

STATEMENT OF THE PROBLEM

While sleep-related fatigue is seen as a major cause of road accidents, vigilance fluctuations are also evident during the day, where no sleep-related factors should be of concern (Schmidt *et al.,* 2009). Daytime fatigue is therefore characterised by a task-related fatigue. Fatigue during monotonous driving situations has been characterised as an underload and therefore passive fatigue; however a debate exists as to whether this is indeed an underload, or whether it is more characteristic of a high workload situation. This study proposes the use of both performance and physiological measures in an attempt to determine whether a prolonged monotonous driving situation adheres more to the characteristics of an active or passive task. It is also possible, as mentioned above, that a task such as driving is a combination of the two.

In order to achieve this objective, the study considered three experimental conditions – a control where the effect of driving alone on fatigue was analysed and compared to two other conditions involving intermittent secondary tasks requiring different resources. The introduction of secondary tasks was expected to provide insight into the type of workload and/or fatigue that the driving task produces.

RESEARCH HYPOTHESIS

It is expected that the prolonged driving situation will induce fatigue responses in both performance and physiological variables over time. Subjective ratings will also be recorded in order to highlight any commonalities or differences between subjective feelings of fatigue and physiological indicators of fatigue induced by the task. One of two results is expected during the conditions involving secondary tasks: If the fatigue imposed is an underload, it is expected that the secondary task will improve driving performance by functioning to increase arousal and increase mental workload to a more optimal state (i.e. a greater task engagement). If the fatigue is more characteristic of an overload, it is hypothesized that the addition of the secondary task will either hamper the driving performance further, or the performance of the secondary task will be compromised due to the depletion of resources. The main resources utilised during the tracking task are visual perception, spatially-coded working memory and motor response (Liang and Lee, 2010). One of the secondary tasks required the same visuo-motor resources, while the second required auditory perception and verbal response, resources considered to be idle during the primary task.

STATISTICAL HYPOTHESES

As mentioned previously, objective measures of both performance and physiological response as well as subjective measures were taken. The following hypotheses were tested:

1. Performance measures will show a decline over time for all three conditions, indicating that fatigue is evident.

2. The decline in performance will be greater during the control task where no secondary tasks are administered.

3. The physiological measures will show a time-on-task effect, synonymous with previous literature.

4. The physiological measures will show a workload effect during secondary task performance (e.g. pupil increase, decrease in heart rate variability)

5. Effect of secondary task:

    a. If underload: performance will improve during dual-task periods; physiological measures (i.e. heart rate variability) will depict less effort;

variables such as pupil diameter will depict an increase in mental workload.

   b. If overload: performance will decrease due to interference from secondary task; physiological measures (i.e. heart rate variability) will depict that greater effort is required, variables such as pupil diameter will depict an increase in workload.

6. The effect of the secondary task may not remain constant throughout (while in the beginning the secondary task may improve performance, it may be detrimental near the end of the protocol if the nature of the fatigue changes).

7. The effect of the secondary task is transient (i.e. driving goes back to normal after the secondary task is stopped) – this would indicate a fatigue rather than a down-regulation effect.

DELIMITATIONS

The sample group in this research consisted of 42 Rhodes University students (21 male and 21 female) between the ages of 19 and 27.

The main task consisted of a driving task performed for a period of approximately 115 minutes. Three experimental conditions were performed – a control group where no secondary task was used, a memory group where an auditory memory test was implemented periodically, and a choice reaction time (RT) group, where a visual choice RT task was implemented periodically. A between-subject design was used, randomly assigning 14 subjects to each of the three experimental groups. Each group consisted of seven males and seven females, and the groups were evenly distributed in terms of driving experience, gaming experience, and experience with the specific driving simulator used.

Individuals were excluded from the study if they had a history of sleep disorders, epilepsy, ADHD or any similar attention-related disorders. Subjects included in the study were required to have had 7-8 hours sleep the night before testing, and refrain from alcohol consumption 24 hours and strenuous physical exercise 12 hours prior to testing. Caffeine intake was limited to a maximum of two cups of coffee on the day, with no caffeine consumed 1-2 hours before the testing.

As previously mentioned, the study focussed mainly on the reaction of physiological parameters to the experimental conditions. Dependent variables included heart rate and heart rate variability (time- and frequency-domain), pupil diameter, blink frequency and duration, fixation duration, various saccade parameters, as well as critical flicker fusion frequency. Subjective measures included a Borg CR-10 scale as well as the NASA Task Load Index. Performance measures included mean driving deviation as well as performance of both the auditory memory and choice reaction time tasks.

LIMITATIONS

The use of three independent sample groups compounds the problem of individual variability, especially with regards to physiological responses. While provision was made to accommodate some of the differences that may affect results, it must be noted that not all variables could be controlled during a study of this scope.

A relatively small sample size of 14 subjects per group (n = 42) was used in this research due to limitations in both time and subject availability. While it would have been more reliable to use a repeated-subject design, the use of students provided a problem with scheduling as well as motivation. It was considered that the motivational factor alone would substantially affect the results, as subjects would be ill-inclined to perform the task three times due to the tedious and fatiguing nature of the task.

The Morningness-Eveningness questionnaire developed by Horne and Osterberg (1979) was administered in order to determine the chronotype of the subjects, but because none of the subjects fell in to the “definitely morning” or “definitely evening” types, this variable was not considered as an important criteria, as all testing took place during the day. With regard to the time of testing, six subjects per group performed the experiment between 9:00-11:30 am, while the other eight performed the experiment between 2:30-5:00 pm. Age was also not considered relevant for group distribution as the entire population fell between a very narrow age group. Gender was evenly distributed between the groups, with seven males and seven females in each group.

As mentioned previously, subjects were distributed between the groups in terms of their driving experience, experience with video games and experience with the Rhodes University driving simulator. Driving experience was assessed as a combination of both years of driving experience and frequency of long distance (>1.5 hour) trips, and gaming experience was determined by both the frequency and duration of play. Other individual factors not considered that may have had an effect on the subject's performance include personality type and/or emotional state at the time of testing, diet, long-term sleeping habits, etc.

With regards to the test itself, the driving task used was considered more of a general perceptual-motor task rather than a realistic driving situation. The purpose of the task was to require sustained attention and concentration in an attempt to facilitate fatigue rapidly. Due to the unrealistic nature of the driving simulator used, this study lacks applicability to real-world driving situations. It is considered, however, that the simplicity of the task used may facilitate insight into the more fundamental questions and mechanisms involved in prolonged task performance without other factors compounding interpretation.

A further consideration is the degree to which the two secondary tasks can be compared. The tasks were initially selected due to their use of different resources; however the amount of cognitive activity required is by no means equal and therefore it is difficult to compare the tasks in terms of workload or difficulty. The auditory memory task required the largest string of numbers the individual was able to remember and therefore taxed one's short-term memory as much as possible. The choice reaction task, on the other hand, was difficult to institute – it was hypothesized that a task with a higher stimulus presentation frequency would both hinder driving performance and result in a habituation effect. A task of greater complexity would also hinder driving in that the visual nature of the task would take the subjects attention off the road for a longer period of time.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

The nature of work has changed over time from activities requiring considerable physical effort to a greater requirement for cognitive effort, sustained vigilance, selective attention, complex decision making and perceptual-motor control skills (Brown, 1982). Because of this, new work-related problem areas such as mental workload and fatigue have become more prominent. The management of cognitive fatigue is important not only for enhancing productivity, but also for occupational safety, as many incidents and accidents are related to cognitive fatigue as a result of sustained performance (Zhang *et al.,* 2009). As yet there is no standard definition for mental workload or fatigue (Saxby *et al.,* 2007). In an effort to overcome this problem, research in the last few years has attempted to find suitable measures of mental workload in order to provide a means of explaining errors or declines in performance associated with prolonged tasks (Recarte *et al.,* 2008). The majority of fatigue-related research is concerned with sleep research and endogenous fluctuations of alertness (Thiffault and Bergeron, 2003a). Fatigue is, however, also affected by the demands of the task itself, and can become evident even in alert and non-sleep deprived individuals (Oron-Gilad *et al.,* 2008).

This review will first consider the general concept of mental fatigue. The mechanisms underlying fatigue will then be addressed, with particular reference to task-related fatigue and the various concepts that have been used to explain this phenomenon. Driving is used as an example of a task subject to such fatigue. Subjective and objective methods of workload and fatigue measurement will be discussed, with focus being placed on cardiovascular and oculomotor measurement techniques.

FATIGUE

What is fatigue?

Fatigue is considered as a functional state somewhere between the extremes of alertness and sleep (Grandjean, 1979; Desmond and Hancock, 2001). Gaillard (2001) considers fatigue to be a response of both mind and body to a reduction in resources due to execution of a mental task, and a warning of increasing risk of performance failing should the task continue. Zhang *et al.* (2009) defines cognitive fatigue as the unwillingness to continue performance of mental work in alert, motivated subjects, characterised by a reduction in performance after continuous workload, and accompanied by subjective feelings of exhaustion. It thus differs from the concept of workload in that it is not only determined by the amount of work done, but also by what still has to be done – in other words, fatigue is a state induced by enduring task performance (Gaillard, 2001). Fatigue is a problematic condition because, due to its personal nature, it is difficult to identify explicitly and therefore difficult to measure and regulate (Desmond and Hancock, 2001). Nilsson *et al.* (1997) state that any activity, if pursued long enough, will result in the inability to maintain skilled performance. It has been recognised, however, that fatigue results not only from prolonged activity, but can be elicited by other psychological, socioeconomic and environmental factors (Brown, 1994). Gaillard (2001), for example, notes that fatigue may also refer to a subjective complaint encompassing a general lack of energy, which need not be related to the amount of work. Fatigue can therefore be defined by the physiological changes that take place, or in terms of environmental or behavioural factors that constitute the necessary conditions for it to occur (Drory, 1985).

There is no way to directly measure the extent of fatigue itself (i.e. no absolute measure of fatigue) – all research concerning fatigue merely measures certain manifestations or indicators of fatigue (Grandjean, 1979). One problem with fatigue research is the definition of the causal agents, which are either within the work environment, in the individual themselves, or in the interaction between the two (Hancock and Verwey, 1997). Sirevaag and Stern (2000) propose that work-induced mental fatigue develops as a function of time-on-task, and the rate at which it develops is a function of the complex interaction between a variety of both subject and task variables. Subject variables include state factors (such as sleep history, drug intake and biological rhythms) and trait attributes, for example the ability to focus and maintain attention (Sirevaag and Stern, 2000). Task variables include the nature of the task (perceptual, central or motor), and the magnitude (i.e. difficulty level) of the demands placed on the operator (Sirevaag and Stern, 2000). Drory (1985), when considering the problem of fatigue solely in terms of task demand, notes that the intensity, duration and monotony of manual and/or mental workload can lead to a physiological and psychological state of fatigue. A third consideration for mental fatigue is the interaction between a given operator and a particular task – here factors such as expertise, motivation and the perceived consequences of a performance breakdown come into play (Sirevaag and Stern, 2000).

Fatigue, workload and vigilance

Hancock and Verwey (1997) propose that fatigue and workload are related, as they are both forms of an energetic response. Desmond and Hancock (2001) differentiate between two forms of task-related fatigue, namely active and passive fatigue. Active fatigue results from prolonged exposure to high workload, caused by continuous and prolonged perceptual-motor adjustments (Desmond and Hancock, 2001). Passive fatigue, on the other hand, is associated with conditions of underload, where little or no perceptual-motor response is required (Liu and Wu, 2009; Desmond and Hancock, 2001). Underload is thought to result in a reduced alertness and lowered attention, while overload results in distraction, diverted attention and insufficient capacity for the necessary information processing (Brookhuis and de Waard, 2010). When an individual is under-aroused, performance failure is thought to occur due to insufficient effort being invested in the task (Kahneman, 1973). Under excessive mental workload, on the other hand, individuals may exhibit delayed information processing or even fail to respond entirely because the amount of information surpasses their capacity to process it (Ryu and Myung, 2005). Kahneman (1973) explains this as a narrowing of attention – when arousal levels are high, attention is focussed on the most important aspects of a situation at the expense of other aspects.

Schmidt *et al.* (2009) note that a task such as monotonous driving integrates both active and passive fatigue. This further compounds the problem of identifying a state of fatigue, as it is hypothesized that active and passive fatigue states may elicit different patterns of both physiological and subjective state response (Saxby *et al.,* 2007). Matthews and Desmond (2002), for example, found in their "fatigue induction" condition that performance deteriorated significantly on the straight road (monotonous) sections, while no significant change in performance occurred during sections where a curved road was used. This indicates the possibility of a type of stress response during active fatigue which allows drivers to maintain a higher level of task engagement during a high workload task (Saxby *et al.,* 2007). Desmond and Hancock (2001) found that an already-fatigued driver was at greater risk of an accident when the demands were low – during periods of low demand fatigued subjects failed to mobilize effort effectively; however when the demands were increased, subjects were better able to maintain a constant level of performance.

Mascord and Heath's (1992) definition of fatigue corresponds to the concept of passive fatigue – they define fatigue in terms of a decrement of non-specific arousal, or "a decrease in human performance efficiency resulting from the maintenance of vigilance in a monotonous psychomotor task for long periods" (pp. 19). According to Schmidt *et al.* (2009), driving can be considered a vigilance task, especially during periods of low task demand, as with monotonous driving situations. The reduction in cerebral activation that accompanies such a task will result in feelings of weariness, decreased vigilance, disinclination for the task and a decline in alertness (Grandjean, 1979). Thiffault and Bergeron (2003b) propose that vigilance fluctuates with physiological alertness (arousal), which is influenced by both endogenous and exogenous (task-induced) factors. Endogenous factors are associated with long-term fluctuations of alertness affecting the state of the individual, such as circadian variations and sleep history (Thiffault and Bergeron, 2003a). Exogenous factors stem from the interaction between the individual and the environment – here factors such as the nature and difficulty of a task are mediated by factors such as the expertise of the individual as well as, for example, motivation or the perceived consequences of failure (Sirevaag and Stern, 2000). For instance, a monotonous and undemanding road can produce fluctuations in arousal that result in a decrease in alertness and vigilance (Thiffault and Bergeron, 2003a). Oron-Gilad *et al.* (2008) were able to produce fatigue symptoms in a monotonous driving situation when subjects were neither tired nor sleep deprived before the experiment – this further highlights the need for task-related fatigue research, as both endogenous and exogenous factors interact continuously and jointly determine an individual's ability to perform (Thiffault and Bergeron, 2003a).

Grandjean (1979) notes the difficulty in determining whether a monotonous, repetitive task is merely boring, or whether excessive vigilance demands of the task are in fact fatiguing. Previous vigilance studies (such as extended driving), while thought to provoke a situation of underload, have been reconsidered as tasks of considerably high workload, with the associated fatigue being explained as a consequence of maintaining the high level of attention that is required by the task (Hancock and Verwey, 1997). It is the belief of Hancock and Verwey (1997) that fatigue during such tasks is directly related to the workload of sustained attention, and while different contributory factors may be involved in the generation of fatigue, the output of such fatigue is similar to that of a prolonged high workload situation. Thackray (1981) proposed that the combination of a monotonous task (characterised by a reduction in arousal) and the opposing requirement for a constant high level of alertness (increased arousal) requires considerable effort, and will therefore result in fatigue. In other words, the level of arousal required for optimal performance is incompatible with the actual determinants of arousal (Brown, 1982). Sustained performance on a task that is not self-paced therefore requires increased control activity to maintain task orientation and activation against (possibly increasing) effort costs (van der Hulst *et al.*, 2001). A vigilance task such as prolonged driving can therefore be considered a demanding task, even though cognitive demands are low (van der Hulst *et al.*, 2001).

Theories relating to fatigue and workload

Arousal and activation theory

The conventional concept of stress, attention and performance considers that external stressors cause an increase in general arousal, which affects the efficiency of information processing and performance (Matthews *et al.,* 2010). This arousal theory considers a general, non-specific energetical or activation system to be responsible for mobilising and regulating the human response to a stressor (Staal, 2004). The inverted U principle, first coined by Yerkes and Dodson (1908), depicts a relationship between arousal and performance, with performance efficiency increasing to a peak as arousal increases, but decreasing as arousal becomes excessively high (Brown, 1982). Therefore performance is negatively affected both when arousal is low and when arousal is too high (Staal, 2004). Arousal is seen as a function of the stimulation from the task and environment, and therefore performance decrements observed during prolonged monotonous tasks can be explained as a reduced stimulation from a virtually unchanging or repetitive task environment (Brown, 1982).

Fatigue is said to occur when an individual is in a state of reduced attentional capacity (Desmond and Hancock, 2001), with attention being affected by a reduced state of non-specific arousal (Mascord and Heath, 1992). This reduction arises from two distinct conditions: either one's attention is depleted by a constant, unavoidable demand placed on it, or a chronic under-stimulation occurs, where attention decreases in an adaptive response to the reduced sampling of the environment (Desmond and Hancock, 2001).

The inverted-U concept of arousal has been greatly criticised (Hancock and Warm, 1989; Matthews *et al.,* 2010) for numerous reasons. Firstly, arousal cannot be overtly generated in a laboratory setting – physiological reactions to workload and stress are typically linked to arousal as supposed markers, but arousal itself is a theoretical construct (Staal, 2004). Matthews *et al.* (2010) state that because multiple brain systems control both cortical arousal and attention it is highly unlikely that there is such a general relationship between the two constructs. It has also been found that various stressors have different effects and result in different patterns of behaviour. Therefore it is unlikely that there is a singular mechanism that mediates an individual's response to stress (Broadbent, 1963). Any given stressor will produce multiple changes in both psychological and physiological functioning, and any concomitant change in performance may therefore have nothing to do with arousal (Matthews *et al.,* 2010).

In an attempt to account for the insufficiency of the general arousal theory, further energetical mechanisms were proposed. Pribram and McGuinness (1975) suggested the existence of two cortical regulatory systems in the body – arousal being the externally oriented system, and activation the internally oriented system. Arousal and activation can be distinguished from each other at both cortical and brain-stem level, with arousal being the registration of information, resulting in short, phasic (autonomic) changes, and activation being an organisation of behaviour characterised by a vigilant (tonic) readiness to respond (Pribram and McGuinness, 1975; Mulder 1986). A third mechanism - effort - was also proposed by Pribram and McGuinness (1975), as the mechanism that controls and coordinates both arousal and activation. Sanders (1983) then attempted to link these energetical mechanisms to the linear model of information processing (see Figure 1). In addition to coordinating arousal and activation, effort is also said to be directly responsible for conscious processing, or computational control for decision-making processes (Sanders, 1983; Hockey, 1997).

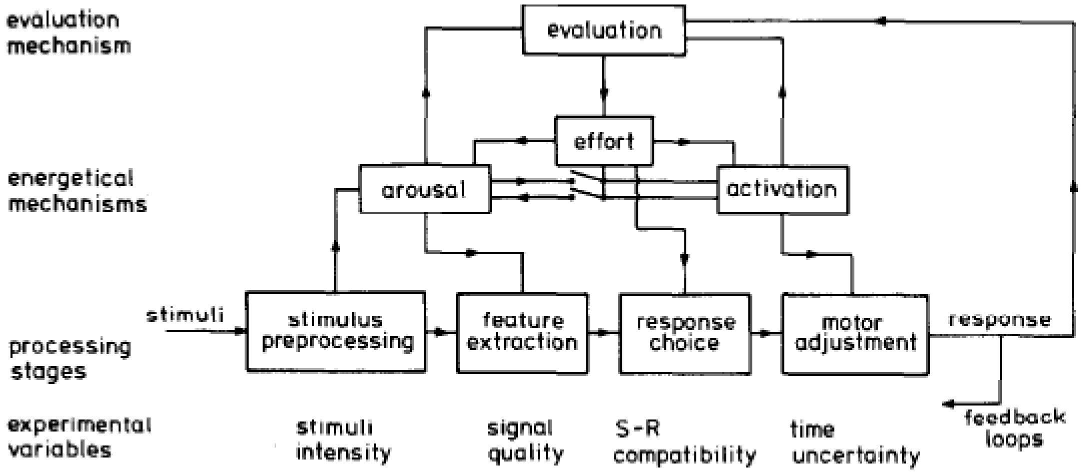

Figure 1: The cognitive-energetical model proposed by Sanders (1983). The basal energetical mechanisms of arousal and activation are linked to input and output processing stages respectively. These basal mechanisms are mediated by effort, which is also directly linked to the central process of response choice.

Resource theory

The concept of resources has strong roots in both information processing and energetic theories (Hockey, 1997). The resource theory suggests the existence of a general reservoir of mental resources that can be drawn from in order to assist an individual in performing a task (Staal, 2004). The individual can therefore be characterised by a limited supply or capacity for both attention and processing (Oron-Gilad and Hancock, 2005). Decrements in performance efficiency are said to occur when the amount of available resources is insufficient to meet the demand presented by the task (Oron-Gilad and Hancock, 2005). Early research by Kahneman (1973) presented a capacity model suggesting a general resource pool used by all tasks. This pool is said to have a finite limit, based on the degree of arousal of the individual (Kahneman, 1973). The ability to perform tasks concurrently would therefore depend on the effective allocation of attention to each task – if the demands of the tasks exceed the upper limit of the available resources, interference will occur and performance will suffer (Young and Stanton, 2002a). Young and Stanton (2002a) then presented an alternate notion to explain the concept of underload: they suggest that the available attentional resources shrink in response to undemanding situations, thereby artificially lowering the individuals' maximum capacity and affecting performance.

Following the initial proposal of a general resource pool, Wickens (1991, 2008) proposed the multiple resource theory, in order to account for factors that arose in workload research such as difficulty insensitivity, structural alteration effects and the phenomenon of perfect timesharing between tasks. This theory contends that there are multiple attentional resources used in different situations (see Figure 2). These resources can be defined by four dimensions, namely *processing stage* (perceptual/cognitive tasks require different resources than those involved in selection and action); *processing code* (spatial activity uses different resources to verbal/linguistic activity), *perceptual modalities* (auditory perception versus visual perception) and, more recently included, *visual channels* (focal or ambient vision) (Wickens, 1991, 2008). Complex or multiple component tasks (such as driving) may draw on multiple resources, and it is unclear whether fatigue differentially affects these different resources, or whether the resources are more generally affected (Matthews and Desmond, 2002). Some performance measures may, therefore, be more sensitive to fatigue than others, so fatigue effects should be considered across a range of performance indicators (Matthews and Desmond, 2002).

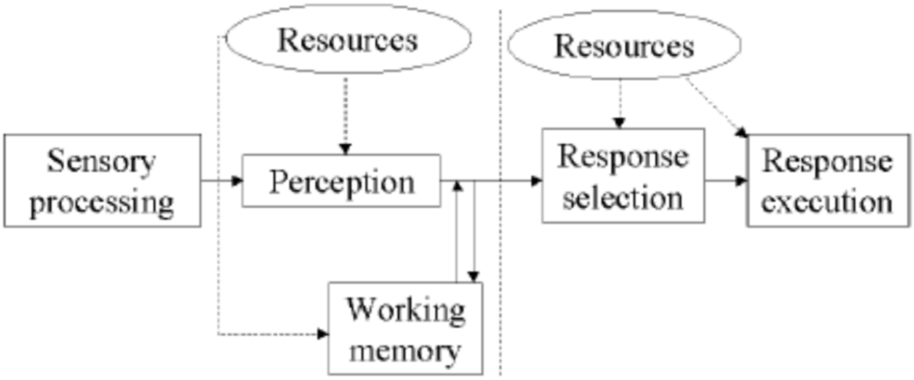

Figure 2: Representation from Wickens (2002) of two separate resources supplying different stages of information processing.

Effort

The concept of resources has also been used to imply the mobilisation of energy, to refer to activities which incur costs and require additional mental effort (Hockey, 1997). Matthews and Desmond (2002) note that both resources and effort may be implicated in the effects of fatigue, as well as the ability for self-regulation and voluntary control over resource allocation. This theory considers the critical aspect not to be resource availability, but rather the individual’s ability to meet the level of effort required by current task demands (Matthews and Desmond, 2002). Mulder (1986) differentiated between two types of mental effort that can be invested, namely “task effort”, a response to computational demands of a task (such as high working memory load, multi-tasking), and “state effort”, which is needed to maintain or “protect” performance from detrimental influences such as fatigue.

Fatigue is seen to increase the difficulty of continuous performance, and to maintain performance the individual must increase the effort exerted in order to counteract the increasing difficulty (Kahneman, 1973). The extra energy (in the form of mental effort) allocated to maintain performance can only be maintained for a short period, as physiological and psychological costs are high and will induce cognitive strain and mental fatigue (Gaillard, 1993; 2001). Effort can be invested in terms of mobilising extra resources to meet the requirements of a challenging task, or it may be invested as a concentrated attempt to counteract the boredom induced by a monotonous task (Brown, 1994). Performance will therefore only be degraded if the total effort required by a task surpasses the limitations of the individual's information processing system (Jorna, 1992).

A potential product of fatigue is a reduced ability to match one's effort to the demands of a task, as fatigue reduces the range or efficiency of strategies available for effort regulation (Oron-Gilad and Hancock, 2005). Jorna (1992) notes that human behaviour is adaptive in nature, and seeks to maintain an acceptable level of performance at a comfortable energetical state, or a comfortable level of effort. Therefore if maintaining performance is associated with increasing effort costs, fatigue may have a general adaptive role in shifting behaviour towards a strategy that demands less effort (Hockey, 1997). This is achieved by either lowering the standard of acceptable performance, or by adopting a strategy that requires less effort (Matthews and Desmond, 2002). Common strategies include altering the speed-accuracy trade-off, or concentrating on the most relevant aspects of the task and ignoring other aspects (Gaillard, 2001). This response, known as the "passive coping" mode of effort investment ensures that effort remains stable and the individual does not incur further costs (Hockey, 1997). Strategy shifts can therefore be interpreted as economising on effort while attempting to maintain adequate performance and protect task priorities (van der Hulst *et al.*, 2001).

Matthews and Desmond (2002) found this effort-related theory to apply to a driving situation more stringently than the resource theory, with fatigued drivers appearing to have more difficulty mobilizing sufficient task-directed effort only when task demands were very low. The concept of fatigue occurring during times of low task demand implies that underload results in a general reduction in executive control with several possibilities for the source of maladaptive effort regulation, such as failing to detect the performance deficit or an increased acceptance of the deficit (Matthews and Desmond, 2002). This corresponds with a question proposed by van der Hulst *et al.* (2001) of whether performance decrements due to fatigue can be explained by reduced motivation or the involuntary inability to adequately monitor performance. Matthews and Desmond (2002) considered the aspect of motivation in their second study, and found that motivation failed to influence the more demanding parts of the driving task – this suggests that highly demanding tasks are themselves sufficient to maintain active, effortful control of performance regardless of the individual's motivational state.

Oron-Gilad and Hancock (2005) proposed that individuals adopt different strategies for coping with fatigue relative to the demands and conditions of the task. If an individual becomes subjectively aware of fatigue, a variety of outcomes are possible: the individual may choose to rest, they may resort to external stimulation such as chemical stimulants to offset fatigue, or they may continue to perform regardless of the fatigue experienced (Job and Dalziel, 2001). Individuals are able to choose and modify coping strategies and motivational factors based on their level of fatigue as well as the changing demands of a task (Gawron *et al.,* 2001). The way in which an individual copes is mediated by factors such as prior learning, individual differences in the physiology of relevant systems, and psychological factors (Job and Dalziel, 2001). Brown (1994) notes that with sufficient motivation the investment of extra effort can be maintained over longer periods. Fatigue will therefore have adverse effects on efficiency, though not necessarily effectiveness, when an individual continues with a task after they have begun to experience fatigue (Brown, 1994).

MEASURES OF MENTAL WORKLOAD AND FATIGUE

Empirical measures of workload can be categorized into three major classes of techniques, namely performance-based techniques, subjective workload assessment techniques and physiological workload assessment techniques (Eggemeier *et al.*, 1991). Behavioural and subjective measures can be used to make detailed inferences on an operator's mental workload, however Ryu and Myung (2005) consider that physiological measures may be more suitable for practical applications in the field, as they provide continuous data and are not intrusive on primary task performance. Mascord and Heath (1992) note that the level of performance of a task can be maintained following the onset of fatigue by increasing motivation and/or other compensatory adjustments. This means that while subjective feelings of fatigue may be high, there may be little or no effect on overall performance – it is for this reason that physiological measures are of interest, as they may depict a change in operator state before performance breakdown, loss of attention or reduced accuracy occur (Mascord and Heath, 1992).

Properties of measurement techniques

When examining the usability of various assessment techniques, Eggemeier *et al.* (1991) cite three important properties that need to be considered, namely sensitivity, diagnosticity and intrusiveness of the various measures. *Sensitivity* refers to the ability of a technique to differentiate between the levels of workload variables (e.g. complexity, multi-tasking) that are associated with the performance of a task (Eggemeier *et al.*, 1991; Fairclough *et al.,* 2005). This is an important consideration, as techniques with low sensitivity will be less able to discriminate workload differences between tasks or conditions (Eggemeier *et al.*, 1991). Variables that could affect sensitivity are those such as the type of task, as well as rapid changes in workload – measurement techniques need to be able to respond to sudden changes in workload in order to provide a reliable estimate of the different levels of workload imposed on the subject (Eggemeier *et al.*, 1991).

Diagnosticity refers to the capability of a technique to discriminate between different types of mental workload (Eggemeier *et al.*, 1991). A workload measure should not only be able to identify when workload varies, but also indicate the cause of the variation – i.e. a measure is said to be diagnostic within the multiple resource theory context if it is sensitive to specific resources and not to others (Wickens, 1984; de Waard, 1996). While one assessment technique may be able to provide a global measure of resource allocation, another may be more sensitive to verbal perceptual/central processing resources, while a third may be selectively sensitive to variations in spatial perceptual/central processing load (Eggemeier *et al.*, 1991). The workload measure chosen is dependent of the objective of the study – if a general workload level needs to be established, diagnosticity is not the main concern of the experimenter (de Waard, 1996). If, however, the source of the workload is of interest, a diagnostic measure could provide more insight to a situation with high workload demands (de Waard, 1996). A highly diagnostic measure responds in a unique manner and is unaffected by confounding variables such as physical activity, emotional stress and room temperature that may be unrelated to mental workload or information processing ability (Fairclough *et al.,* 2005; Wickens 1984). Eggemeier *et al.* (1991) cite certain measures, such as primary-task and subjective measures as being globally sensitive and able to provide an index of variations in workload across a variety of information processing functions. Other techniques, such as secondary-task methodology and certain physiological measures are more highly diagnostic and able to identify variations in workload imposed on particular types of processing functions (Eggemeier *et al.*, 1991). Pupil diameter is an example of a global measure, reflecting general demands and having low diagnosticity (de Waard, 1996). Beatty (1982) noted that pupil diameter is equally responsive to different processing stages, such as response load or encoding and central processing load.

Intrusiveness refers to any disruption of an ongoing primary task performance resulting from the application of a workload measurement technique (Eggemeier *et al.*, 1991). This disruption due to application of a measurement technique is undesirable and should be kept to a minimum where possible (de Waard, 1996).

Performance measures

Performance-based approaches for workload measurement include two major types of measures, namely primary-task measurements and secondary-task measurements (Eggemeier *et al.*, 1991). Primary-task measures assess workload by considering aspects of the individual's capability to perform the required task (Eggemeier *et al.*, 1991). Fatigue is often characterised by a reduction in performance after a continuous workload, with the most frequently observed effect being a slowing of sensorimotor performance (Zhang *et al.,* 2009; Mascord and Heath, 1992). The performance decrement is often attributed to a reduced alertness that impairs both an individual's capability and willingness to perform (Wijesuriya *et al.,* 2007). One limitation of performance measures is that they often only occur when fatigue is already high (Mascord and Heath, 1992). This is because performance can be stabilised against deteriorating fatigue effects through the mobilisation of additional mental resources, motivation and other coping strategies (Mascord and Heath, 1992; Hockey, 1997; Schleicher *et al.,* 2008). Individuals are able to choose and modify coping strategies and motivational factors based on their level of fatigue as well as the changing demands of a task (Gawron *et al.,* 2001). It is therefore difficult to determine a general performance measure that would indicate fatigue, as error patterns may vary with different levels of fatigue, as well as the individual characteristics of each subject (Schleicher *et al.,* 2008). It is important to note, however, that while fatigue may not necessarily generate a detectable performance decrement, it can still cause a loss of attention that could lead to an accident (Mascord and Heath, 1992).

Primary task measures are also unable to differentiate the level of workload between two individuals: while one operator may be at the limit of his/her capacity, another may be capable of performing an additional task without any change in the level of primary task performance (de Waard, 1996). de Waard (1996) therefore stresses the necessity of combining primary task measures with other workload measures in order to draw valid conclusions about the operator's energetical state.

Secondary task performance

The dual-task paradigm measures mental workload by observing the subject's performance on a second concurrent task – this is assumed to be a direct representation of the degree of load imposed by the primary task (Whelan, 2007). Two types of secondary tasks can be employed: the "loading task paradigm", where secondary task performance is maintained regardless of performance decrements to the primary task, and the "subsidiary task paradigm", where subjects are instructed to maintain primary task performance at any cost (de Waard, 1996). The rationale behind this is that any spare processing capacity not used by the primary task can be allocated to the secondary task, which allows an index of primary task workload to be derived from the level of performance on the secondary task (Eggemeier *et al.*, 1991). Secondary tasks may reflect differences in task resource demand, automation, or practice that are not reflected in primary task performance (Wickens, 1984). The use of a secondary task is advantageous in that it is able to give real-time indications of workload with a high degree of sensitivity, as well as being effective in a within-subject design, making the measurement of mental workload independent of individual differences that corrupt a between-subjects design (Whelan, 2007).

During tasks of sustained attention and vigilance, the introduction of a secondary task has been shown to improve performance of the primary task (Drory, 1985). This has been explained by arousal theory – it is hypothesized that a secondary task which requires some additional alertness but is not too demanding assists in breaking the monotony of the primary task and improves the individual's responses (Drory, 1985). When considering it from a workload point of view: in an underload situation, an additional task functions to increase the task demand to a more optimal load level (Oron-Gilad *et al.,* 2008). For this type of application, it is suggested that the secondary task should not be so demanding so as to distract attention from the primary task, but yet still require the individual to maintain a higher level of alertness (Drory, 1985).

This type of secondary task application has been considered in settings of monotonous and fatigued driving as a means of intervention, or prevention of fatigue. The type of secondary task used, however, requires careful consideration: Drory (1985) found that while a voice communication task improved the driving performance of the subjects, the subjective report of fatigue was greater than in the control conditions. Oron-Gilad *et al.* (2008) tested the effect of an intermittent choice reaction task, working memory task and "trivia" long term memory task on a two-hour driving task. They found that each task had a different effect: while the trivia task provided consistent positive results, the working memory task interfered with the driving, and the choice reaction task appeared to actually induce fatigue (Oron-Gilad *et al.,* 2008). Atchley and Chan (2011) used a verbal word association task as a secondary task during monotonous driving and found that a strategically placed concurrent task (in the last time block) had a greater effect than a concurrent task run throughout the experiment. They concluded that it was perhaps not the concurrent task per se, but rather the level of engagement with the task that is important (Atchley and Chan, 2011). Oron-Gilad *et al.* (2008) suggested, for example, that the modification of the content of a trivia-like task to suit the individual's personal preferences may enhance the effect observed.

Subjective measures

Nilsson *et al.* (1997) stress the usefulness of subjective measures of fatigue, due to the fact that the brain is able to monitor many more physiological processes than is feasible by objective methods, as well as the use of cognitive factors including information from the external environment, motivational states and memory to calculate fatigue. Hart and Staveland (1988) stated that subjective ratings may be a more sensitive and valid indicator of mental workload than other measurement techniques. As stated by de Waard (1996): “no one is able to provide a more accurate judgement with respect to experienced load than the person concerned” (pp. 31). Recarte *et al.* (2008) note, however, that many internal processes are not consciously accessible. It is also possible that individuals may not be able to discriminate between different task dimensions (such as difficulty versus effort), and even if they do, different values could be obtained through differing decision criteria (Recarte *et al.,* 2008). It is, however, important to take subjective feelings of fatigue into account, as physical factors need to be reinforced by subjective assessment before one can correctly assume that they indicate a state of fatigue (Grandjean, 1979).

While there has been much debate concerning the use of multi-dimensional versus unidimensional subjective scales for workload estimates, comparisons of these scales have shown little or no advantage over multi-dimensional scales for a wide range of tasks (Verwey and Veltman, 1996). While diagnosticity is probably greater with a multi-dimensional scale (for example, NASA-TLX), if a global rating of workload is required, a unidimensional scale is sufficient (de Waard, 1996). Verwey and Veltman (1996) concluded that a unidimensional rating scale appeared sufficient for evaluating subjective workload during driving. Zhang *et al.* (2009) made use of the Borg CR10 scale before and after a fatiguing switch task, and found that it depicted significant post-task fatigue.

Both the NASA-TLX and the Subjective Workload Assessment Technique (SWAT) are examples of widely used multi-dimensional scales (de Waard, 1996; Rubio *et al.*, 2004). Rubio *et al.* (2004) compared properties of three multidimensional workload scales, namely the NASA-TLX, Subjective Workload Analysis Technique (SWAT) and the Workload Profile (WP), which is based on the multiple resources model proposed by Wickens (1984). Two main drawbacks to SWAT are its lack of sensitivity for tasks with low mental workload as well as the time-consuming pre-task procedure (Luximon and Goonetilleke, 2001). With regards to sensitivity, Rubio *et al.* (2004) found WP to be most sensitive as it revealed differences of both task complexity and the interaction of tasks, with NASA-TLX being more sensitive than SWAT. The NASA-TLX was found to have greater concurrent validity, and with regards to diagnosticity WP was superior in that it was able to discrimate between different tasks, while NASA-TLX and SWAT produced similar task clusters (Rubio *et al.,* 2004). Hill *et al.* (1992) compared the NASA-TLX, SWAT, Overall Workload scale (OW) and the Modified Cooper-Harper scale (MCH) in terms of sensitivity, operator acceptance, resource requirements and special procedures, and while all four scales were considered as acceptable analysis methods, the NASA-TLX and OW were found to be better both in terms of sensitivity and operator acceptance.

Physiological measures

Physiological measures have been used extensively to examine changes in energetical state as a function of various stressors, or to index load as a function of task parameters and the involvement of the subject in the task (Jorna, 1992).

Physiological assessment techniques provide a measure of workload through analysis of an operator’s physiological responses to a task (Eggemeier *et al.*, 1991). The level of cognitive demand generated by a task is characterised by neurophysiological changes as well as a shift within the autonomic nervous system to catabolic activity (Causse *et al.*, 2009; Fairclough *et al.,* 2005). Wilson and Eggemeier (1991) propose that since both central and peripheral nervous systems are involved in and responsible for acquiring, processing, and responding to information from the environment, measures of the related activity should provide knowledge concerning these processes.

While most physiological measures predict on the single resource model of workload, field research has revealed that single physiological measures are often inadequate to assess multi-task operations (Ryu and Myung, 2005). Wickens (1984) found it difficult to determine whether changes in a particular physiological index reflect changes in the demands on certain specific resources (in which case the measure is diagnostic), or changes in any and all resources, in which case diagnosticity is sacrificed for greater total sensitivity. In their research, Ryu and Myung (2005) found that the physiological measures used were sensitive to different aspects of the tasks presented, and therefore a combined measure of various physiological aspects would be better able to measure the entire workload in a multitask condition. For example, eye blink rate conveys information with regard to the visual demands of a task, whereas heart rate is said to determine the operator's global response to task demands (Wilson and Russell, 2003).

Physiological measures can also be influenced by a number of variables that may not reflect the cognitive or mental workload imposed by a group of tasks (Wilson and Eggemeier, 1991). Miyake (2001) notes that in order to solve problems of individual variability and task specificity one needs to analyse several physiological (and subjective) responses with different attributes, and integrate them in such a way that individual differences in physiological sensitivity and task-specific responses can be reflected. For example, response sensitivity to a mental task differs between individuals, as will the physiological responses induced by the same task; physiological response patterns will also differ from task to task (Miyake, 2001).

Heart rate and heart rate variability

Heart Rate

Heart rate (HR) has been considered for many years as an index of arousal, task involvement, anxiety and, more recently, mental load and effort (Jorna, 1992). It has been reported to vary as a function of the mental load imposed by the task, by increasing as the cognitive demands on the operator increase (Brookings *et al.*, 1996; Wilson and Russell, 2003) and decreasing during tasks of low difficulty and fatigue (Mascord and Heath, 1992; Jorna 1992). Sayers (1973; in Mascord and Heath,1992) note that interpretation of the direction of HR change in terms of the task demands is complicated by the interaction between sympathetic and parasympathetic pathways. Both sympathetic and parasympathetic processes influence the heart's inter-beat-interval – sympathetic acceleration of HR results from the release of noradrenaline, usually increased during emotional excitement and exercise, while parasympathetic activity increases vagal tone and causes a deceleration in heart rate (Mascord and Heath, 1992). Jahn *et al.* (2005) note that HR lacks sensitivity as a mental workload measure, as it is also sensitive to changes in emotional strain and physical activity, as well as varying with respiration.

Time-domain Analysis

Time-domain analyses of heart rate variability (HRV) calculate measures such as standard deviation or number of successive waves from the inter-beat interval (Jorna, 1992). HRV is a measure of the variability in the interval between consecutive heartbeats; irregularities in heart rate are caused by a continuous feedback between the central nervous system and peripheral autonomic receptors (Lin *et al.,* 2008; de Waard, 1996). Heart rate variability has been used in the field of human factors as a measurement of mental workload in both laboratory studies and in operational contexts (Lin *et al.*, 2008). It has been found to increase as a function of time-on-task, while a decrease in HRV is often found as task complexity increases (Mascord and Heath, 1992). HRV is usually less sensitive than heart rate to autonomic influences (Mascord and Heath, 1992), and a decrease in HRV is more sensitive to increases in workload than an increase in heart rate (de Waard, 1996).

It is important to note that while HRV is sensitive to task-rest effects, once the subject is performing a task it is very difficult to reduce HRV any further by simply manipulating the characteristics of the task (Jorna, 1992). Jorna (1992) noted that only major changes in task structure (such as single-dual task or automatic versus controlled processing) seem to induce significant HRV effects. Mulder (1986) found that HRV was only able to differentiate between tasks if they differ significantly in terms of controlled processing. This type of analysis is also unable to account for the sources of variance influencing HRV, and therefore spectral analysis techniques are considered the preferred method (Jorna, 1992).

Spectral Analysis

Spectral analysis decomposes HRV into three different frequency ranges, namely very low frequency (0-0.04 Hz), low frequency (0.04-0.15 Hz) and high frequency (0.15-0.4 Hz) (Lin *et al.*, 2008). The very low frequency band is related to the regulation of body temperature, low frequency to short-term regulation of blood pressure, and the high frequency band reflects respiratory sinus arrhythmia, or momentary respiratory influences on heart rate (Jorna, 1992). The low frequency component of HRV is thought to reflect complex processes of blood pressure regulation resulting from the interplay between sympathetic and parasympathetic influences, mediated by the baroreflex (Jahn *et al.,* 2005). Suppression of the low frequency component is often demonstrated under conditions of increased cognitive demand, and the high-frequency component (functioning as an indicator of parasympathetic activity, or vagal tone) tends to decrease when task demand is high (Fairclough *et al.*, 2005).

Increasing mental load and attention have been shown to cause a decrease in both the time and frequency domain estimates of HRV, especially in the low frequency component of spectral analysis (Lin *et al.*, 2008). Various authors (Egelund, 1982; Mascord and Heath, 1992) have found the low frequency band to be sensitive to fatigue, with an increase in spectral power occurring during conditions of fatigue, and a decrease in spectral power depicted during cognitive processing. Gershon *et al.* (2009) found HRV (calculated from the total spectrum between 0- 0.4 Hz) to increase with time-on-task for a 140 min simulated driving task, as well as the post-task rest value being higher than the resting value taken prior to the test. They also found that HRV decreased during the intermittent addition of an interactive cognitive task; however HRV rapidly increased again once the additional task was removed. While often the low frequency band alone is used to indicate increases in mental workload, some authors (Miyake, 2001; Lin *et al.*, 2008; Zhang *et al.*, 2009) have suggested the use of a low frequency/high frequency ratio, suggesting that it reflects sympathetic modulations.

Eye movements

It has been established that eye tracking technology can be useful for the evaluation of cognitive activity (Marshall, 2000). Changes in eye position control the flow of visual information into the nervous system, therefore eye movement data can be used to infer an operator’s strategic, high-level decision making processes (Sirevaag and Stern, 2000). The sensitivity of the ocular system to information processing is, however, not restricted to the acquisition of visual information – the control of gaze can also be influenced by auditory information, as well as task difficulty and complexity (Sirevaag and Stern, 2000).

Eye-tracking apparatus captures eye data in a nearly continuous signal and provides precise information about what the user looks at, how long he/she looks at it and how much the pupils dilate (Marshall, 2002). Current technology involves light-weight head mounted optics to remote systems that are non-invasive and therefore studies can be conducted without significantly disrupting the subjects concentration on the task provided (Marshall, 2000). Measures of eye movement activity are able to provide more continuous, moment-to-moment measures of workload and therefore allow the possibility of capturing fluctuations in workload that occur over short time intervals (Ahlstrom and Freidman-Berg, 2006).

Several eye movement parameters have demonstrated sensitivity to time-on-task, linked indirectly to the onset of drowsiness in monotonous task environments that require sustained attention (Van Orden *et al.,* 2000). Stern *et al.* (1995) note, however, that while a variety of oculometric measures have been considered for their ability to detect manifestations of fatigue, most have been found wanting in terms of their ability to demonstrate such effects. Instances of behavioural variance may also reflect changes in subject strategy and/or the level of effort that is not directly related to drowsiness (Van Orden *et al.,* 2000).

Pupillary dilation

Pupil dilation results from the integrated activity of two groups of muscles within the iris (Marshall, 2000). The circular muscles encircle the pupil and constrict the diameter to make it smaller, while the radial muscles cause the pupil to become larger (Marshall, 2000). A decrease in pupil diameter is thought to result from muscles innervated by the peripheral nervous system, while the muscles causing dilation of the pupil are innervated by the sympathetic nervous system (de Waard, 1996).

It is well-known that the pupil dilates as workload increases (Kahneman, 1973; Beatty, 1982; Sirevaag and Stern, 2000). When the individual experiences a psychosensory stimulus (e.g. a task requiring significant cognitive processing) the radial muscles are activated and circular muscles are inhibited, causing the pupil to dilate to a greater degree than one muscle group could affect alone (Marshall, 2000). It has been hypothesized that the magnitude of pupil dilation is a function of the mental effort required to perform a task, with increases in pupil size correlating with increased mental workload (Beatty, 1982; Lin *et al.,* 2008). During effortful cognitive processing, the pupil responds rapidly with a reflex reaction which can be separated by the reflex caused by changes in light (Marshall, 2002). The dilation reflex produces sharp, irregular pulses that often exhibit large jumps followed by rapid declines that are not seen in the reflex to changes in light (Marshall, 2000). The pupillary dilations accompanying cognitive processes occur at short latencies (onset between 100 and 200 ms) following the onset of processing and terminate rapidly once processing is complete (Beatty, 1982). Wang *et al.* (2010) were able to demonstrate a significant effect of task demand on pupil diameter – pupil diameter increased during a dual-task situation with a driving simulator and auditory digit recall, with a significantly greater increase during the most difficult digit recall condition.

Pupil diameter has also been shown to reflect time-on-task effects (Sirevaag and Stern, 2000). While some authors have found pupil diameter to decrease as a function of time-on-task, Beatty (1982) found no change in tonic pupil diameter during a 48 minute auditory vigilance task. Amplitude of the task-related pupillary response, however, showed a reduction over time from approximately 0.07mm in the first third of the task to 0.04mm in the last third. Van Orden *et al.* (2000) note that the usefulness of pupil diameter as a measure of fatigue in visually-oriented tasks still remains to be determined.

It may be beneficial to note that pupil diameter is said to be able to distinguish between data-limited and resource-limited processing, as it is insensitive to data-limited processes (i.e. processes that cannot benefit from allocation of additional resources) (Beatty 1982; Kramer, 1991). When looking at resource-limited tasks, Beatty (1982) suggests through the findings of various research, that as long as there is residual information processing capacity, increasing memory load is reflected by increased dilation, but once the capacity limits have been reached, further increases in task demand do not yield further increases. Recarte *et al*. (2008) found that the pupil response to a dual-task (cognitive task plus visual search task) condition was larger than in single cognitive tasks with low mental workload, whereas tasks classified as requiring high mental workload presented greater pupil dilation during the single task than when coupled with the visual search task. They suggested that pupil diameter does not differentiate between visual and mental workload, but rather reflects the highest activation state, or perhaps an average value of the brain activation areas associated with the performance of the task. Brain areas associated with the tasks eliciting higher mental workload would, hypothetically, be less activated in dual-task conditions because a part of such activation would correspond to resources shared with the visual detection task (Recarte *et al.*, 2008).

Causse *et al.* (2009) suggest that the pupillary response may be strongly affected by the dynamic aspect of a task, where the amount of visual scanning required may be responsible for the high pupil dilation found in their study as well as similar results in other literature. Wickens (1984) notes that changes in pupil diameter correlate quite closely and accurately with resource demands of a large number of diverse cognitive activities – this implies that this measure may be highly sensitive, but undiagnostic, as it will reflect demands imposed anywhere within the information processing system. It is also important to note that due to the association with the autonomic nervous system, pupillary measures will be susceptible to variations in emotional arousal (Wickens, 1984). Beatty (1982) suggests that the effects of emotional arousal are generally longer, and therefore changes in emotionality are more likely to affect basal or tonic pupil diameter rather than phasic pupil changes.

Blink frequency and duration

Endogenous eye blinks are those that are not a reflex in response to specific environmental stimuli (Wilson and Eggemeier, 1991). Eye blink frequency and duration are sensitive to cognitive demand if the task is primarily visual (Fairclough *et al.,* 2005). Various authors (Fairclough *et al.,* 2005; Ha *et al.,* 2006) have found blink duration and frequency to decrease with increased task demand, attributed to the need to maximise the viewing time of visual information. Since no visual information can be obtained when the eyes are closed, a reduced blink frequency functions to maintain continuous visual input when high levels of visual attention are required (Ha *et al.,* 2006). Contrary to this finding, other authors (cited in Wilson and Eggemeier, 1991) have found a higher blink rate during dynamic tasks with high visual demands

– this was attributed to an increased rate of information intake, as one tends to blink after acquiring visual information. In their research, Fairclough *et al.* (2005) found that a greater task demand significantly reduced mean blink duration, analogous to the above statement that suppression of blinks reduces the likelihood of missing relevant information during tasks that require a high level of visual attention (Wilson and Eggemeier, 1991; Brookings *et al.,* 1996; Fairclough *et al.,* 2005).

Contrary to the numerous findings of blink inhibition during high workload, studies with tasks involving vocalisation have reported an increase in blink rate, as did other combinations of task requirements not requiring vocalisation (Stern *et al.*, 1984). Stern *et al.* (1984) concluded that increases in blink rate may be secondary to speech or motor activity, or reflect a more generalized activation function. Recarte *et al.* (2008) also found that during concurrent performance of a visual search task and cognitive task, blink rate was lower than with a single cognitive task. This presents the eye blink measure with the ability to discriminate between visual demand and cognitive workload, with a high visual demand functioning to inhibit blinks and a high workload leading to an increase in blink frequency (Recarte *et al.,* 2008). Tsai *et al.* (2007), however, found blink frequency to increase during a dual driving and auditory task when compared to a driving-only condition. Recarte *et al.* (2008) explain this by considering the inhibition of blinks during a visual task to require attentional resources; when the attentional resources are required for a secondary (mental) task, there is a decreased ability to inhibit eye blinks and therefore blink rate will increase (Recarte *et al.*, 2008).

In addition to workload, fatigue has also been shown to have an influence on blink parameters. Situations with lower visual demands, or the onset of fatigue, produce blinks of longer duration and have been reported to correlate with subjective sleepiness (Wilson and Eggemeier, 1991). Stern *et al.* (1995) found a significant increase in both blink rate and blink duration during a fatiguing two-hour air traffic control task, as did Campagne *et al.* (2005) during a two-hour simulated driving study. The increase in blink rate is explained by the reduced ability for attention-driven inhibition of blinks when fatigued (Schleicher *et al.,* 2008). The longer blink duration is considered to reflect deactivation, and the slowing down of several physiological processes caused by reduced neuronal firing rates within the nervous system (Schleicher *et al.,* 2008). Schleicher *et al.* (2008) required their subjects to drive in a simulator for a period of two hours or until they were extremely sleepy - they found blink duration to be the most reliable oculomotor variable correlating with both subjective and objective fatigue. This is perhaps because blink rate is also greatly affected by timing and frequency of stimulus presentation as well as visual information-processing load and perceived risk (Sirevaag and Stern, 2000). Stern *et al.* (1984) note, however, that not all data supports the time-on-task effects described above – therefore explanation of a time-related effect on blink rate requires an understanding of the general effects of activation, effort, fatigue and attention as well as the demands imposed by a specific task.

Fixations

The pattern of eye movements, the objects fixated on and the duration of the fixation provide a good indication of the intake of visual information as well as workload (Wilson and Eggemeier, 1991; Ha *et al.,* 2006). Driver's eye fixation duration has been extensively studied as a feature for the estimation of workload (Zhang *et al.*, 2009). A fixation is defined as a relatively motionless gaze that lasts for 200-300 ms during which information about a visual stimulus is extracted (Lin *et al.,* 2008). Fixation duration is defined as the time between two successive saccades (Schleicher *et al.,* 2008). It is assumed that the location of fixation indicates the area of interest, the frequency of fixation indicates the importance of an object, and the duration of fixation indicates the difficulty associated with interpreting the information (Lin *et al.,* 2008; Wilson and Eggemeier, 1991). It is, however, important to note that eye fixations do not necessarily imply the perception of information (de Waard, 1996).

While fixation duration is closely related to cognitive processing in alert subjects, a clear relationship with sleepiness or fatigue has yet to be discovered (Schleicher *et al.,* 2008). Schleicher *et al.* (2008) propose that this is due to the fact that durations of different lengths may reflect different neuronal processes – very short fixations (<150 ms) may be considered as a distinct category caused by low-level visuomotor behaviour, possibly reflecting reflexive unconscious or non-cognitive aspects of behavioural control. They demonstrated this during their two hour driving simulator experiment, where mean fixation duration showed no correlation to fatigue, but when divided into very short (<150 ms), medium (150-900 ms) and very long (>900 ms), fixations of medium length showed a definite decrease in duration while very short and very long fixations increased in duration with fatigue.

Saccades

Saccades are rapid and ballistic movements of gaze between fixations (Lin *et al.,* 2008). They are conjugate movements (i.e. the eyes move equally in the same direction), and in laboratory conditions, the central nervous system (CNS) produces a saccade after a latency of approximately 200 – 250 ms following a change in target position (Yang *et al.,* 2002). The starting and ending points of saccades, as well as the duration of fixation between saccades provide valuable information about the modes of acquisition of visual information (App and Debus, 1998). Lin *et al.* (2008) found that saccades may be relatively more sensitive to changes in user cost than other eye movement parameters, as it was significantly correlated with normalised HRV and overall NASA-TLX scores.

Ryabchikova *et al.* (2009) note that saccadic eye movements have been shown to accompany cognitive processes such as attention, memory and thinking, and cognitive processes are often suppressed without saccadic eye movements. Cognitive (psychophysiological) and saccadic (neurophysiological) processes are closely related, attributed to the functional and anatomical overlap of the brain pathways and structures which enable planning, programming and decision making on the one hand, and regulation of saccade generation on the other (Ryabchikova *et al.,* 2009). Saccadic activity can therefore be used to reflect dynamic processes in the brain in order to evaluate various forms of cognitive activity (Ryabchikova *et al.,* 2009).

The saccadic main sequence comprises of saccade amplitude, duration and peak velocity, with relationships evident between duration and amplitude as well as peak velocity and amplitude (Bahill, Clark and Stark, 1975). Some research has revealed a relationship between saccadic dynamics and mental activation (App and Debus, 1998; Galley 1998). Peak saccadic velocity can be influenced by factors such as task complexity, the presence of a second task or the state of mental activation in a visual performance task. App and Debus (1998) also cite time-on-task as having an effect on saccade velocity, with velocity varying with the activational state of the subject during long-lasting visual performance tasks. Various authors (Di Stasi *et al.*,

2009) note that saccadic velocity can be related to natural fluctuations in alertness, vigilance, mental fatigue and mental workload. Schleicher *et al.* (2008) found that saccade duration, speed and amplitude all showed a relationship to sleepiness. They found, however, that the standard deviation of these measures showed a greater relation to fatigue than the mean values, attributing the increasing variance not only to a reduced vigilance, but to intensified attempts to counter-regulate against increasing sleepiness (Schleicher *et al.,* 2008). In a tracking task aimed at reducing alertness, Galley (1998) found that saccadic velocity deteriorated, but the performance measures did not follow the same pattern. He concluded that performance is “protected” and therefore independent of changing activation, but activation is dependent on momentary performance – additional activation is demanded if the individual is not reaching his/her performance goals (Galley, 1998).

Critical flicker fusion frequency

Critical flicker fusion, said to provide an objective measure of mental fatigue, has been widely applied in occupational health research (Wilson *et al.,* 2003). Critical flicker fusion frequency (CFFF) or critical flicker fusion threshold (CFFT) is the individual level or frequency at which a continuous flickering light is perceived as a steady source of light (Luczak and Sobolewski, 2005; Seitz *et al.,* 2005). The point of fusion is said to correspond to the alteration of a perceptual state (Curran and Wattis, 1998) and is seen as a measure of “total processing capacity” (Seitz *et al.,* 2005), or an index of central nervous system activity or cortical arousal (Wilson *et al.,* 2003).

CFFF is accepted as an indicator of both fatigue and workload (Luczak and Sobolewski, 2005), and has been used extensively in the field of fatigue, despite the lack of evidence supporting its validity (Wilson *et al.,* 2003). The use of CFFF as an index of central fatigue is based on the assumption that the adequacy of neural functioning is directly proportional to the maximal impulse-frequency which can be differentiated (Berger and Mahneke, 1954). Reductions in CFFF between 0.5-6.0 Hz have been observed after mental stress (Grandjean, 1979). Hancock *et al.* (1995) found CFFF to decrease as a function of time-on-task, rather than being sensitive to changes in task demand. They later retract their interpretation and conclude that the changes in CFFF in their experiment were most probably due to more mechanical than arousal-related factors.

It should be noted that while a reduction in CFFF can be interpreted as a sign of fatigue, it is still a hypothetical measure (Grandjean, 1979). Literature regarding CFFF as a measure of fatigue finds more studies claiming an absence of an effect than those able to report a decrease in CFFF as a function of fatigue (Stern *et al.*, 1995). Wilson *et al.* (2003) note that because numerous mental and physical mechanisms have been suggested to alter CFFF performance (e.g. cortical arousal, fatigue, visual fatigue, visual health, vigilance), any findings with regard to CFFF are difficult to interpret unless more easily interpretable measures are used concurrently.

As it can be seen from this chapter, fatigue is a multi-faceted problem involving numerous exogenous and endogenous aspects. There is still some uncertainty regarding the role of mechanisms such as arousal, effort and resources in fatigue generation, and this is further compounded by the similarity of the fatigue response to other cognitive concepts (for example vigilance, monotony and down-regulation). Performance, physiological and subjective measures have been employed in an attempt to gain a better understanding of mental fatigue; with physiological measures considered to depict changes most relative to actual mental functioning. Results for the various measures have often produced opposing results in different studies, however, thereby further complicating the interpretation of fatigue.

This study aimed to analyse task-related mental fatigue through performance of a monotonous yet attention-demanding simulated driving task. Performance and physiological measures were analysed, in order to ascertain whether a correlation between the two was evident, or whether performance was protected regardless of the costs incurred which would be depicted in the physiology. Also of interest was the interaction of the various physiological measures – whether certain cardiovascular and oculomotor responses to the task would correlate with reviewed fatigue and workload literature, whether the measures themselves would correlate with each other or show different aspects of the induced state, as well as considering the interpretation of such measures in terms of arousal theory, resource depletion and the expenditure of mental effort.

CHAPTER III

METHODOLOGY

INTRODUCTION

The aim of this research was to investigate the effect of sustained attention and task-fatigue on performance and physiological measures. This was done using a simplistic driving task, which was chosen due to its limited demand on higher cognitive processes as well as easy identification of the mental resources required. While the effect of fatigue on driving performance has received great interest, it is difficult to determine whether the performance decrement observed over time is due to a lack of stimulation (causing an underload or monotonous situation), or fatigue due to a prolonged high mental load, or both (van der Hulst *et al.*, 2001). While most studies have considered task-related fatigue as a general concept, Desmond and Hancock (2001) suggested two separate states, namely active fatigue (relating to high-workload conditions) and passive fatigue (relating to situations of underload). The problem with this differentiation, however, is that a task such as monotonous driving may integrate both active and passive aspects of fatigue (Schmidt *et al.,* 2009) thereby producing paradoxical results and compounding interpretation.

The role of vigilance during passive fatigue has also become an important question, with researchers arguing as to whether the fatigue is caused by the monotony of the task resulting in a reduced state of arousal (Thiffault and Bergeron, 2003b), or whether it is a function of the increased exertion of effort required to maintain performance of a monotonous task against this reduced level of arousal (Thackray, 1981). This study therefore aims to provide some clarity into the mechanisms behind task-related fatigue by analysing the changes in various physiological parameters over time, as well as their correlation with performance and subjective measures.

RESEARCH CONCEPT

While there is still difficulty in defining fatigue adequately, it is well established that fatigue is a phenomenon observed during prolonged task performance, usually resulting in the inability to maintain performance (Brown, 1982; Nilsson *et al.,* 1997).

Initially, the intention of this project was to evaluate the effect of task-related mental fatigue on various physiological parameters, with specific focus on cardiovascular and oculometric measures. A driving simulator task was chosen as this was considered to induce fatigue symptoms rather rapidly, and due to the simplicity of the task, the mental resources utilised could be easily identified, as the simulator requires continuous visuo-motor resources and little other higher cognitive function. The task represents a continuous tracking task where subjects are required to follow a line with changing curvature as precisely as possible, The task therefore requires the subject to continuously perform at their limit in terms of motor control precision.

In order to identify whether the driving simulator would elicit the desired fatigue symptoms, numerous pilot studies were conducted. Firstly, two subjects were required to drive on the driving simulator for two hours – while heart rate and oculometric data were inconclusive, heart rate variability (HRV) showed a distinct increase over time, which is indicative of fatigue (Mascord and Heath, 1992; de Waard, 1996; Gershon *et al.,* 2009). An area of concern with this type of task was whether the response could be explained by fatigue, or whether it was merely a down-regulation mechanism. During the drive, an ice pack was applied to the back of the subject's neck for 1.5 minutes after every 20 minute driving period in an attempt to differentiate between fatigue and down-regulation by artificially increasing arousal, but this did not elicit any observable arousal effect.

Further testing included a two hour drive during the day and during the circadian nadir at night. Both day and night revealed an increase in driving deviation over time; however the extent of deviation was greater during the night, which correlated with the notion of circadian effects on performance. It is interesting to note then, that HRV increased to a greater extent during the day than at night – this was considered a task-related fatigue effect similar to the situation of passive fatigue explained by Matthews and Desmond (2002), where a reduction in executive control capability limits the individual's ability to regulate performance through increasing effort investment. The lower HRV during the night was hypothesized to be due to the additional investment of "state effort", an effort directed in an attempt to stay awake and protect performance (Mulder, 1986). Pupil dilation was shown to decrease over time and blink frequency increased, another indication of fatigue (Sirevaag and Stern, 2000).

The next step was to assess the effect that an additional task would have on driving performance during a fatigued state, mainly in order to determine whether resource depletion could be implicated in the interpretation of results or not. Various secondary tasks were considered, with an auditory memory task seeming the most efficient. As with the initial pilot with ice water, it was decided that an auditory memory span task would be administered after every 20 minute driving period in order to assess the individual's spare mental capacity and to determine whether the prolonged driving task affected mental activation in general, or if it affected only the specific resources required for driving. It was hypothesized that performance would decrease during dual task period due to the additional task load, while physiological measures would depict a greater effort demand (higher mental workload) in order to cope with the dual-task situation. Results obtained were contradictory to what was expected, however, and it seemed that the introduction of a dual task situation functioned to increase arousal and therefore improve performance of the primary task. Pupil diameter increased during the dual task condition, indicating a greater mental workload, but HRV also increased, indicating that less effort was required to perform the dual-task than the driving task alone.

From these results it was evident that the performance and physiological changes identified during such a task could be related to a number of theoretically different phenomena, and could not be specifically labelled as "fatigue" per se. Therefore, with the concepts of active and passive fatigue as a base, the interest of the researcher became determining the factors that lead to such states by means of performance and physiological inference.

EXPERIMENTAL DESIGN

This research aimed firstly to evaluate the task-related fatigue effect elicited by a prolonged driving task, and secondly to evaluate to which extent this was an active or passive fatigue. This was achieved by introducing intermittent secondary tasks requiring either the same resources used for the driving task (visual-motor), or different resources that were not utilised during the driving task (auditory-verbal). It was hypothesized that if passive fatigue was the main cause of performance failure, the introduction of a secondary task may alleviate some of the problem encountered by an underload situation, moving the individual into a more optimally-loaded mental state (Oron-Gilad *et al.,* 2008). It was also hypothesized that if the driving task's main downfall was that of an active fatigue (i.e. an overload or resource depletion situation), the secondary task requiring the same resources would hinder driving performance even further. Performance of the secondary task may also be compromised in this situation. Physiological reactions to the various scenarios were of great interest in order to determine which measures were most sensitive to the type of fatigue elicited, and which measures were able to depict the changes in mental demand with the addition of the secondary task.

The current study made use of a simplistic driving simulator (considered as more of a continuous tracking task with a geometry representative of a driving scenario) with the main goal of inducing a fatigued state fairly quickly. It was impossible to determine whether this was a task that would induce active or passive fatigue; on one hand it is a very monotonous task which would suggest a passive fatigue effect, while on the other hand the large amount of attention and effort required in order to perform the task adequately could indicate a more active state of control. Secondary tasks requiring either the same (visual-motor) resources or different (auditory-verbal) resources to the driving task were employed periodically in order to assess the effect they would have on driving performance. Physiological measures in the form of heart rate, heart rate variability and numerous oculomotor measures were obtained with the intention of gaining insights into the different states of mental load.

The experiment consisted of three conditions (see Table I) and a between-subject design, with subjects spread evenly between the three conditions. The between-subject design was chosen over a within-subject design as factors such as motivation and aversion to performing the task three times were considered to have a significant effect on the results. All three conditions required the subject to drive on the driving simulator for a continuous period of approximately 115 minutes. This time period was considered long enough to elicit the required responses through prior pilot studies. The control condition involved pure driving, with no additional tasks presented to the subjects in this group. The second and third conditions involved the intermittent introduction of a concurrent auditory memory span task or choice reaction task respectively. The secondary task was applied for five minutes after every 20 minute driving period, without interrupting the driving task. After 105 minutes loud music was introduced for two minutes in an attempt to arouse the subject and reduce the mental down-regulation that may have occurred during the driving period. After this two minute period, the subject continued to drive in silence for a further five minutes before the experiment was terminated.

Table I: Experimental design for each condition. Highlighted areas indicate where secondary tasks are implemented: yellow indicates the memory span task, blue indicates the choice RT task and red indicates the music stimulus.

		CONDITION		
INTERVAL	**TIME (MIN)**	**CONTROL**	**MEMORY SPAN**	**CHOICE RT**
1	0-5	DRIVE	DRIVE	DRIVE
2	5-10	DRIVE	DRIVE+MEMORY	DRIVE+CHOICE RT
3	10-15	DRIVE	DRIVE	DRIVE
4	15-20	DRIVE	DRIVE	DRIVE
5	20-25	DRIVE	DRIVE	DRIVE
6	25-30	DRIVE	DRIVE	DRIVE
7	30-35	DRIVE	DRIVE+MEMORY	DRIVE+CHOICE RT
8	35-40	DRIVE	DRIVE	DRIVE
9	40-45	DRIVE	DRIVE	DRIVE
10	45-50	DRIVE	DRIVE	DRIVE
11	50-55	DRIVE	DRIVE	DRIVE
12	55-60	DRIVE	DRIVE+MEMORY	DRIVE+CHOICE RT
13	60-65	DRIVE	DRIVE	DRIVE
14	65-70	DRIVE	DRIVE	DRIVE
15	70-75	DRIVE	DRIVE	DRIVE
16	75-80	DRIVE	DRIVE	DRIVE
17	80-85	DRIVE	DRIVE+MEMORY	DRIVE+CHOICE RT
18	85-90	DRIVE	DRIVE	DRIVE
19	90-95	DRIVE	DRIVE	DRIVE
20	95-100	DRIVE	DRIVE	DRIVE
21	100-105	DRIVE	DRIVE	DRIVE
22	105-107	DRIVE+MUSIC	DRIVE+MUSIC	DRIVE+MUSIC
23	107-112	DRIVE	DRIVE	DRIVE

SUBJECT CHARACTERISTICS

A total of 44 non-professional drivers participated in this study, with fourteen subjects assigned to each condition. Subjects were recruited from the Rhodes University student population, and were between the ages of 19 and 27 years, with a mean age of 22.2 (± 1.6) years. All subjects were required to be in possession of a valid driver's license. Participants were only admitted into the study if they were currently healthy and reported no form of sleeping disorders. Individuals with normal or corrected-to-normal vision were allowed to participate, with individuals requiring glasses being excluded due to the possible interference of the glasses with the eye tracking equipment. Subjects were also excluded if they had a history of epilepsy or any similar conditions, due to the graphic properties of the driving simulator.

Because the subjects would only perform one of the three test scenarios, it was important to obtain groups that were as homogenous as possible. A pre-screening questionnaire (see Appendix A1) was therefore filled out by each potential candidate in order to try and match the groups as accurately as possible. Factors that were considered in the questionnaire included age, gender, amount of driving experience, experience with the driving simulator, experience with video games, and chronotype (determined by the Morningness-Eveningness questionnaire developed by Horne and Ostberg, 1976, see Appendix A1).

Subjects were distributed evenly in the groups with regards to gender – each group consisted of seven males and seven females. Only one subject fell within the "definitely morning-type" group on the Morningness-Eveningness questionnaire, with the majority of subjects (28 of 42) falling into the "neither" category, and the rest in the "moderate" groups – this was therefore not considered an important factor by which to group the subjects, as all testing took place during the day. Age was also reconsidered as a factor for grouping the individuals, as the age bracket was very narrow. Subjects were therefore placed in the groups in accordance to their scores of driving experience, videogame experience, and experience with the Rhodes University driving simulator. Driving experience consisted of two variables, namely the number of years of driving experience, as well as the frequency with which long distance (over 1.5 hours) was driven. These two scores were combined to give the subject a score between 1 and 5. Driving experience on the simulator was rated as none (0), less than an hour (1) or more than an hour (2). Experience with videogames took into account both the frequency with which the subject partakes in videogames, and the average amount of time they usually play for, with the two combined scores giving the individual a score between 0 and 6. The score of these three factors was used to create homogenous testing groups.

INSTRUMENTATION AND MEAUREMENT OF VARIABLES

The equipment used consisted of the Rhodes University Human Kinetics and Ergonomics Department driving simulator and an auditory digit span task. Physiological measures were collected by the means of a Suunto heart rate memory belt and a Dikablis eye tracker.

The dependent measures used in this study included performance, physiological and subjective measures. Performance measures included driving performance (in the form of mean deviation from the centre line, reaction time, information processing capacity and steering alteration frequency), as well as performance of the secondary task over time. Physiological measures included those of heart rate, heart rate variability (both time-domain and frequency-domain variables) and various eye movement parameters including blink frequency and duration, pupil diameter, fixation duration and saccadic parameters. Subjective workload was measured throughout testing using a Borg CR10 scale (Appendix B1), and overall workload of the task was rated using the NASA Task Load Index (NASA-TLX) after completion of the task. Critical Flicker Fusion Frequency (CFFF) was also measured before and after the test.

A Data Reduction Tool developed at the Rhodes University Human Kinetics and Ergonomics Department was used in order to analyse performance and physiological parameters, providing the mean for each 5 minute interval for each measure. This provided a total of 23 intervals.

Performance analyses

Driving simulator (Primary task performance)

The driving simulator presented a curved road with an arrow at the bottom of the screen representing the bonnet of the car (see Figure 3). The subject was required to track the middle white line with the tip of the arrow as accurately as possible, while the driving speed was set at a constant level and could not be manipulated by the subject.

Four performance variables were calculated from the driving simulator:

- *Mean deviation* calculated the average deviation from the target line in meters.
- *Reaction time* produced the effective reaction delay (in seconds), taking into account both the deviation from target line and the amplitude and frequency of the target line. This parameter was therefore independent of the driving speed and the curvature of the line.
- *Information Capacity* is the Log_2 of the reciprocal value of the reaction delay, expressed as an information processing capacity in bit/s.
- *Steering alteration frequency* considers the alteration frequency of vehicle control by measuring oscillation frequency in 1/s.

The initial output sample interval was set to 5 s, so as to produce one output sample every 5 seconds and avoid strong variations due to changes in street curvature. A response delay of 1 s was compensated for, as with this type of task the individual tended to look further ahead on the road and produce a proactive response, which would confound measures of reaction time.

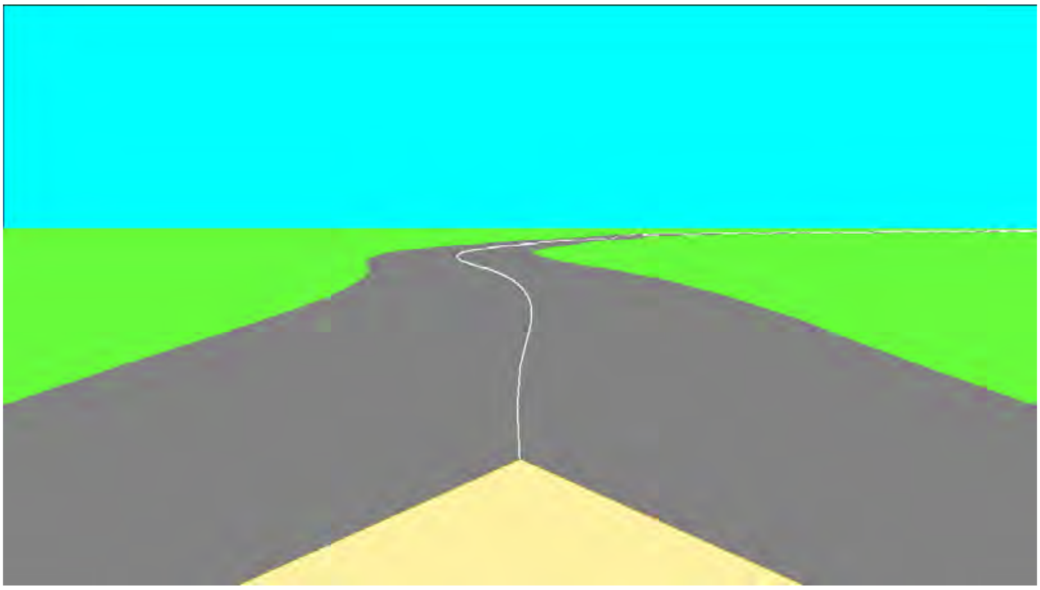

Figure 3: Screenshot of the driving simulator used.

Secondary task performance

Memory span task

The auditory memory span task (Digit Span Version 0.1) was obtained from the PEBL Psychological Test Battery Version 0.5 (http://pebl.sourceforge.net/battery.html). This was a standard digit span task with visual/auditory presentation of number strings and a keyboard input. The subject was, however, only exposed to the auditory presentation and required to respond verbally while the experimenter keyed their responses into the computer. The task began with a four digit string, and increased in length until the subject responded incorrectly. When an incorrect response was elicited, the following string was one digit shorter than the previous string. This task was therefore considered to tax the individual's memory span to their maximum ability, as it constantly required the longest number string the individual was able to remember. A waiting period of five seconds between presentation and response was created, requiring the subject to retain the numbers for a longer period before responding in order to tax the subject's mental capacity further. A total of 12 number strings were presented in each five minute period.

The Digit Span task provided the average memory span of the individual after the 12 trials – this average value was used to compare the four memory tasks embedded within the testing period, and determine how memory was affected by fatigue over time.

Choice response time task

The choice reaction task was embedded within the driving simulator software (see Figure 4) – when the secondary task was activated, a box appeared in the middle of the road (at 40% of screen height) depicting either a leftward-pointing arrow (<---) or a right-pointing arrow (--->) to which the subject was required to press the corresponding button on the steering wheel. Time between successive events varied randomly between 2000 and 8000 ms, giving an average event rate of 12 events per minute, and a total of approximately 60 events for each five minute period. It was determined through pilot studies that this event rate was frequent enough to require the constant attention of the driver, but not too frequent that it hindered performance of the primary driving task or allowed for anticipation of the stimulus presentation.

The reaction time to each stimulus was recorded, and the average response time (RT) over each five minute period was calculated and compared between the periods to determine whether RT became longer over time due to fatigue.

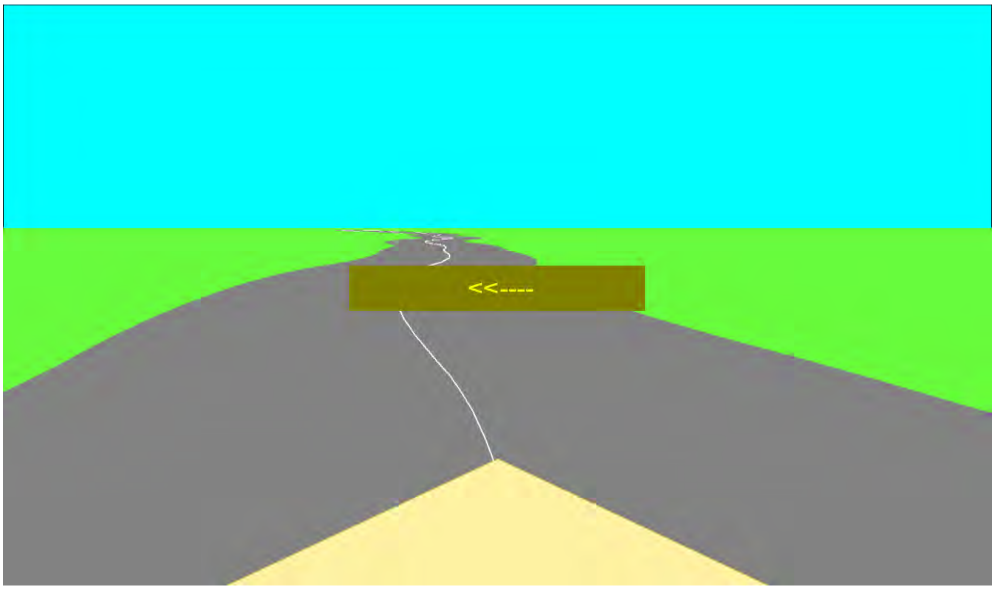

Figure 4: Example of the choice RT display embedded within the driving simulator.

Physiological analysis parameters

Heart rate and heart rate variability

A Suunto T6 memory belt was used to record cardiac responses during the test session. The electrode strap was placed around the mid-chest, at the inferior border of the pectoralis major muscle in line with the apex of the left ventricle. Conductive gel was applied to the sensors, in order to ensure the signal was not lost due to lack of moisture, or friction between the electrodes and the skin. All data stored within the belts was downloaded via the docking station and Suunto Training Manager 2.2.0.8 software after the test was completed.

The Suunto heart rate belts allow for a detailed beat-to-beat analysis, and also provide R-R intervals and ratios which are important for the calculation of heart rate variability (HRV) parameters. Heart rate (HR) was calculated from the inter-beat-interval. The data was filtered by accepting a minimum heart rate of 50 bpm and a maximum of 180 bpm. The maximum variation between beats was set to 200%.

HRV is the variability in the interval between consecutive heartbeats (Lin *et al.,* 2008). Analysis methods of HRV include both time-domain and frequency-domain analyses (Jorna, 1992).

Time-domain analyses

There are a number of different time-domain analyses that can be performed. This study considered four different analyses, namely SDNN, RMSSD, PNN50, and the PNN30 (an altered version of the PNN50). SDNN refers to the mean difference between adjacent beat-to-beat intervals, while RMSSD calculates the square root of the mean of the sum of squares of differences between adjacent beat-to-beat intervals. The PNN50 evaluates the percentage of adjacent beat-to-beat intervals that differed by more than 50 ms compared to the total beat-to-beat interval. PNN30 is calculated identically to the PNN50, using 30 ms as the differentiation criteria – this variable was constructed in order to improve identification of phases with lower variability.

The interval length for time-domain analyses was set to 240 s. This was the longest interval possible without compromising the data obtained during the two minute music interval.

Frequency-domain analyses

Frequency-domain analyses decompose the HRV signal into separate frequency ranges, with the most widely used being high frequency (0.15-0.4 Hz) and low frequency (0.04-0.15 Hz) in the case of mental workload (Jorna, 1992). The low frequency spectrum is thought to reflect sympathetic activity and high frequency to reflect vagal/parasympathetic activity (Berntson *et al.,* 1997). This study analysed both high frequency and low frequency spectra, which were calculated using an FFT transformation. For each frequency band both the total power and the centre frequency were calculated – the power variable reflects the total power within the band in ms^2, while the centre frequency considers the frequency at which the power spectrum is split into two portions of equal power (Hz).

The ratio between low and high frequency has also been suggested by various authors to reflect sympathetic modulations (Miyake, 2001; Lin *et al.*, 2008; Zhang *et al.*, 2009). For this analysis, the low frequency component of the (LF+HF) power was calculated.

Eye movement analyses

A Dikablis eye tracker system was used to record various oculomotor responses throughout the testing session. The Dikablis system consists of three subunits, namely the head unit, receiving unit and recording unit. The head unit was placed on the head of the subject, with the weight of the device supported by the nose piece (See Figure 5). A field camera situated above the nose recorded a wide-angle picture depicting the field of view of the subject, while the eye detection camera located above the left cheek recorded the cornea reflex and identified and recorded pupillary movements. The head unit then sends the information to the receiving unit via Bluetooth; this information is then forwarded to the recording unit where it is stored as both video information and the numerical coordinates of the pupil at a rate of 25 Hz.

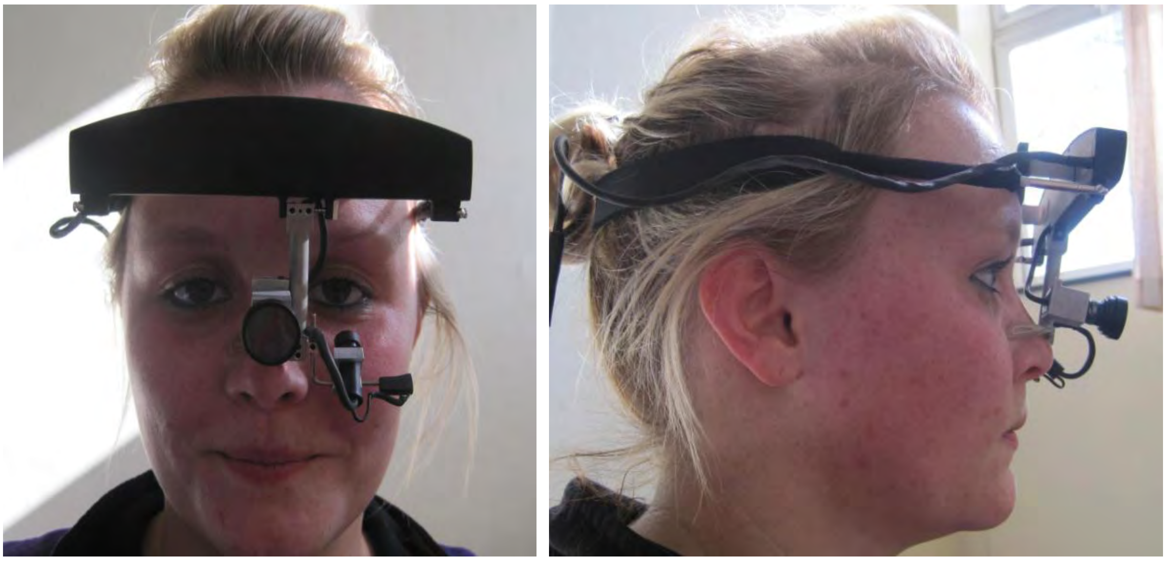

Figure 5: Subject fitted with the Dikablis eye tracking system.

Measures obtained from the eye tracking system included pupil size, blink frequency, blink duration, fixation duration and also the speed, amplitude and duration of saccades. Testing was performed in a light-controlled room to prevent changes in pupil diameter due to light changes over the two hour period.

Pupil diameter

The pupil size variable (measured by the area) of the Dikablis system was used to calculate pupil diameter, as this was found to be the most robust of the available measures. A dynamic pupil filter was also employed in order to exclude any change in pupil size greater than 20% per 100 ms period.

Blink frequency and duration

When considering blink duration and frequency, it was decided to divide the blinks into normal (short) blinks and longer blinks that may be characteristic of the subject falling asleep or becoming fatigued. When considering the threshold for defining short and long blinks, the 90th percentile of blink duration was examined for all subjects. The majority of intervals produced a 90th percentile value between 200-240 ms. It was therefore decided to group blinks between 50 and 300 ms as “short blinks”, and any blinks above 300 ms as “long blinks”. Due to the low number of long blinks in the data, a measure of total blink frequency and duration (encompassing all blinks between 50 and 5000 ms) was first considered, and thereafter the effect of the extremely long blinks was negated by considering the “short” blinks only. Blink frequency was calculated as the number of blinks per five minute interval, and blink duration was calculated as the average duration per five minute interval.

Fixation duration and percentage

Fixations were defined when eye movements did not move faster than a 5^{o}/s in order to allow pursuit movements and to consider detection noise of the eye tracking system.

In accordance to Schleicher *et al.* (2008), short, medium and long length fixations were analysed as 0 - 150 ms, 150 – 900 ms and 900+ ms respectively. In addition to the average duration of each type of fixation per five minute period, the percentage of time occupied by each type of fixation was also calculated.

Saccades

Saccades were defined as any movement above the threshold of 10^{o}/s. While saccades typically occur at a much greater speed, the lower threshold was considered more suitable due to the low pass filter function caused by the temporal resolution of the Dikablis system. Further, small saccades would be expected during the tracking task, as only the road had to be focused. Mean saccade speed, duration and amplitude were calculated for each five minute interval.

Critical Flicker Fusion Frequency

Critical flicker fusion frequency (CFFF) is seen by some as an accepted indicator of fatigue and workload in many different situations (Luczak and Sobolewski, 2005). A pair of binoculars was modified in order to measure the CFFF threshold of the subjects, with the ends of the binoculars being covered in order to prevent ambient light from entering. Monocular observation of the flickering light was achieved by a white light-emitting diode (LED) placed in the right visual field of the binoculars while the left eye remained in total darkness. The ascending (fusion) threshold was used, which is an indicator of an individual’s sensitivity to the end of light flickering (Luczak and Sobolewski, 2005). A dial controlled by the subject was used to increase the frequency (Hz) of the flickering until such time as the subjects observed the flickering to cease and become a steady, non-flickering light. While it was stipulated that the ascending method was to be used, if subjects were unsure of the exact point at which the flickering stopped, they were permitted to alternate back and forth until they were sure of the cessation point. The measure was taken both at the beginning and end of the testing session, and three measurements were taken each time in order to ensure the subject reached a similar point each time (and therefore was capable with the equipment). The average of the three instances was used in the final evaluation.

Subjective analyses

Borg CR10

After every 20 minute driving period (i.e. before the secondary task was introduced) the Borg CR10 scale was used in order to assess the effort required to perform the task. The CR10 scale is a uni-dimensional rating scale that has been shown to be a reliable measure for the intensity of overall fatigue (Åhsberg *et al.,* 2000). The CR10 scale (Appendix B1) ranges from 0 to 10 and contains text rating from "very very light" to "very very hard" alongside the values in order to assist the individual with choosing the most correct rating. Subjects were introduced to the scale and taught how to use it during the habituation session.

NASA-TLX

Following completion of the test, subjects were required to complete a subjective workload questionnaire (NASA-TLX) in order to determine whether subjective feelings of fatigue corresponded to the physiological and performance indicators measured. While research by Rubio *et al.* (2004) tends to favour the Workload Profile (WP) for this type of application, the lack of research regarding use of this method as well as the ease of application of the NASA-TLX resulted in NASA-TLX being the favoured method for this study. The NASA-TLX is a commonly used workload indicator developed by Hart and Staveland (1988). It is a multi-dimensional subjective workload index that uses six dimensions to assess mental workload, namely mental demand, physical demand, temporal demand, performance, effort and frustration (Brookings *et al.,* 1996). Ratings for the dimensions are obtained through twenty-step bipolar scales, and a score of 0-100 is obtained for each (Rubio *et al.,* 2004). Paired comparisons are then done, where the subject is presented with two dimensions to which they have to choose the most relevant. A total of 15 paired-comparisons are performed, and from this a global score of workload can be obtained. An electronic version of the NASA-TLX (obtained from the Naval Research Laboratory, Washington, DC: http://www.nrl.navy.mil/aic/ide/NASATLX.php) was administered after the subjects had completed the experiment – this version first asked the subjects to rate the various dimensions (see Figure 6 for explanation of dimensions), and thereafter asked the 15 pair comparison questions. From this, the program produced an Excel document containing the score for each dimension as well as the weighted scores and an overall workload score.

It is important to note that the subjective measurement of fatigue and workload was not the main objective of this study, and therefore the aforementioned subjective measures were merely taken in order to provide additional insight into the physiological phenomenon and possibly assist with interpretation of the performance and physiological results obtained.

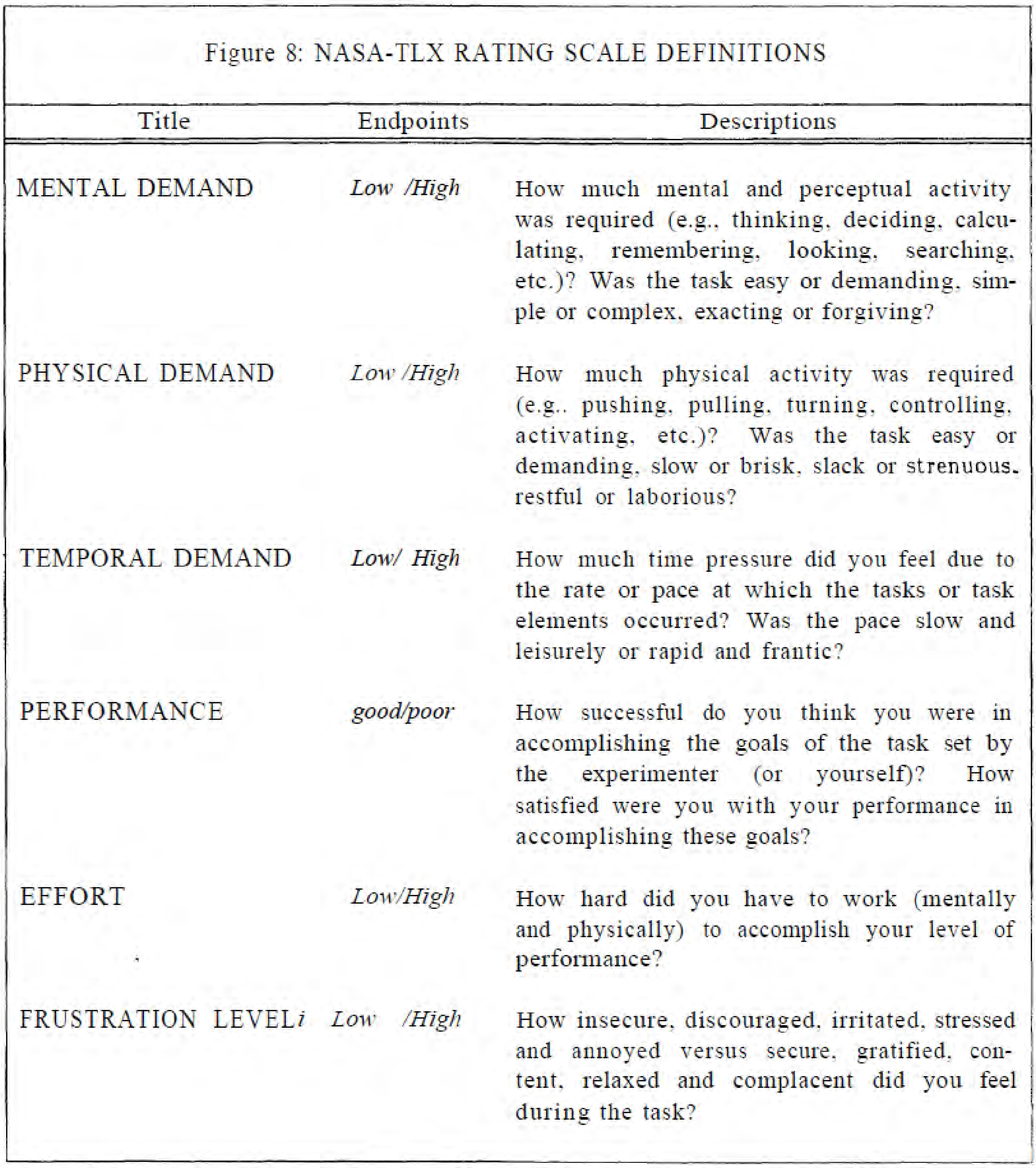

Figure 8: NASA-TLX RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low /High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low /High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/ High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*good/poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL*i*	*Low /High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Figure 6: NASA-TLX subscale definitions (taken from Hart and Staveland, 1988).

EXPERIMENTAL PROCEDURE

Ethical approval was granted by the Human Kinetics and Ergonomics ethics committee prior to subject recruitment. The ethical application included an outline of the experimental procedure, methodological considerations and subject requirements. The letter of information and informed consent that the subjects would receive during their habituation session was also included.

Once subjects were recruited they were required to complete a pre-screening questionnaire (Appendix A1). From this questionnaire the subjects were spread as evenly as possible into the control, memory, and choice RT testing groups at the discretion of the researcher.

Session 1: Habituation

Subjects were required to attend an initial habituation session within the Human Kinetics and Ergonomics Department 1-3 days prior to their testing session. The investigator explained the details and objectives of the study both verbally and in writing (Appendix A2), after which the subject was required to sign an informed consent form (Appendix A3). Following this, the subject was introduced to the recording equipment to be used, which included the Suunto heart rate monitor as well as the Dikablis eye tracker. The subject was fitted with the equipment in order to become accustomed to it.

Depending on the group the subject was placed in, the experimenter demonstrated the driving simulator as well as either the auditory memory span task or the choice reaction task. The subject was then allowed to practise in the driving simulator for 10 minutes or longer, until they felt comfortable and capable with the task.

The subject was also introduced to the CFFF binoculars. Once the concept was explained, the subject was required to put on the binoculars and turn the dial until they perceived the light to stop flickering and become constant. Once they were happy with the measurement, the researcher recorded the value and the subject was required to repeat it twice more in order to ascertain whether they were competent enough with the equipment to get a consistent reading.

Finally, the subjective scales were explained to the subject. The CR10 scale was demonstrated and the individual was instructed to relate their rating to the amount of difficulty they were having in continuing the task (i.e. the amount of effort performing the task required at that specific point in time). The NASA-TLX was then explained, and the meaning of each dimension was explained as shown in Figure 6. Any questions the subject had regarding the equipment or the protocol were answered at this time.

Once the subject felt confident and comfortable with the procedure and equipment, and all questions and/or concerns had been answered, a date and time for the following session was set up.

The subjects were required to refrain from alcohol for 24 hours prior to the testing session, and were not allowed to have had coffee or any other form of caffeine at least an hour before testing, with less than 2 cups within 12 hours prior to the testing session. Subjects were required to have had 7-8 hours of sleep the night before, as insufficient sleep has been shown to negatively affect cognitive ability, including attention and memory (Zisapel, 2007). Subjects were also asked not to participate in any strenuous exercise 12 hours prior to the testing session, and were asked to enquire as to what “strenuous” exercise entailed if they wished to participate in some activity that they were unsure of.

Session 2: Experiment

Testing took place in a light-controlled room in order firstly to ensure that subjects were exposed to the same environment regardless of time of testing, and secondly to eliminate any possibility of light changes over the testing period, as this may have affected eye measures negatively. Subjects were tested either between 9:00-11:30am or 2:30-5:00pm in order to avoid any circadian factors that may affect performance. These periods have been found to be similar with regard to circadian rhythm, and avoid the periods of greatest change due to circadian effects (Wijesuriya *et al.,* 2007).

When the subject arrived, the researcher first inquired as to whether all the requirements prior to testing were upheld. Once this was confirmed, the subject was given the CFFF binoculars and asked to determine their CFFF threshold as they were taught to do so in the habituation session (see above). The CFFF reading was taken three times in order to obtain an average reading that the researcher considered acceptable.

The subject was then fitted with the heart rate monitor and eye tracker, and allowed to sit in the seat of the driving simulator. Once the eye tracking equipment was calibrated, the subject was asked to sit and relax for five minutes in order to obtain a baseline HR measurement.

Once reference measures were obtained, the subject was reminded that they would be required to drive continuously for approximately two hours, and the Borg CR-10 scale was shown to them once more to ensure they knew the meaning of the scale. They were asked to refrain from conversing with the researchers during the driving, as this would reduce the state of fatigue and monotony that the experiment aimed to induce. They were, however, asked to inform the experimenter of any discomfort they may experience, and were assured once again that should they feel the need to stop the experiment at any time they could.

Group 1: Control group

Subjects in the control group were required to drive continuously without any interruptions (other than to obtain the CR10 rating) for 105 minutes. The subject was required to rate the difficulty of the task on the CR10 scale at 30, 55, 80 and 105 minutes. After the CR10 rating at the 105th minute, loud music was switched on in an attempt to increase arousal and counteract any down-regulation that may have occurred during the testing period. The music continued for a period of two minutes, whereafter it was switched off and the subject was required to drive for a further five minutes (refer to Table I on page 41 of Chapter III).

Group 2: Memory task group

An auditory memory span task was applied in the second group, where a string of numbers was presented orally and subjects were required to repeat the string verbally after a five second delay. The number string started at four digits and increased by one digit each time the subject answered correctly, and decreased by one digit if the subject was unable to recall the correct sequence. Subjects in the second group drove for five minutes, after which the secondary memory span task was added for five minutes. This early secondary task was added in order to assess the effect it would have on the driving before the fatigue effect became apparent. After the memory span task was complete (i.e. the subject had completed 12 digit strings, equating to approximately five minutes), the subject was required to drive continuously for a further 20 minutes. At this point (30 minutes of continuous driving) the subject was required to give their subjective rating, whereafter the memory span task was started again for another five minutes. Once the memory span task had been completed the subject then continued to drive uninterrupted for another 20 minutes. This was repeated until four cycles of 20 minute driving had elapsed (See Table I). The final subjective rating was taken at 105 minutes, and music was then introduced as in the control group. Again, the subject drove for a further five minutes after cessation of the music and then the test was stopped.

Group 3: Choice response time group

The choice RT task consisted of a visual stimulus embedded in the driving simulator, where an arrow pointing either left or right was presented and subjects were required to respond by pressing the corresponding control on the steering wheel. The procedure for the third group was identical to the procedure followed by the second group.

Once the final drive was complete, the driving simulator was stopped, and the subject was then required to perform the post-task evaluations. The NASA-TLX was completed by the subject at this time, followed by the CFFF measurement as performed in the beginning of the session. Another five minute reference period for heart rate was included at the end of the experiment to provide an additional comparison of pre- and post-task state.

STATISTICAL ANALYSIS

The HKE Data Reduction Tool was used to aggregate all performance and physiological measures into 23 intervals (22 five minute intervals and one two minute interval for the music condition). Statistical analyses were performed using the Statistica version 10 program, using the average values per interval generated by the Data Reduction Tool. Significant differences were considered at the 0.05 level, and Tukey post-hoc analyses were conducted where necessary.

Time-on-task effect

Performance and physiological variables

A General linear model was used to evaluate the change in dependent variables over time. The change between each 20 minute driving period (excluding the secondary task intervals) was analysed for all driving, HR, HRV and eye movement measures, as well as the variance between the four intervals within each of these blocks (i.e. intervals 3-6, 8-11, 13-16 and 18-21 were analysed; see Table I). The categorical predictors considered included the group, the time of day testing took place, and the gender of the subject.

The change in CFFF pre- and post-task was assessed, and again the effects of group, gender and time of day were investigated.

Subjective variables

The same general linear model was used in order to assess the change in subjective fatigue rating over time – differences between the four instances of the Borg CR-10 were evaluated both as a whole, and in terms of group, gender and time of day.

The weighted NASA-TLX was examined in order to determine which factors the subjects felt contributed most to the overall workload of the task.

Secondary task effect

The effect of the secondary task was evaluated by considering the interval before, during, and after each occurrence of the secondary task for both driving performance and physiological variables. This was done using a general linear model, and variance between each of the four instances was assessed, as well as the difference between the three intervals of each. Effects of gender and time of day were analysed as covariates.

The change in performance on the memory task and choice reaction time task over time was also assessed, and considered for effects of gender and time of day.

Effect of music

As with the secondary task effect, the effect of the music stimulus was evaluated by examining the difference in intervals before, during and after the music was implemented. Again, a general linear model was used to evaluate the difference between the three intervals, and covariates of group, gender and time of day that testing took place were assessed.

CHAPTER IV

RESULTS

INTRODUCTION

The present study aimed to evaluate the change in physiological and performance parameters over time during a fatiguing tracking task involving prolonged sustained attention. In doing so, it was hypothesized that firstly, the onset of fatigue would be depicted in both performance and physiological measures, and a better indication of the physiological measures which best depict the presence of such fatigue could be gained. Secondly, the study considered the effect of intermittently increasing the workload of the task – this was included in order to study whether such a task should be considered as inducing an active or passive fatigue. This was analysed via performance parameters and physiological measures depicting variance in mental workload.

The initial analysis (see section labelled “Time-on-Task Effects”) analysed the change in dependent variables over time, excluding both the intervals during which the secondary task was performed as well as the interval directly after the secondary task in order to negate the effects that may have been induced by the secondary tasks. The general change over time as well as the influence of the three experimental groups on the results was focussed on in this section. Following this, the effect of increasing workload through the addition of a secondary task was analysed (see section entitled “Secondary Task Effects”). This was done by looking at the change between intervals before, during and after application of the secondary task (minutes 0-15, 25-40, 50-65 and 75-90, see Table I in Chapter III). Finally, the reaction of the dependent variables to the addition of a music stimulus was examined (see section labelled “Effect of music”). The hypothesis behind this was that the addition of a loud music stimulus may provide a means to identify whether the effects observed over the testing period could be attributed to fatigue, or merely a down-regulation induced by the monotonous nature of the task.

Furthermore, gender and the time of day of the testing session were also analysed as covariates throughout all analyses. While these covariates were taken into consideration during statistical analysis, they were found to have only very minor effects. In order to avoid compounding the main results of interest, these covariates are discussed separately at the end of the sections.

Due to the large amount of data as well as the complexity of the various measures, only the significant results deemed pertinent to the aims of this study will be discussed. Tables of all effects are included in Appendix C should the reader wish to examine them further. Terms for the measures and/or abbreviations used are explained in the relevant sections in Chapter III.

TIME-ON-TASK EFFECTS

This section considers the change in dependent variables over each five minute interval throughout the protocol. The intervals during and directly after performance of the secondary task (and the corresponding time intervals of the control group) were excluded in order to purely evaluate the overall time-on-task effect, or “fatigue profile”, while negating the effect that the secondary task may have induced. The interval following the secondary task was also eliminated from this evaluation in order to ensure that no residual task effect was included in the general fatigue analysis. Each dependent variable or group of dependent variables is discussed regarding the overall change over time, as well as considering the difference in overall profiles between the three experimental conditions.

Performance parameters

Because the intervals involving the secondary task were negated in this section, only the driving performance variables were considered. The three driving parameters of mean deviation, reaction time and information processing capacity are all derived from the same basic parameter (i.e. deviation from the target line) and therefore depict the same trend. For this reason, only the mean deviation parameter will be considered throughout the analyses.

Driving performance

The measures of driving performance showed a significant decrement over time, with the mean deviation (Figure 7) increasing over time ($p < 0.01$). Driving performance over time was not affected by either of the secondary tasks, with all three groups showing a similar fatigue profile. Gender had a significant effect on these parameters; this will be discussed within the *Gender* section (see page 81). Steering alteration frequency did not show any significant change over the driving period ($p = 0.35$).

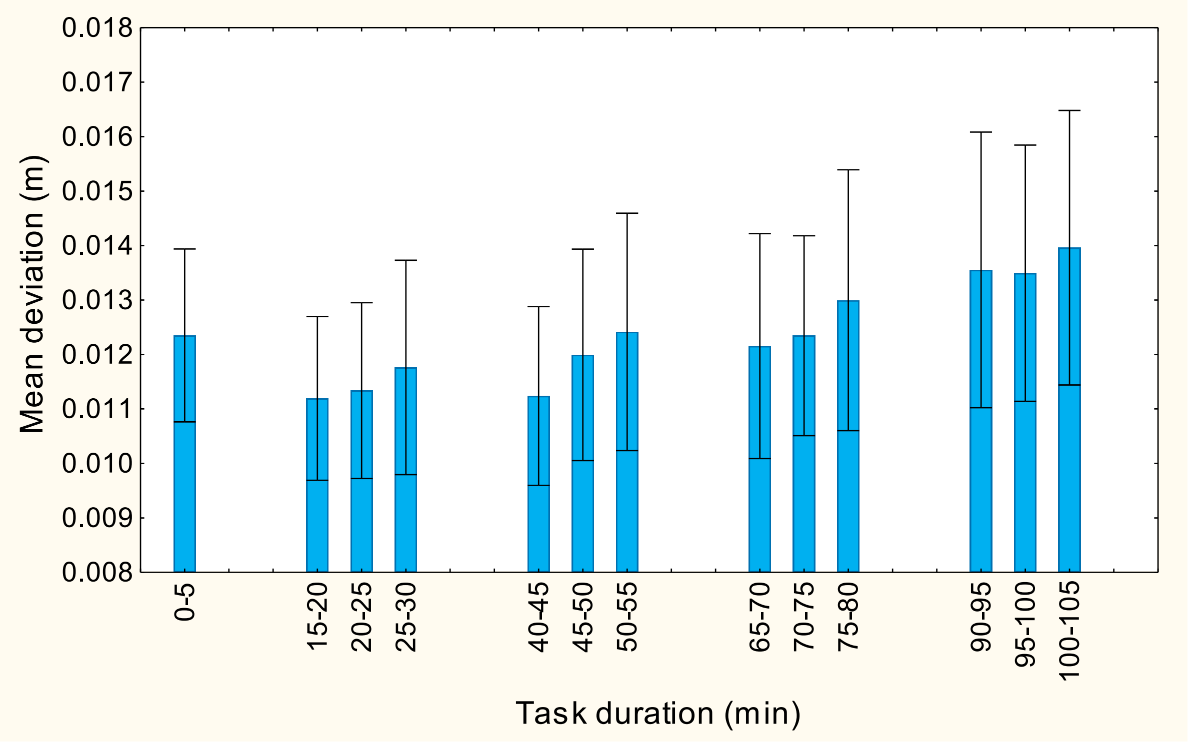

Figure 7: Change in mean deviation over time for all subjects. Note: while deviation is measured in metres, this corresponds only with the road geometry used on the specific simulator, therefore the measure should rather be considered as an arbitrary unit. Error bars depict 95% confidence interval.

Cardiovascular responses

Heart rate frequency

Baseline effect

A baseline heart rate was taken for five minutes both before and after the testing session. The two baselines were also compared for the heart rate parameters in order to see if a “lasting” fatigue effect was demonstrated after the driving task had been completed.

The heart rate baseline after the testing session was found to be significantly lower than the baseline before testing. None of the covariates (gender, time of day) had any significant effects.

Time-on-task effect

Heart rate declined significantly over the testing period ($p < 0.01$; Figure 8). The different experimental groups had no effect on the fatigue profile.

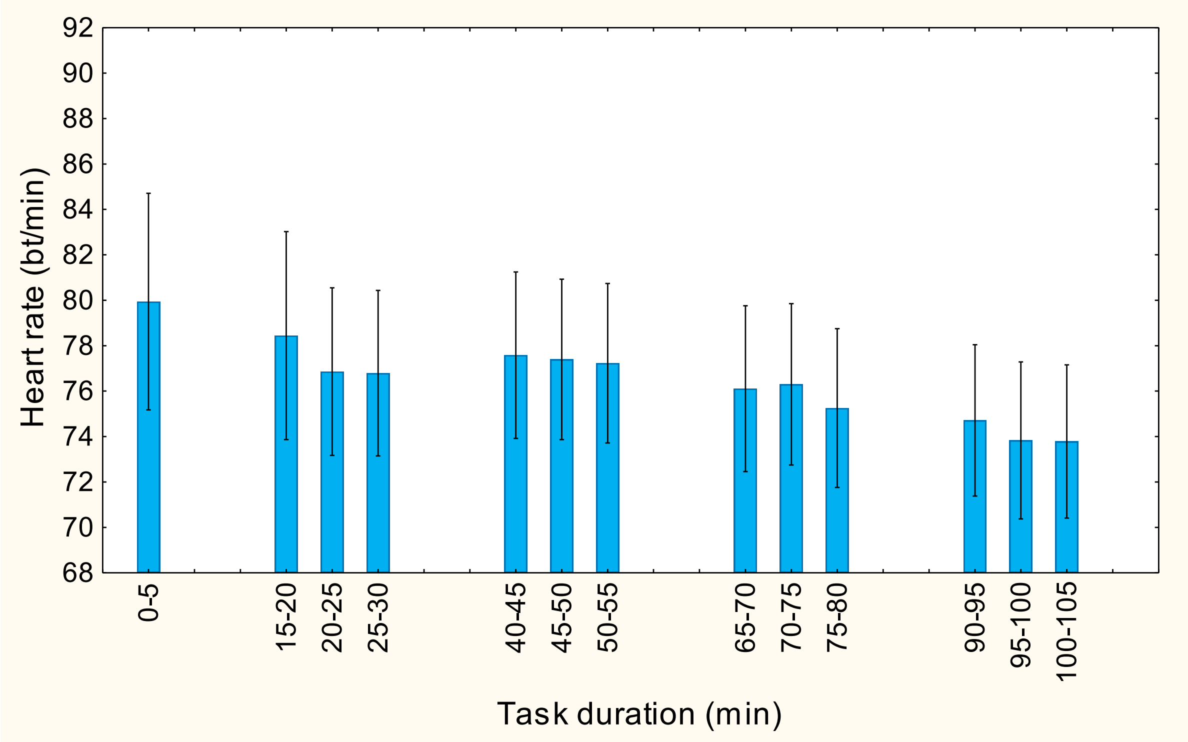

Figure 8: Change in heart rate frequency over time for all subjects. Error bars depict 95% confidence interval.

Heart rate variability: Time-domain analyses

The time-domain analyses considered included SDNN, RMSSD, PNN50 and PNN30. Due to the fact that SDNN and RMSSD are calculated according to the same principle (differing only in the weighting of deviations), only RMSSD is discussed here. For the PNN analyses, some intervals yielded a value of zero for the PNN50 measure. It was therefore decided that the PNN30 would be a more suitable measure to use – this measure performs the same function of the PNN50, but allows for lower variance by considering intervals that differ by 30 ms instead of 50 ms.

Baseline effect

The change in baseline measures for time domain analyses showed a significantly higher RMSSD ($p < 0.01$) and PNN30 ($p = 0.01$) following the testing period (see Figure 9).

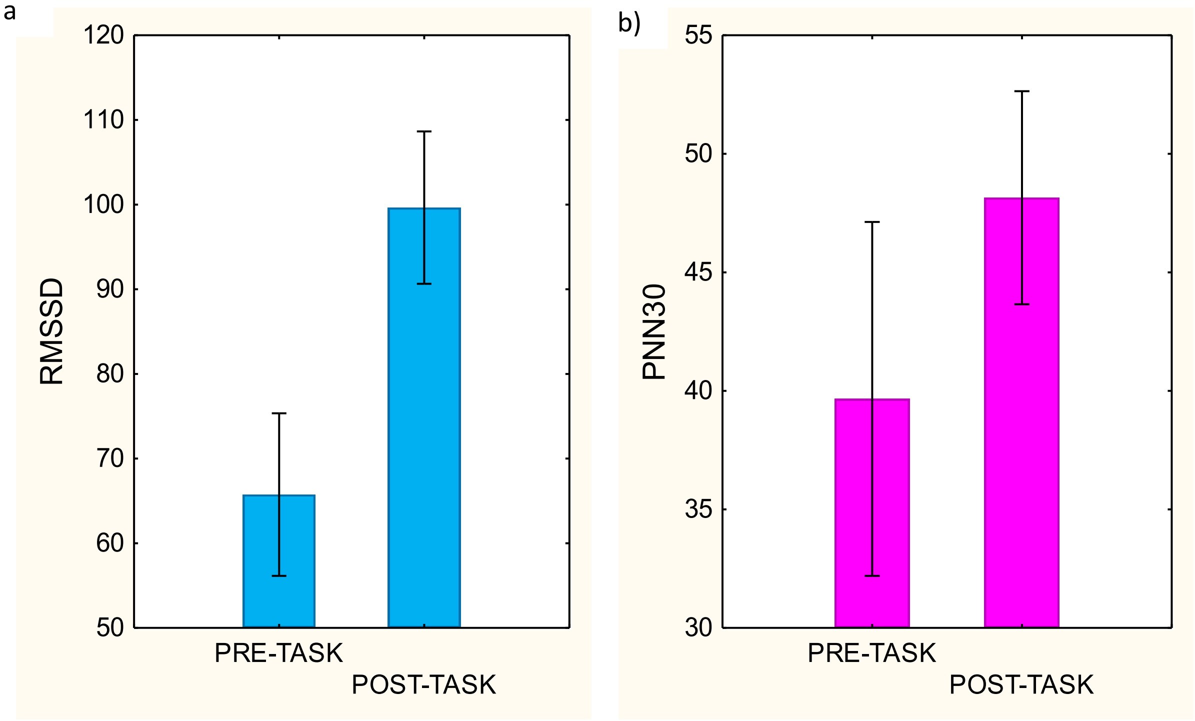

Figure 9: Pre- and post-task baseline measures for a) RMSSD and b) PNN30 variables. Error bars depict 95% confidence interval.

Time-on-task effect

Both RMSSD and PNN30 increased significantly over the testing period ($p < 0.01$; Figures 10 and 11 respectively). The experimental groups showed no significant difference in the profile of these parameters over time.

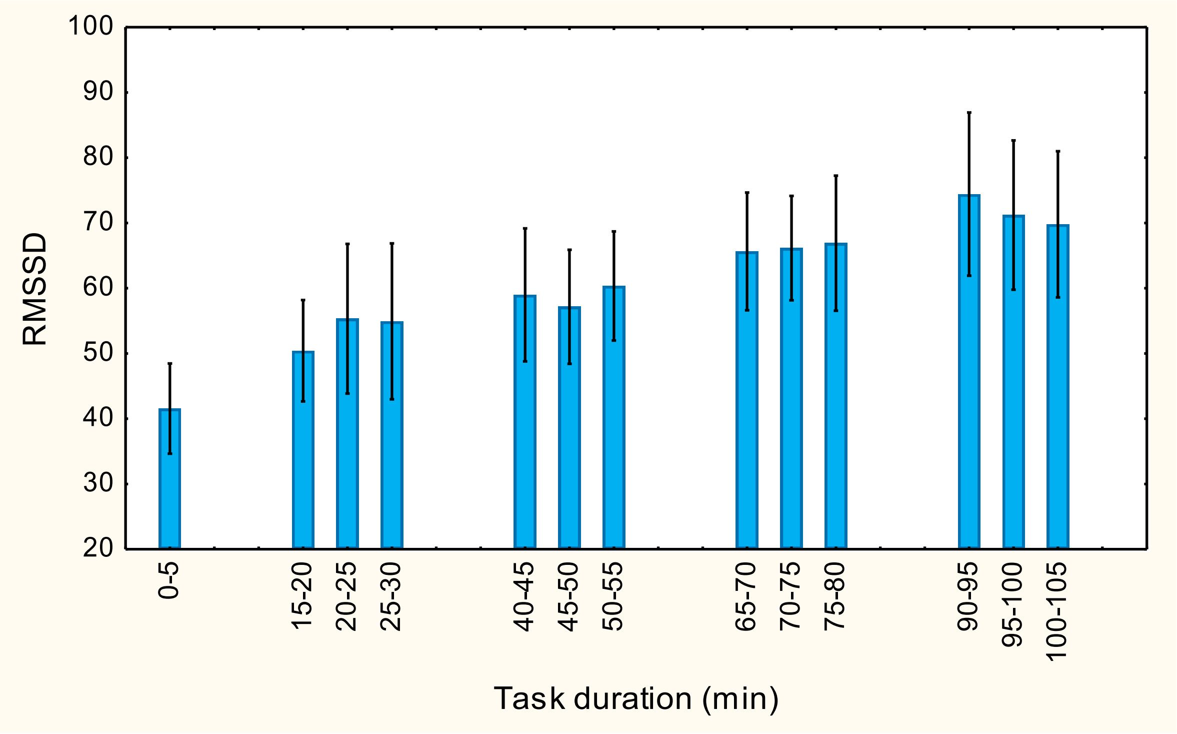

Figure 10: Change in heart rate variability (RMSSD) over time for all subjects. Error bars depict 95% confidence interval.

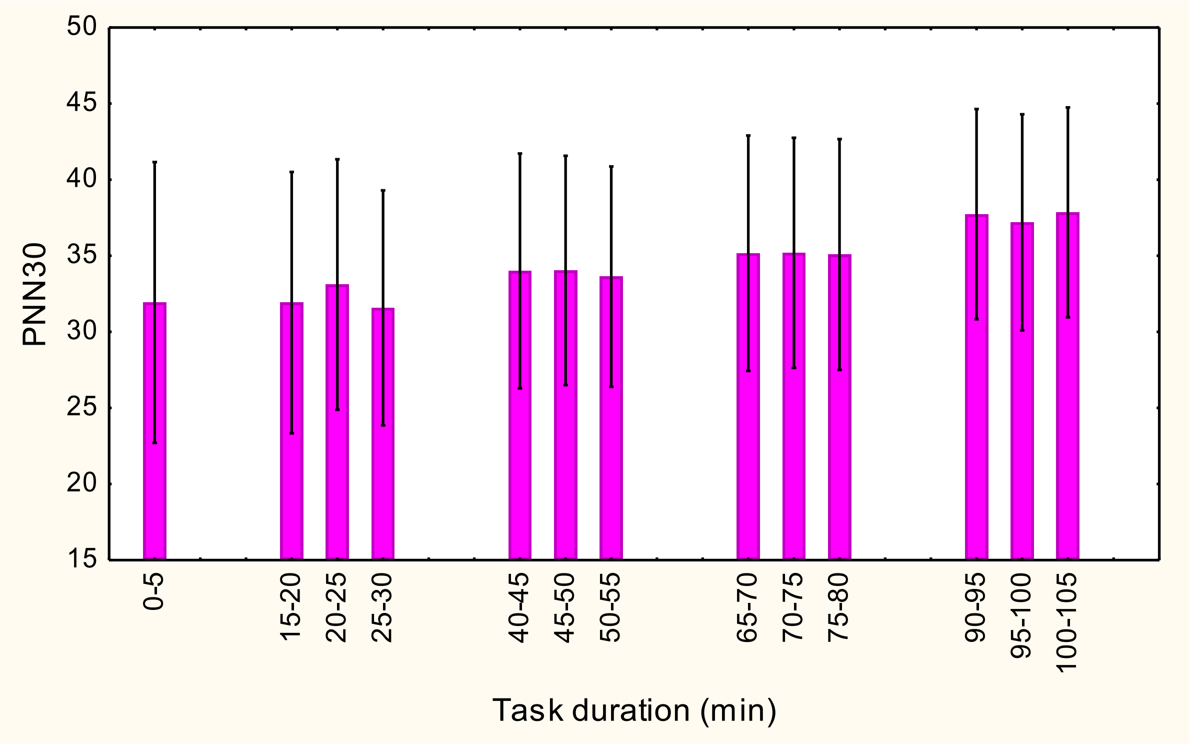

Figure 11: Change in PNN30 over time for all subjects. Error bars depict 95% confidence interval.

Heart rate variability: Frequency-domain analyses

Both high and low frequency spectra were considered for frequency domain analyses of HRV. The centre frequencies (LFcf; HFcf) and the power of the bands (LF power; HF power) were evaluated, as well as the low frequency component of the combined (LF+HF) power spectrum.

Baseline effect

Neither of the high frequency variables showed a significant difference pre- and post-test. Figure 12 shows the effects observed for the low frequency parameters. The LF power variable was significantly higher after the testing session ($p < 0.01$), and showed a general group effect with subjects in the memory span and choice RT groups having a significantly higher post-test LF power value. The change for subjects in the control group was not significant. The low frequency component of the (LF+HF) power also showed a significant increase following the testing period ($p = 0.01$). The LFcf was found to be significantly lower post-test ($p < 0.01$).

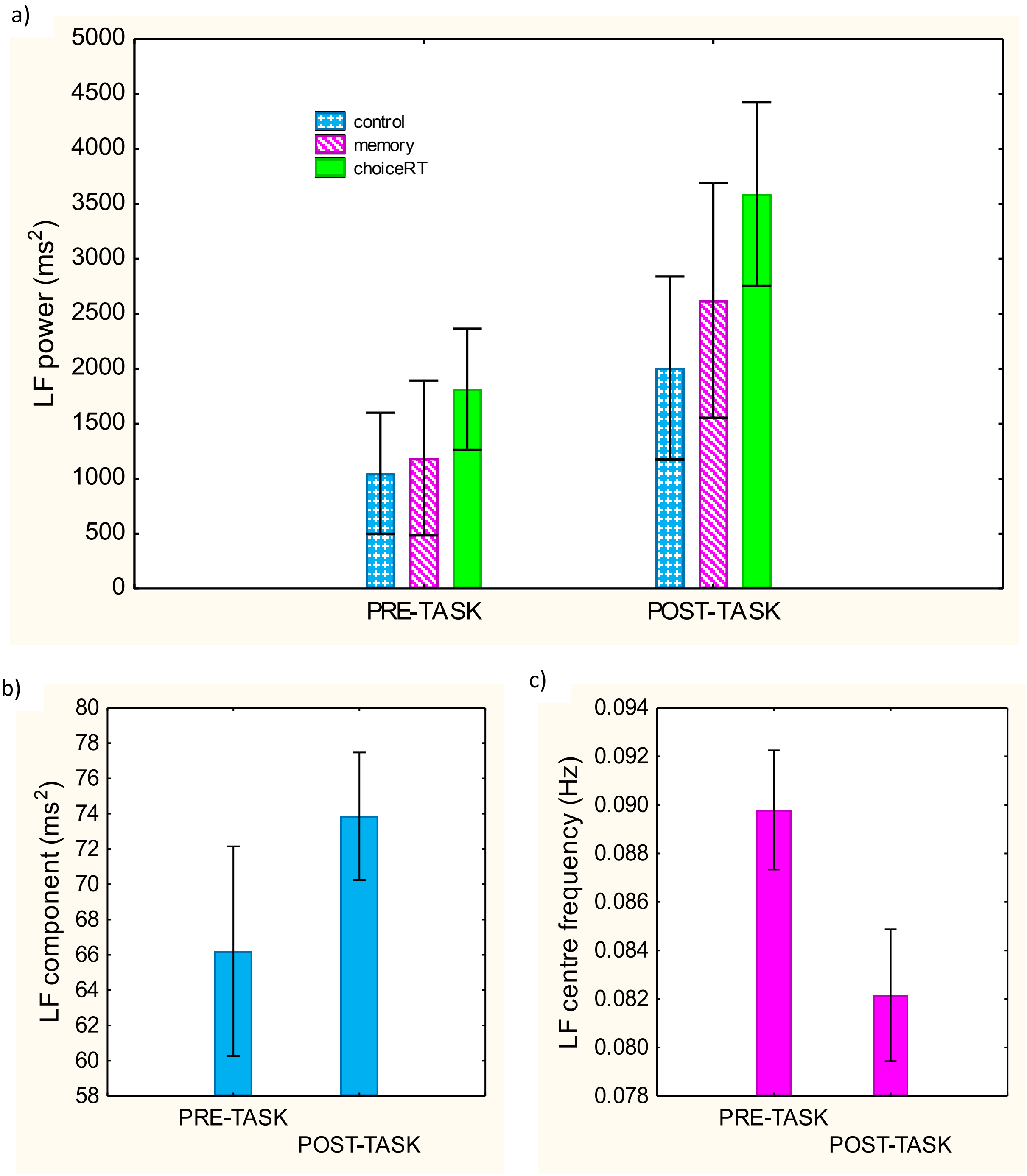

Figure 12: Changes in pre- and post-task baselines for low frequency parameters: a) change in low frequency power for the three groups; b) change in the low frequency component of (LF+HF) power for all subjects; c) change in low frequency centre frequency for all subjects. Error bars depict 95% confidence interval.

Time-on-task effect

The LF power variable was found to increase significantly over time ($p < 0.01$; Figure 13), while no significant change was elicited for HF power ($p = 0.08$; Figure 14). Figure 15 depicts the LF component of (LF+HF) power, which also increased significantly over the testing period ($p < 0.01$). None of the frequency-domain parameters depicted any difference between the three experimental groups.

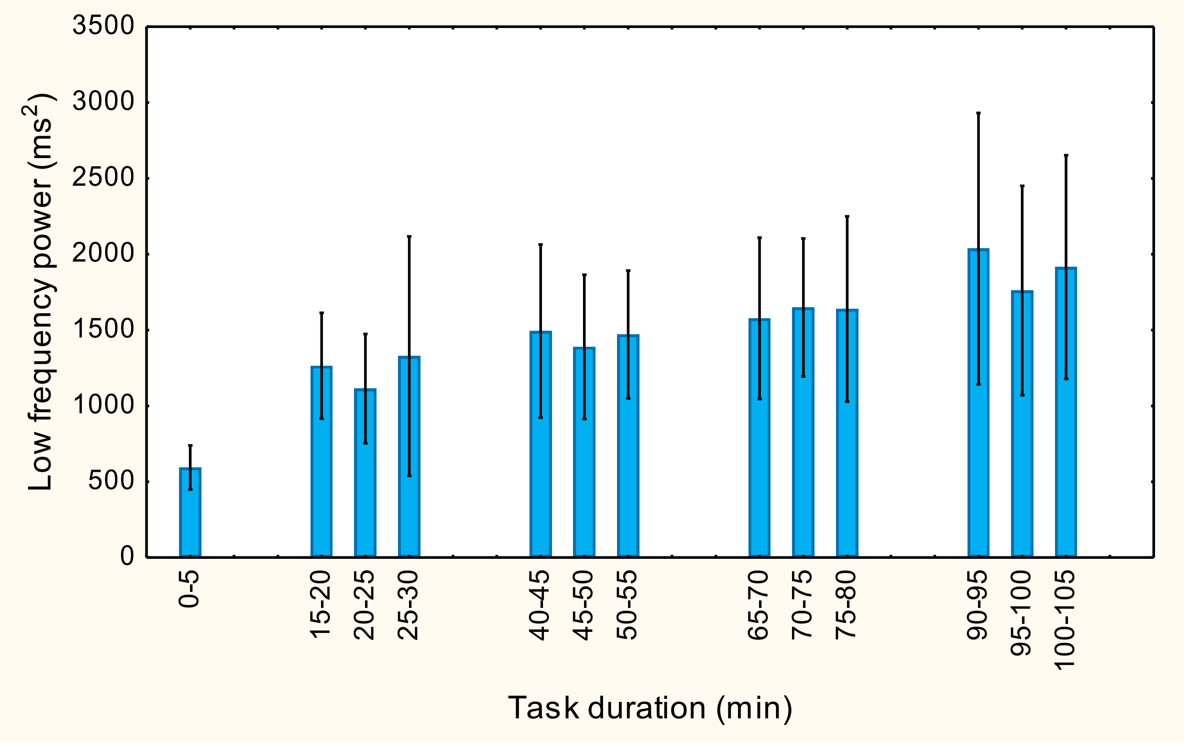

Figure 13: Change in power of low frequency spectrum over time for all subjects. Error bars depict 95% confidence interval.

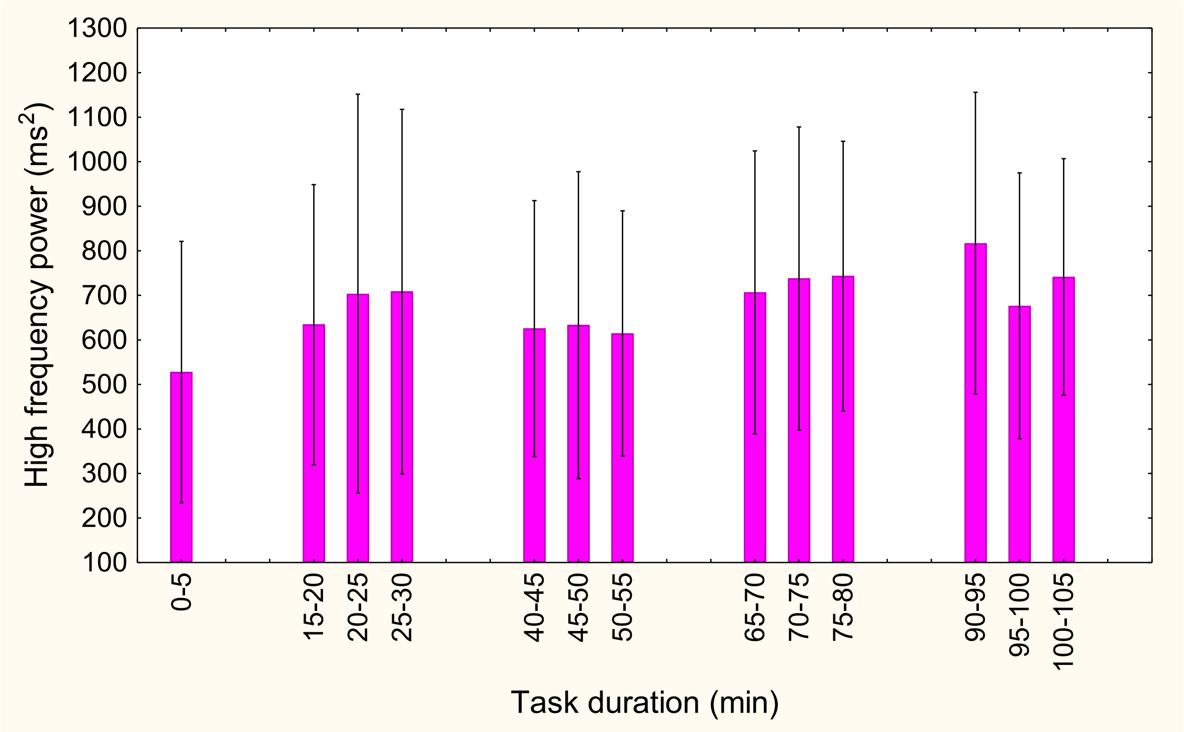

Figure 14: Change in power of high frequency spectrum over time for all subjects. Error bars depict 95% confidence interval.

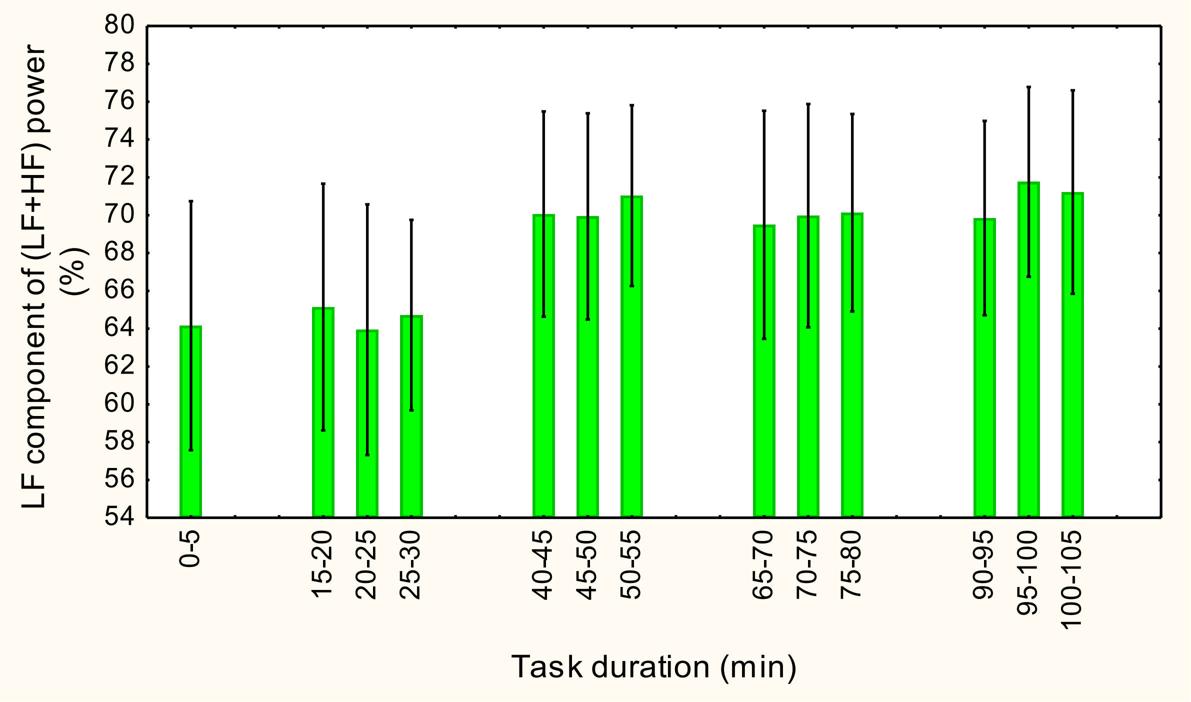

Figure 15: Change in the low frequency component of (LF+HF) power over time for all subjects. Error bars depict 95% confidence interval.

Both the LF and HF centre frequencies declined over time (p = 0.01 and 0.00; Figures 16 and 17 respectively). Figure 17 depicts that HFcf declines during the earlier stages of the protocol, while the measures seem to reach a plateau later in the protocol.

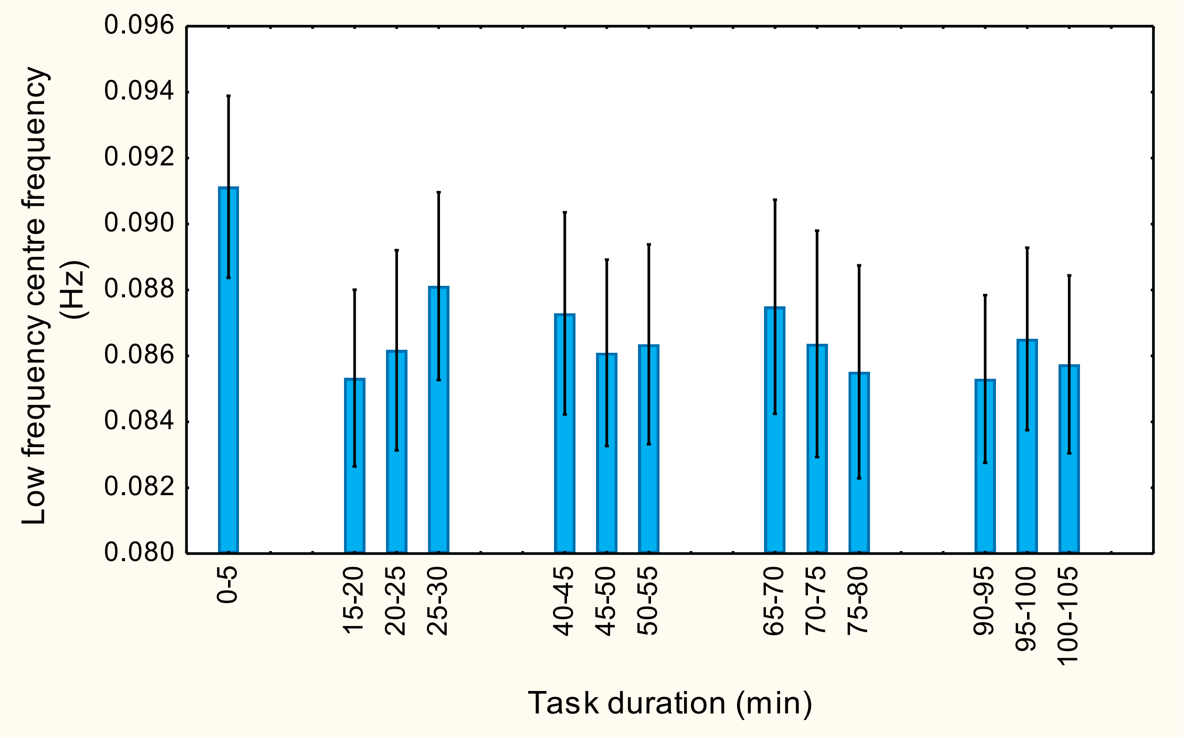

Figure 16: Change in low frequency centre frequency over time. Error bars depict 95% confidence interval.

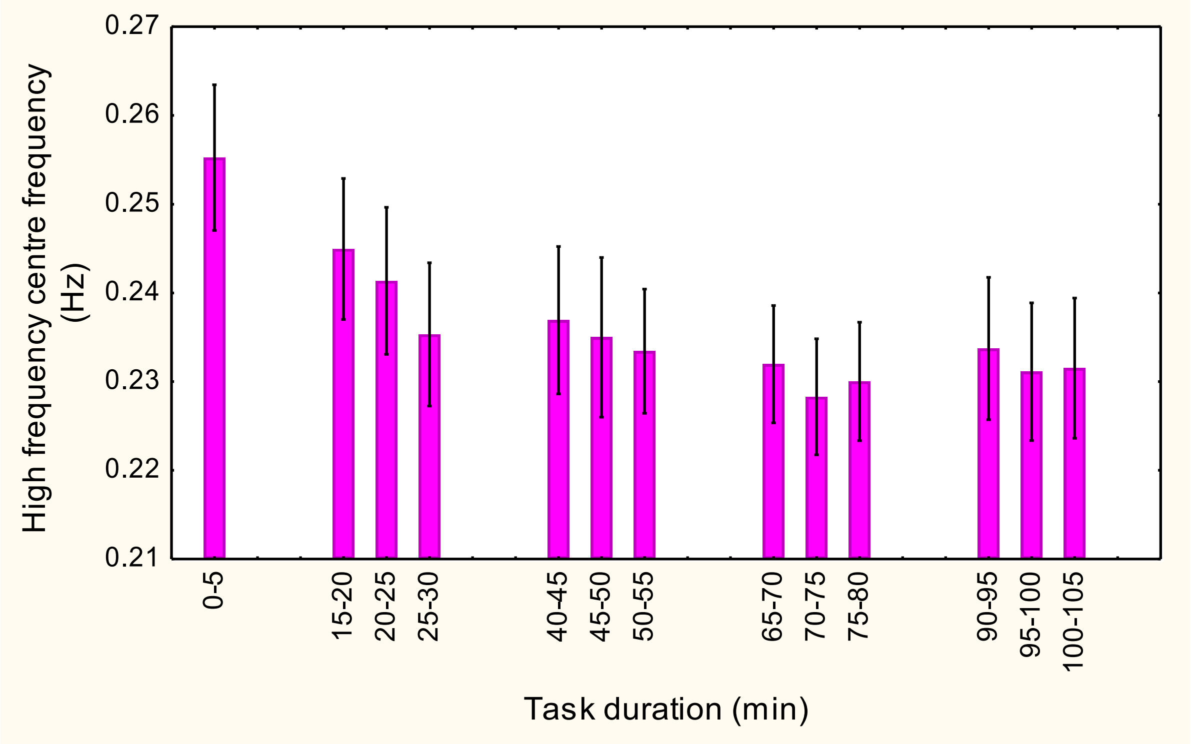

Figure 17: Change in high frequency centre frequency over time for all subjects. Error bars depict 95% confidence interval.

Oculomotor parameters

The eye movement analyses were grouped into four categories, namely pupil dilation, blink parameters, fixation parameters and saccadic parameters. Due to the large amount of inter-individual variability for the eye movement measures, the data was referenced to the values recorded during the first five minutes of driving in order to produce relative values. All eye movement data is therefore expressed as a ratio to the value obtained in the initial five minutes of the protocol.

Pupil dilation

Pupil diameter decreased significantly over the testing period ($p < 0.01$; see Figure 18). No difference between the experimental groups was noted over time.

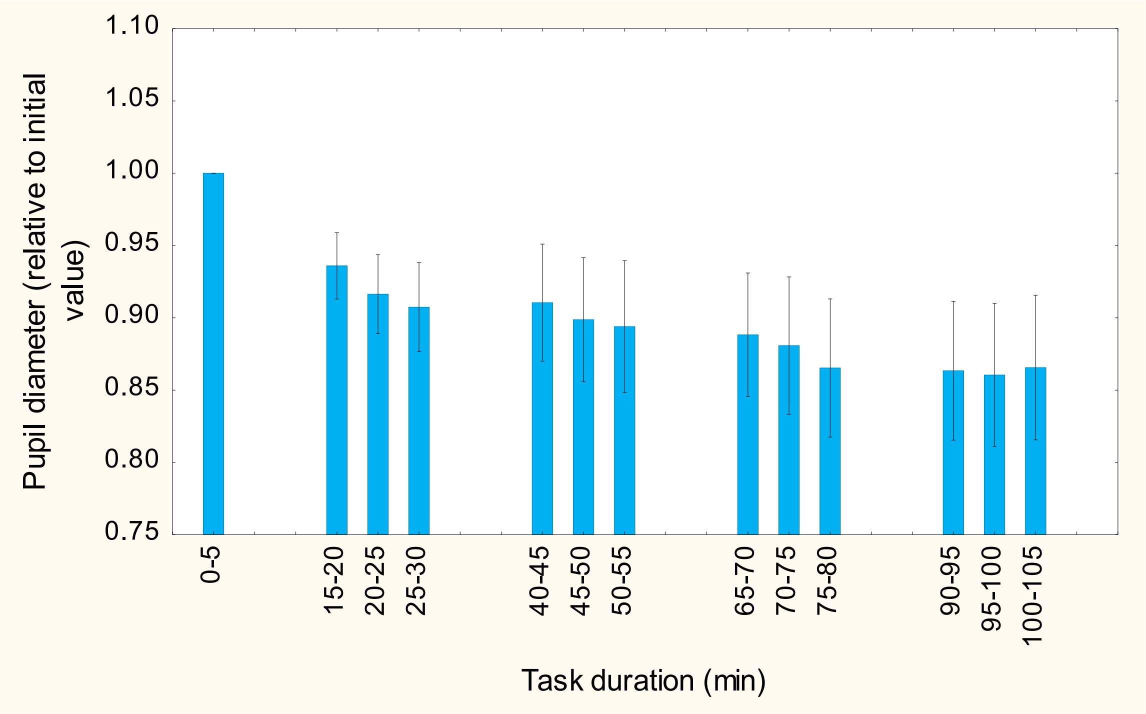

Figure 18: Change in pupil diameter over time for all subjects. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Blink frequency and duration

Initially, the intention of the author was to split the blink parameters into "short" (50 – 300 ms) and "long" (300 – 5000 ms) blinks in order to evaluate separately the effect of longer fatigue- or sleep-related blinks. The data, however, did not yield consistent values for the long blinks as often no long blinks occurred within a five minute interval, making statistical analysis of this measure difficult. It was therefore decided to calculate blink frequency and duration of all blinks, and if necessary, reanalyse the short blinks separately to see whether a clearer result could be obtained.

Blink frequency increased significantly over time ($p < 0.01$; see Figure 19). The three experimental groups did not yield any significant difference in terms of the fatigue profile. Blink duration was not significantly affected by time-on-task ($p = 0.19$). When considering the short blinks only, however, a significant increase in the duration of short blinks was noted.

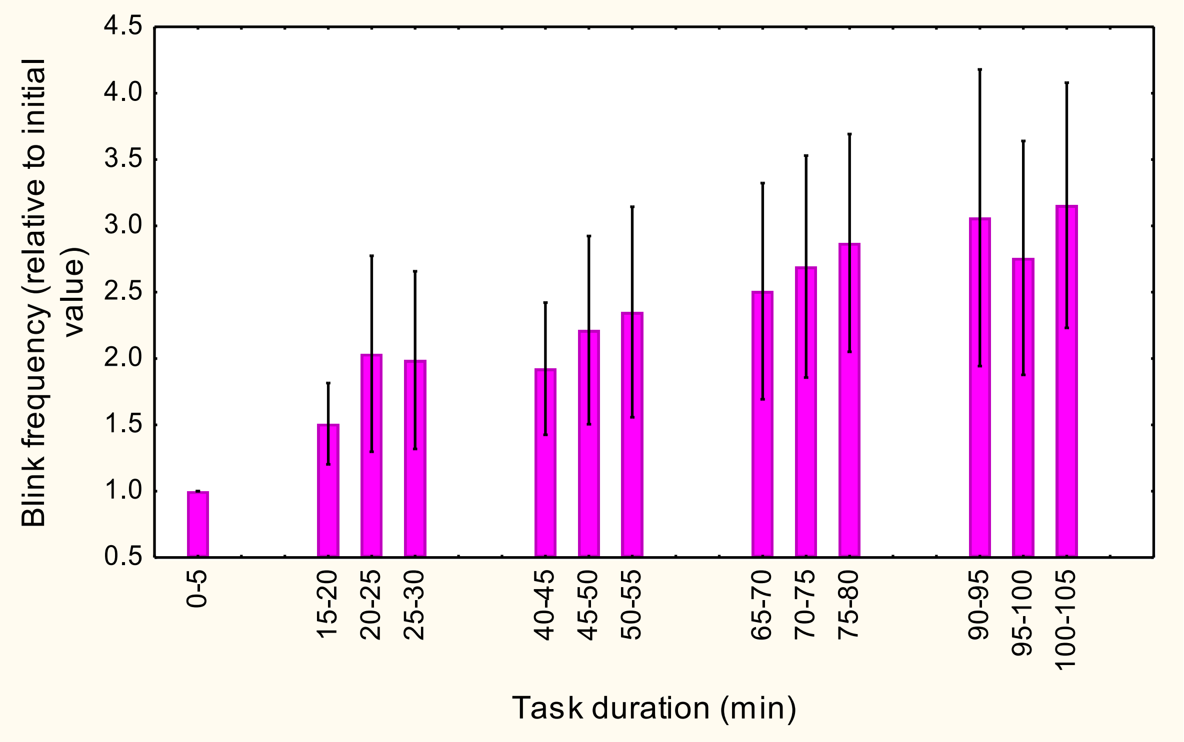

Figure 19: Change in overall blink frequency over time for all subjects. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Fixation duration and percentage time

As per Schleicher *et al.* (2008), fixations were analysed in terms of short (0-150 ms), medium (150-900 ms) and long (900-5000 ms) fixations. Both the average duration in each category as well as the percentage of total fixations each category represented was analysed.

The percentage of short fixations increased significantly over time ($p < 0.01$), and the duration of these blinks decreased over time ($p < 0.01$) (Figures 20 and 21 respectively). The percentage of medium fixations decreased significantly ($p < 0.01$), seen as a reciprocal of the increase in short fixations. A difference between the experimental groups was noted with regards to the percentage of medium fixations, with post-hoc analysis revealing a significant decline only within the group performing the choice RT task (Figure 22). The duration of medium fixations also decreased significantly over time ($p < 0.01$; Figure 23); no interaction with group or gender was found to be significant.

The percentage of long fixations did not yield any significant results. While the duration of long fixations also did not yield any time-on-task effects, a general group effect was observed, with subjects in the choice RT group having significantly shorter long fixations than subjects in the control group

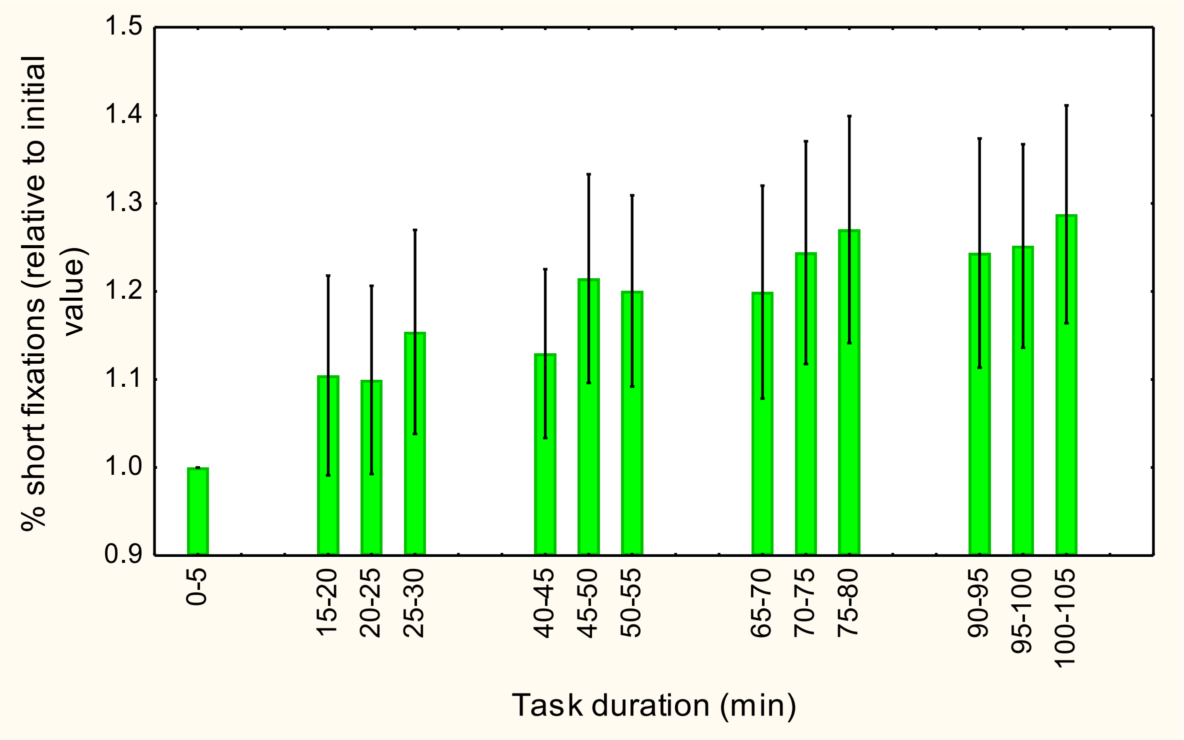

Figure 20: Change in percentage of short fixations and over time for all subjects. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

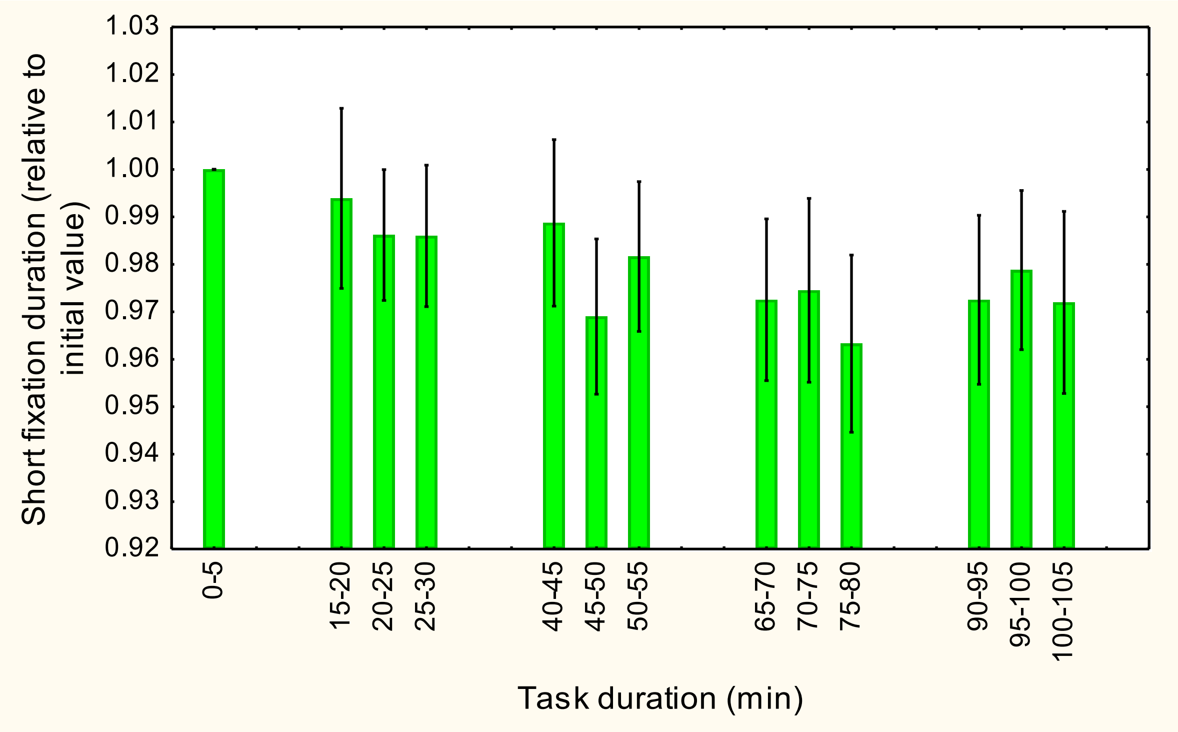

Figure 21: Change in duration of short fixations over time for all subjects. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

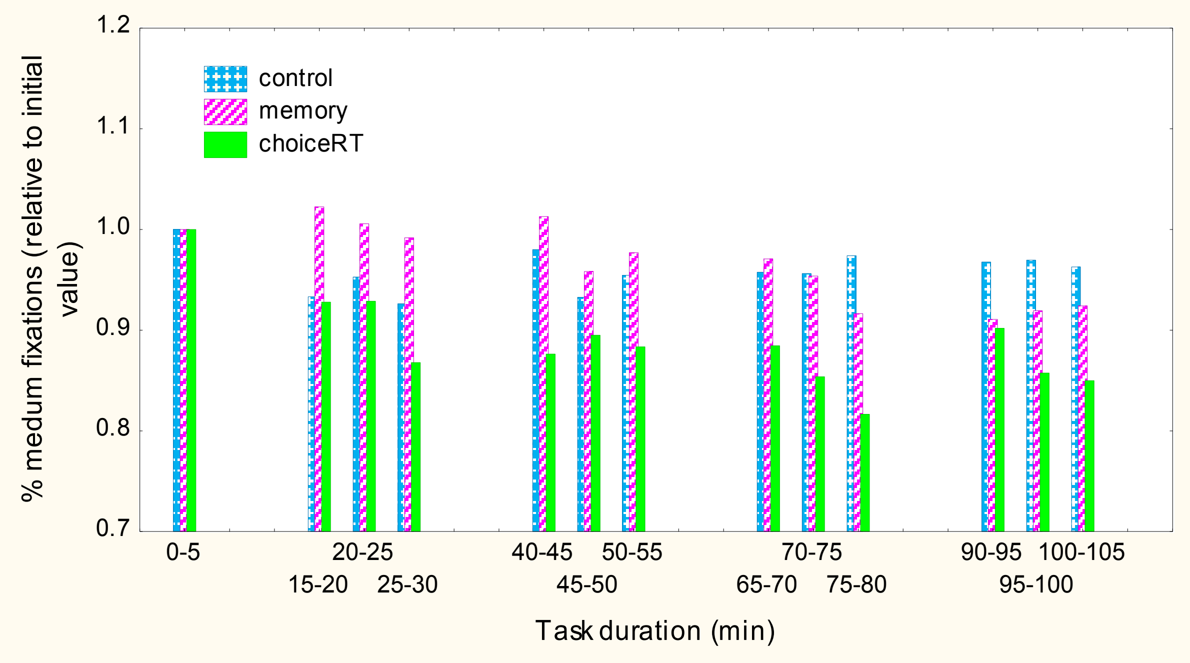

Figure 22: Change in percentage of medium fixations over time for the three experimental groups. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

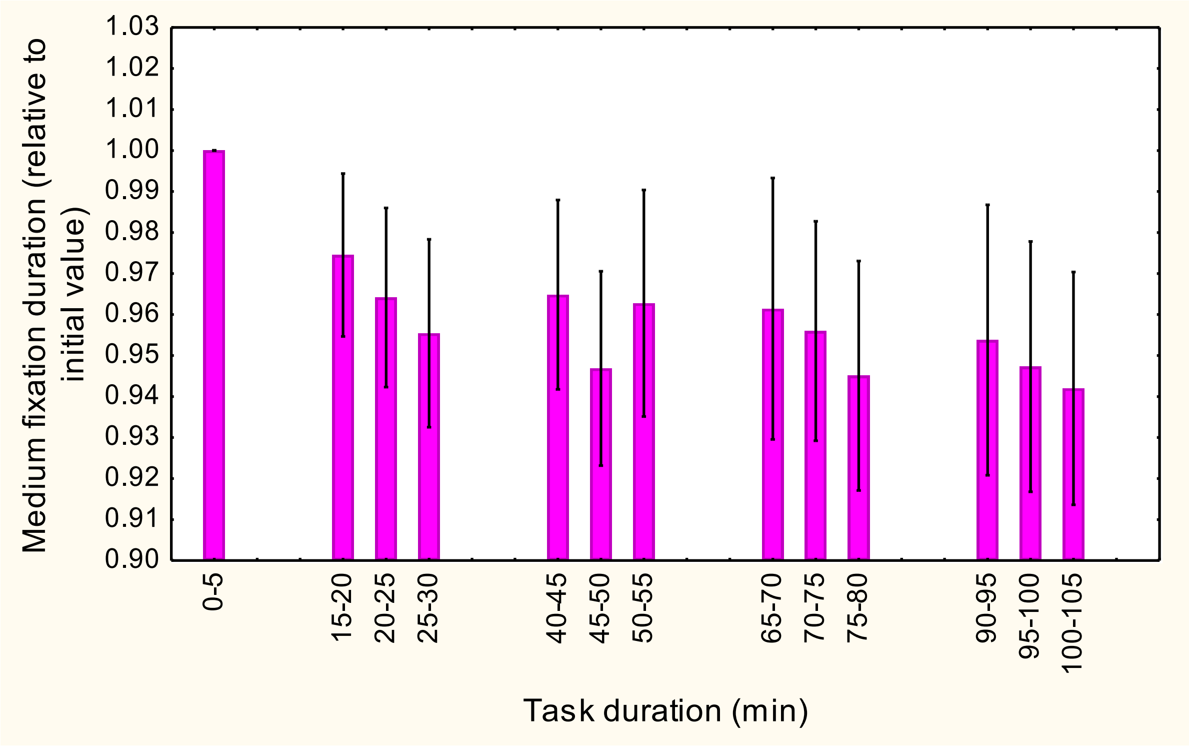

Figure 23: Change in duration of medium fixations over time for all subjects. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Saccades

Saccades were analysed in terms of speed, duration and amplitude. It must be noted that the detection threshold for both small and fast saccades may be compromised due to the limited sampling frequency of the 25 Hz Dikablis system.

A general group effect was evident with saccade duration, with the choice RT group having a significantly longer duration than the control group. All three saccadic parameters increased over time, with saccade amplitude and saccade speed yielding a significant interaction between the experimental group and time-on-task. Post-hoc analysis revealed that only subjects within the choice RT group experienced a significant increase in the amplitude and speed of saccades. Figures 24, 25 and 26 depict saccade amplitude, speed and duration respectively for the choice RT group ($p < 0.01$, 0.01 and 0.00 for saccade amplitude, speed and duration respectively).

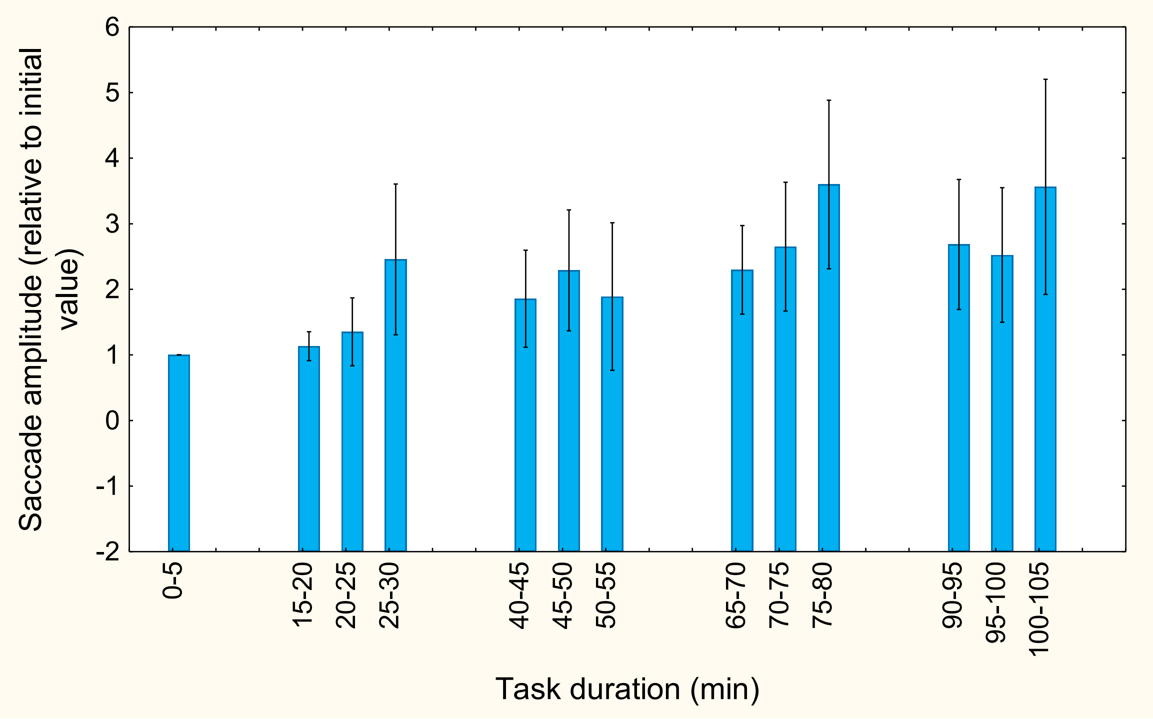

Figure 24: Change in saccade amplitude over time for subjects in the choice RT group. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

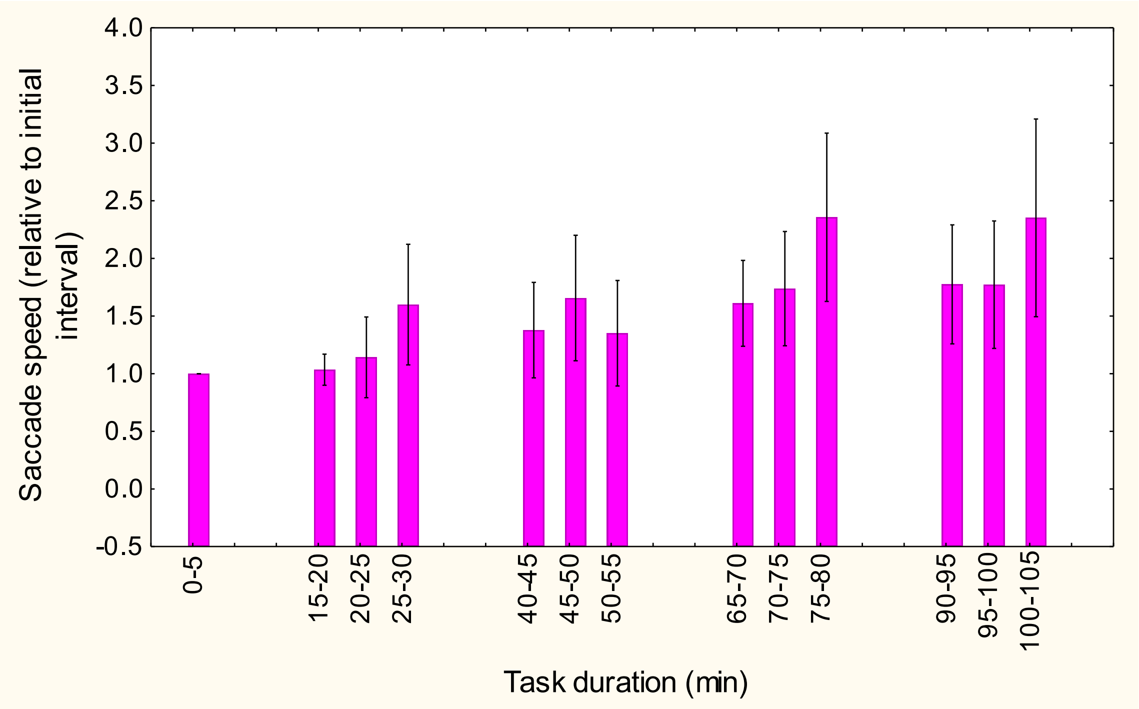

Figure 25: Change in saccade speed over time for subjects in the choice RT group. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

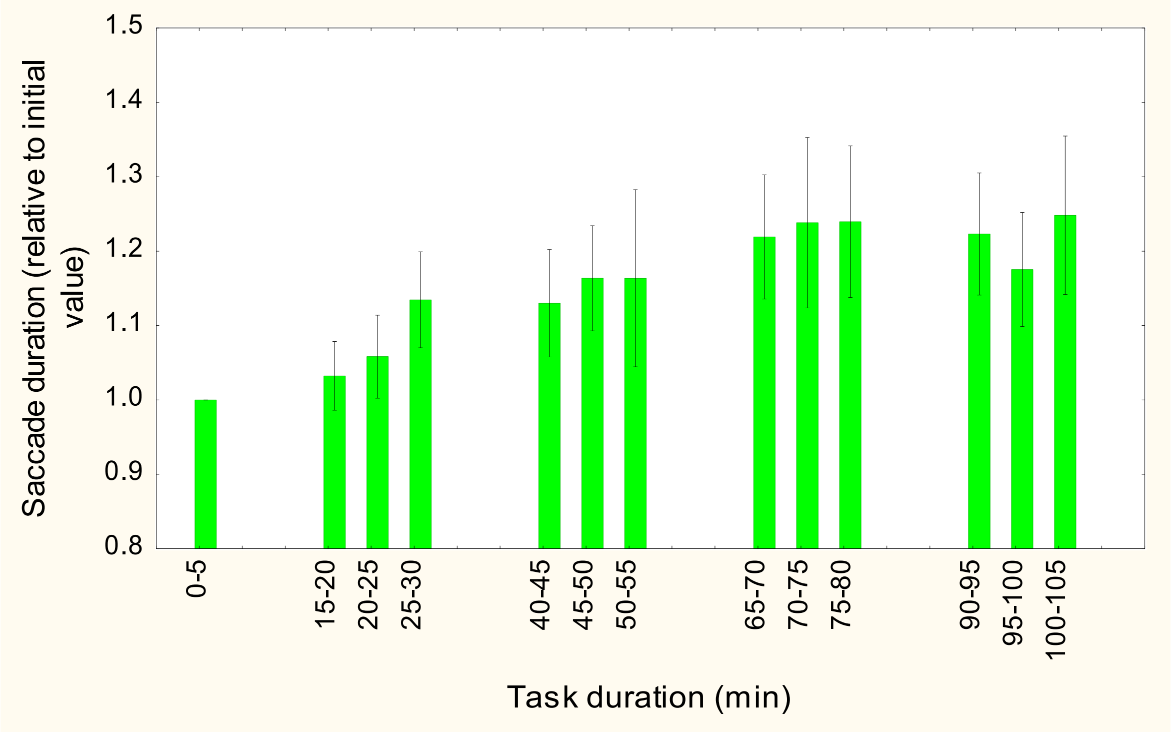

Figure 26: Change in saccade duration over time for subjects in the choice RT group. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Critical Flicker Fusion Frequency

Critical flicker fusion frequency demonstrated a significant decline after the experiment was completed (p = 0.03; Figure 27). The experimental group had no significant effect on this decline, nor did the gender of the subjects, or the time of day the test was performed.

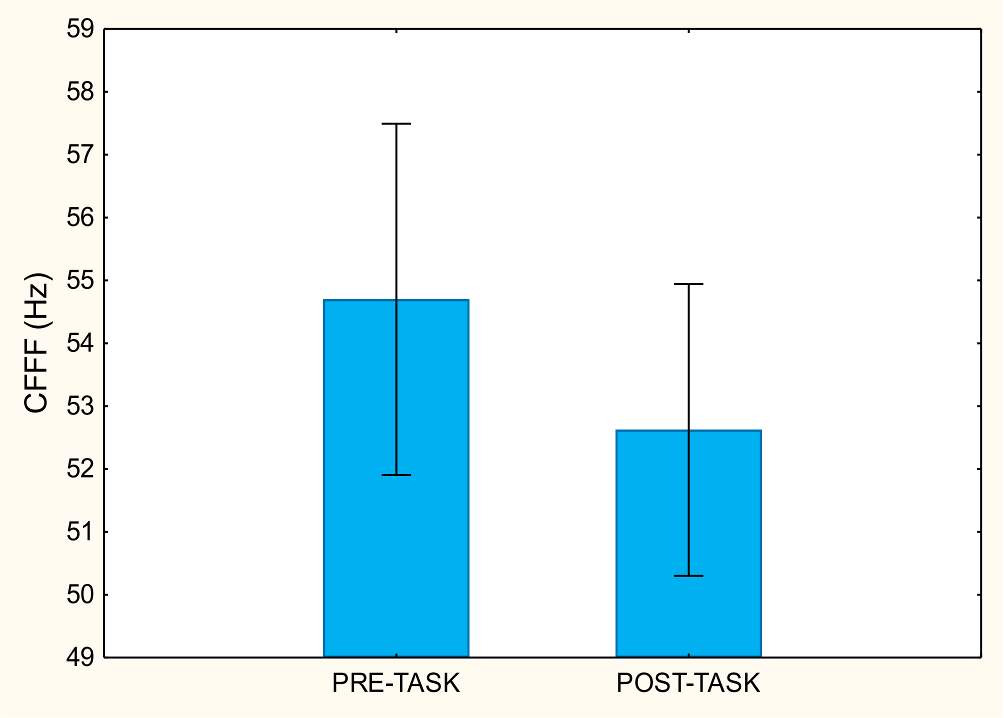

Figure 27: Comparison of average critical flicker fusion frequency for all subjects before and after the testing session. Error bars depict 95% confidence interval.

Subjective parameters

Perception of effort

Subjective feelings of fatigue (or increased effort expenditure) were recorded by means of the Borg CR-10 scale prior to the secondary task intervals (i.e. after intervals 6, 11, 16 and 21; see Table I in Chapter III). A significant increase in subjective effort rating was noted ($p < 0.01$), with a post-hoc analysis revealing significant differences between all of the four instances (see Figure 28). The CR-10 rating was unaffected by the experimental group, gender and time of day the test took place.

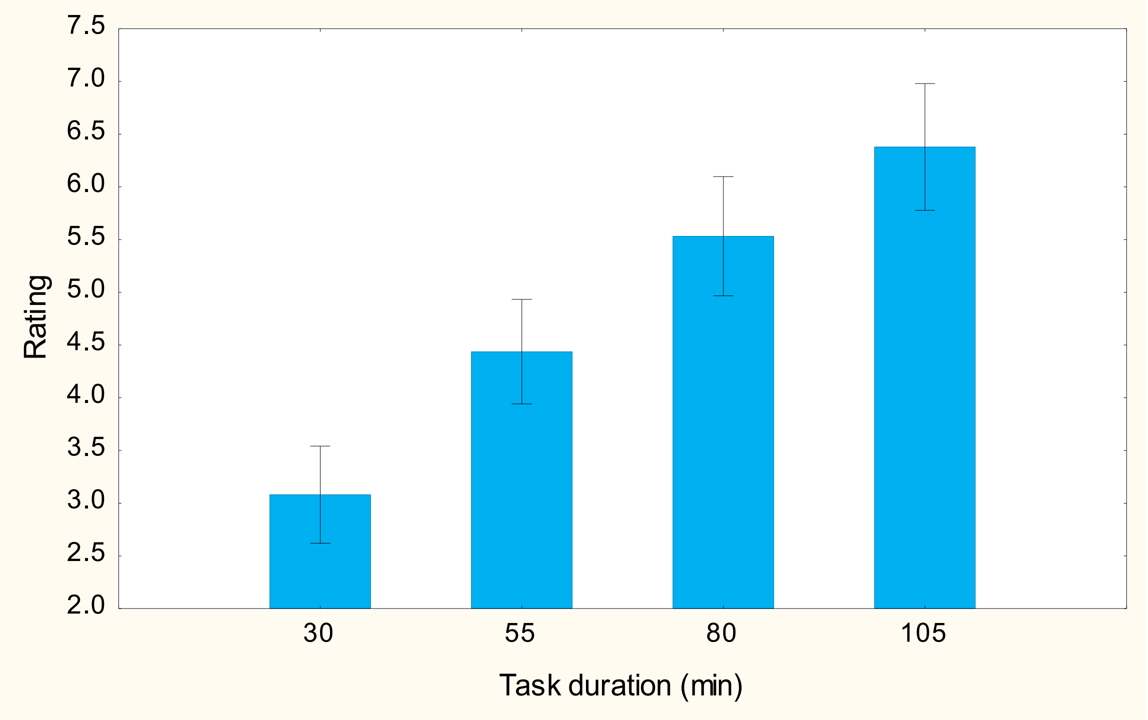

Figure 28: Average CR-10 rating for all subjects over time. Error bars depict 95% confidence interval.

NASA-TLX

A NASA-TLX was completed by the subjects following completion of the experiment in order to evaluate the subjective workload imposed by the driving task. Figure 29 shows the weighted scores for each workload dimension as an average over all 42 subjects. No significant differences were found with regards to the covariates, and the secondary tasks were found to have no significant effect on the overall workload rating From Figure 29 it can be seen that the mental demand was rated as the greatest contributor to the overall workload, followed by the amount of effort required by the task. The level of frustration that the task induced was the third largest contributor, followed by performance. Physical and temporal demand contributed the least to the experienced workload.

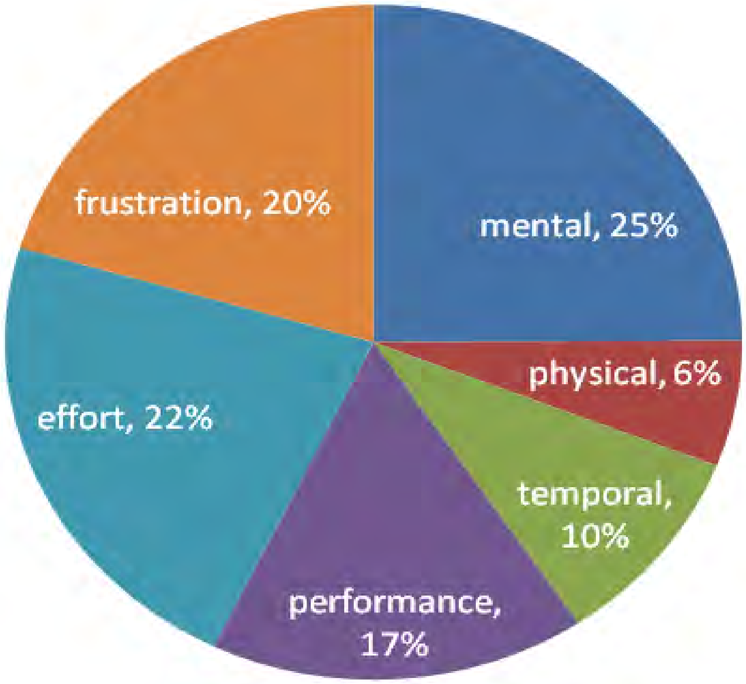

Figure 29: Weighted NASA-TLX scores for all subjects (expressed as percentage of total workload).

Gender effects

The driving parameters discussed above revealed a significant gender difference. While no general gender effect was found to be significant, gender did present a significant difference (p = 0.01) with regards to the change in driving parameters over time. While females started at a slightly lower performance level (i.e. higher mean deviation; see Figure 30), post-hoc analysis revealed that their performance did not change significantly over time. Males, on the other hand, while performing slightly better than the females at the beginning of the protocol, experienced a significant decline in performance parameters over time.

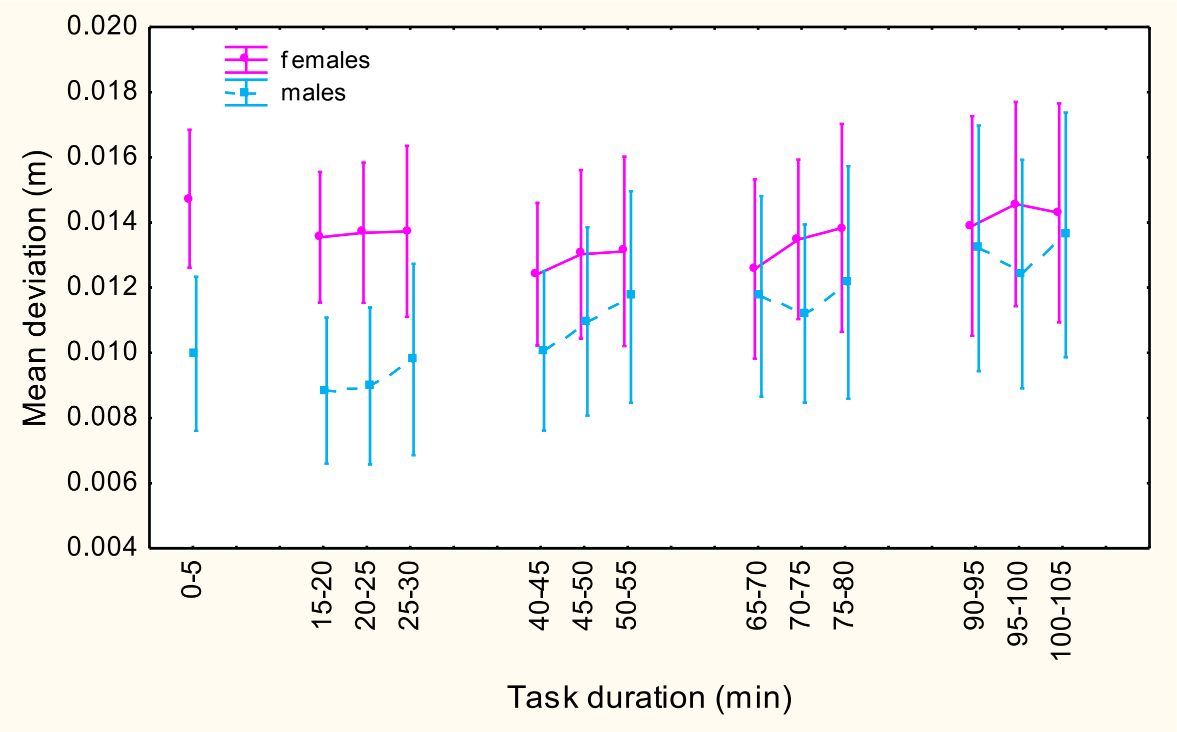

Figure 30: Change in mean driving deviation over time for males and females. Error bars depict 95% confidence interval.

No significant gender effects were found with regards to heart rate data.

Gender was found to have an interaction effect with time-on-task for some of the eye movement parameters. With regards to the decline in pupil diameter over time, the female subjects were found to produce a more significant decline over time when compared to the male subjects (p = 0.02; Figure 31). A general gender effect was noted for both short fixation parameters as well as for the percentage of medium fixations and long fixation duration (Figure 32). In general, males had a significantly greater amount of short fixations, and a lower number of medium fixations when compared to female subjects. They were also found to produce short fixations of shorter duration and long fixations of longer duration than the female subjects. The decrease in duration and increase in percentage of short fixations over time was found to be due to the male subjects, as was the decline in percentage of medium fixations over time (Figures 33, 34 and 35 respectively). Finally, the increase noted for saccade duration over time was also attributed mostly to the male subjects (Figure 36).

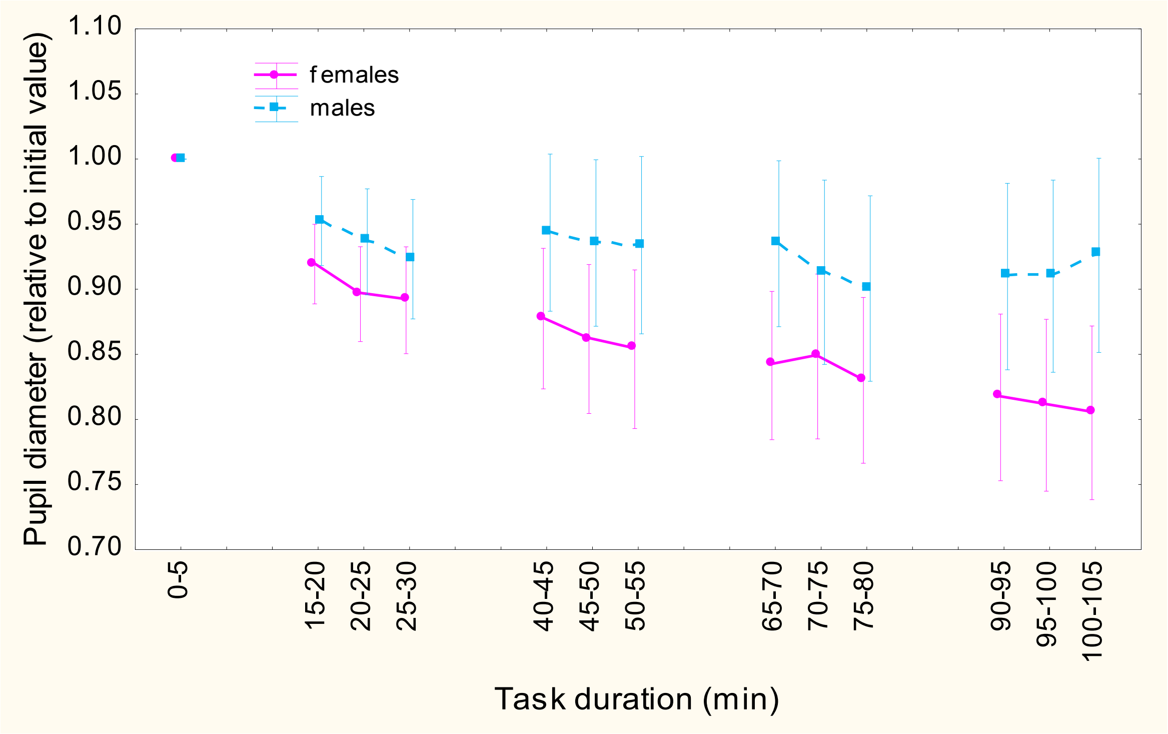

Figure 31: Change in pupil diameter over time for males and females. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

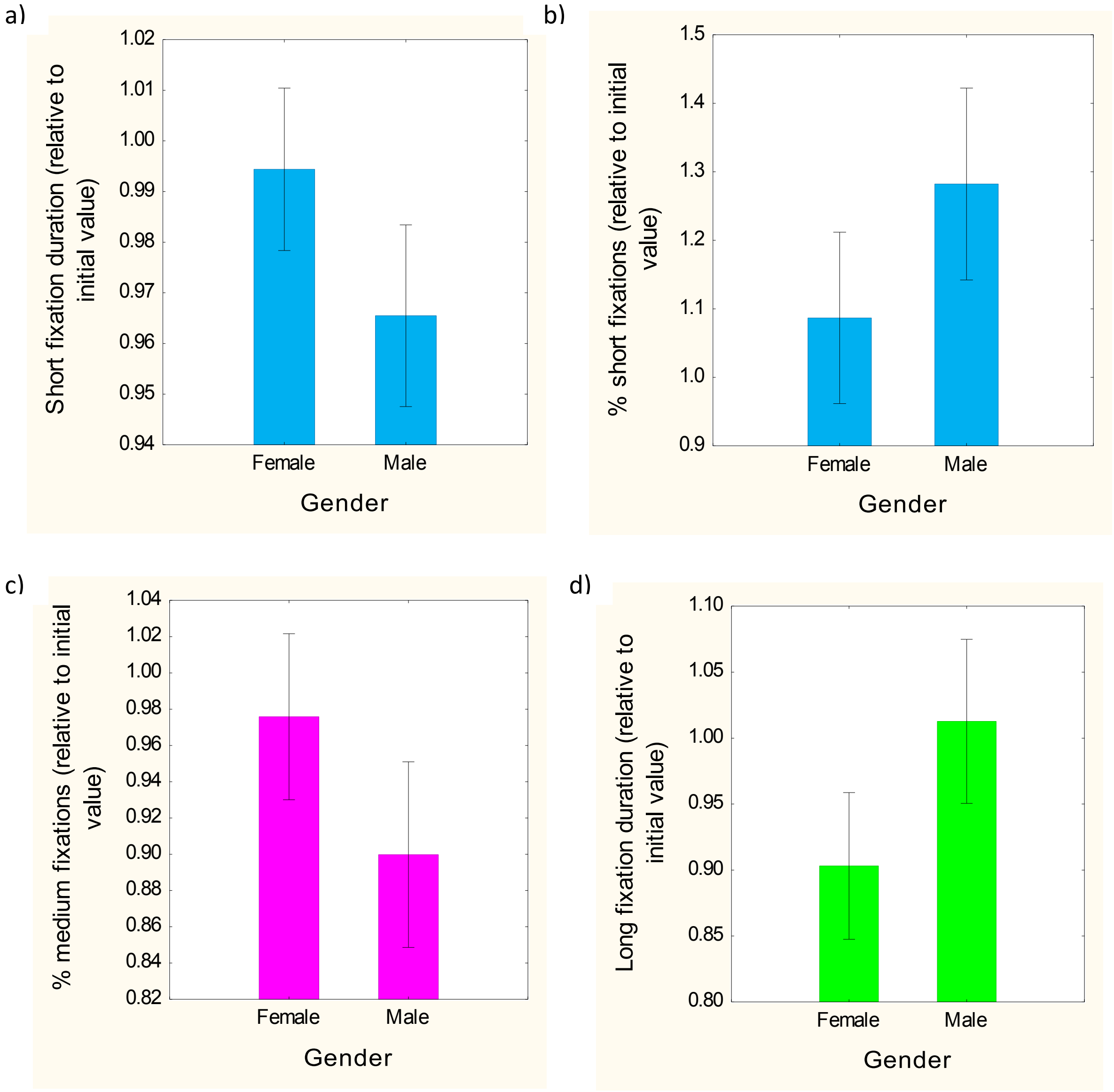

Figure 32: General difference in fixation parameters between male and female subjects: a) short fixation duration; b) percentage of short fixations; c) percentage of medium fixations and d) long fixation duration. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

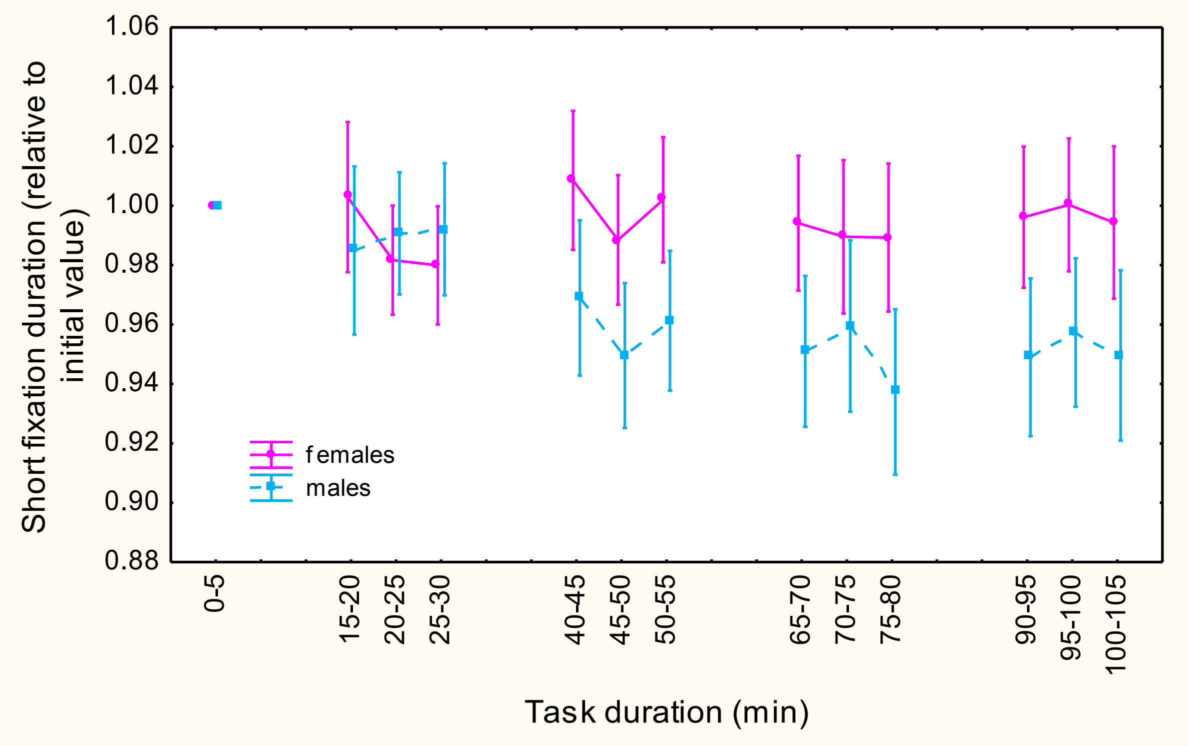

Figure 33: Change in short fixation duration over time for males and females. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

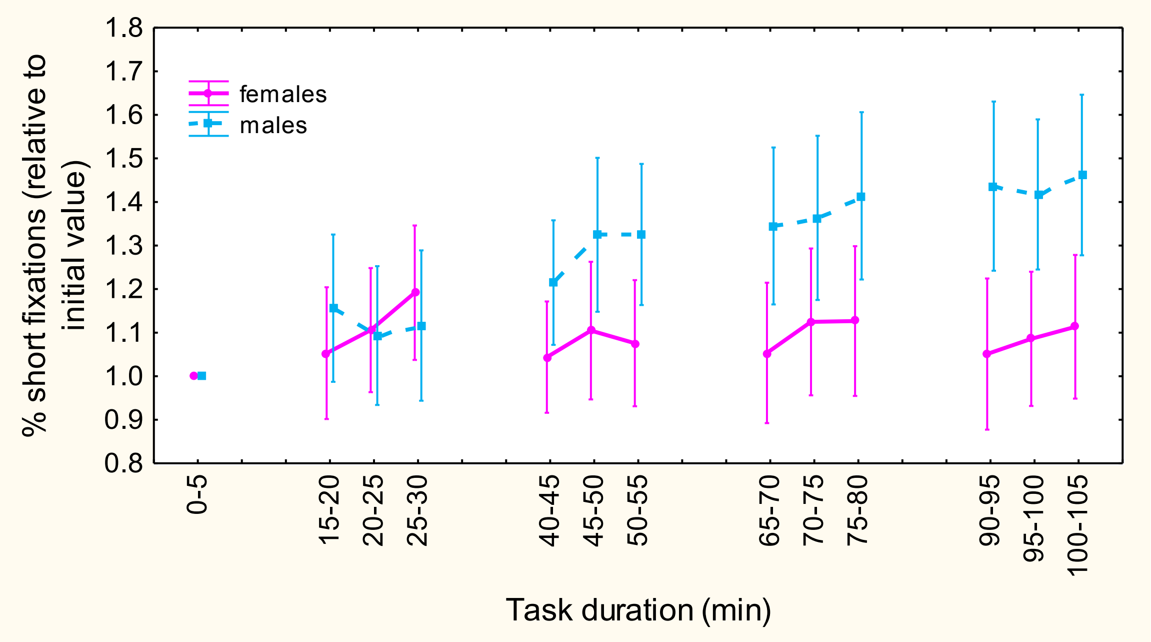

Figure 34: Change in the percentage of short fixations over time for males and females. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

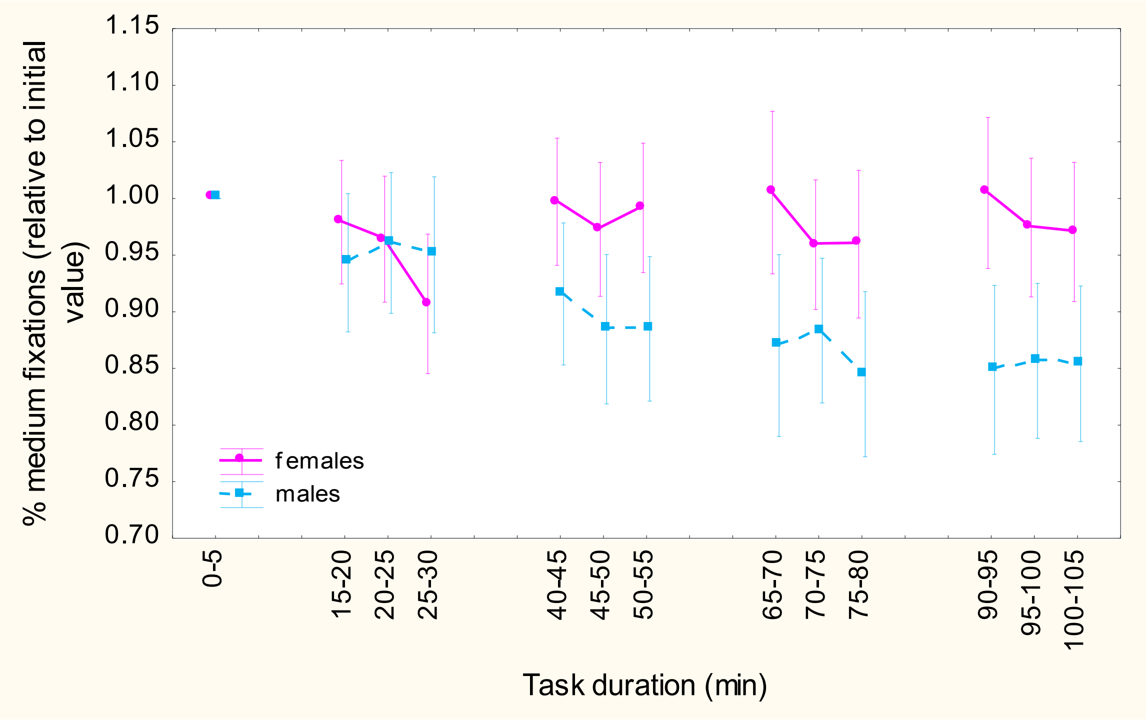

Figure 35: Change in the percentage of medium fixations over time for males and females. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

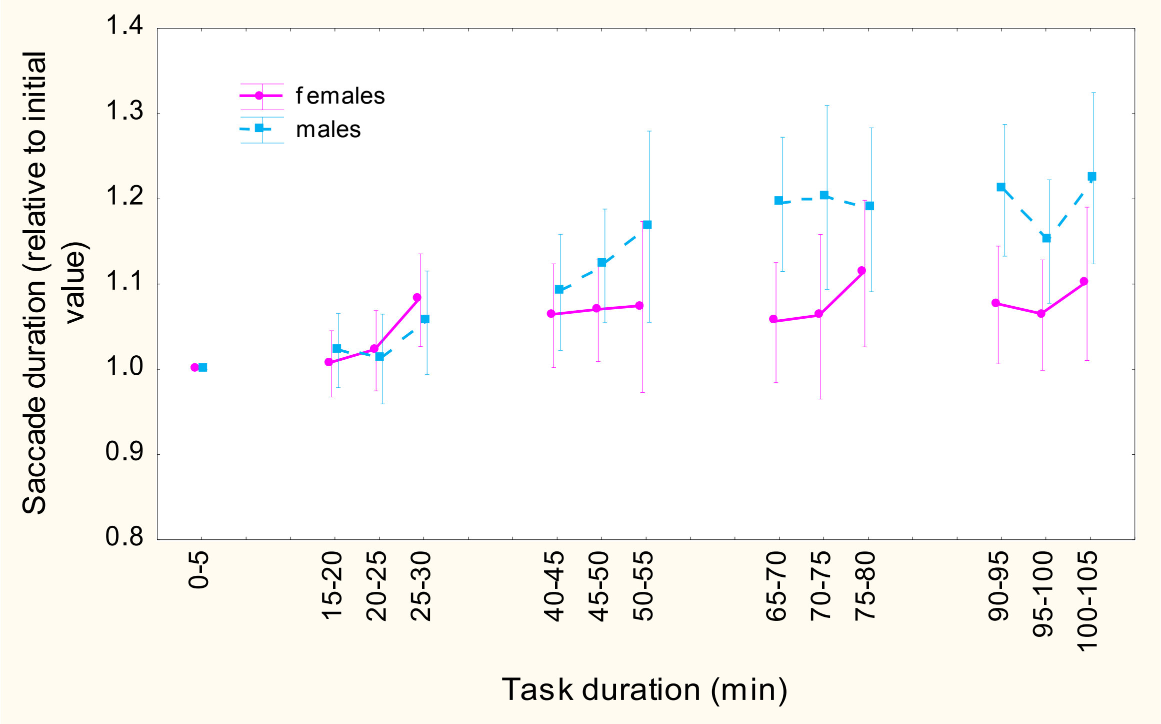

Figure 36: Change in saccade duration over time for males and females. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Time of day effect

The effect of the time of day that testing took place was less prevalent than the gender influence on the results, with only heart rate parameters showing a significant effect. With regards to the baseline cardiovascular measures, the LFcf and HFcf showed a general time of day effect (p = 0.01 and 0.02 respectively), with subjects tested in the afternoon generally having higher centre frequencies. The decline in LFcf post-task was attributed to the significant decline within subjects tested in the morning, where no significant decline was seen for subjects performing the test in the afternoon session (see Figure 37). While the HFcf did not show a significant change between pre- and post-task measures, it did show the same general effect of time of day to be significant.

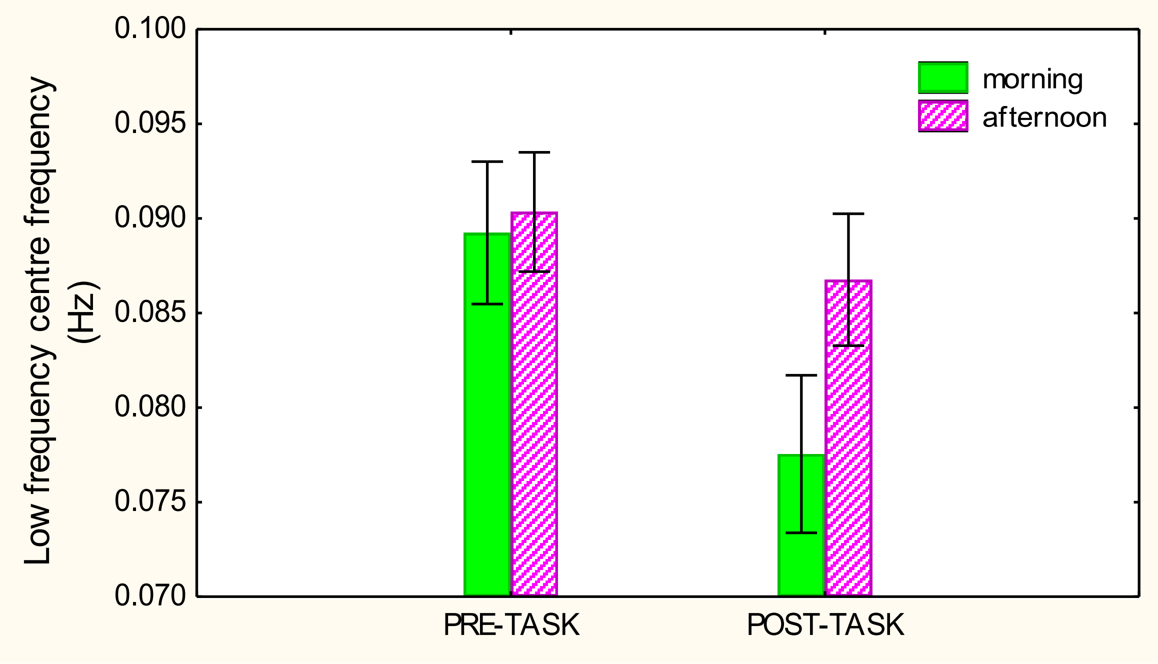

Figure 37: Pre- and post-task difference in HRV (low frequency centre frequency) for subjects tested in the morning and subjects tested in the afternoon sessions. Error bars depict 95% confidence interval.

The decline in heart rate over time during testing was also shown to interact significantly with the time of day testing took place (p = 0.03) – Figure 38 shows that while both morning and afternoon subjects showed a decline in HR over time, the subjects performing the task in the morning produced a more significant decline than did the afternoon subjects.

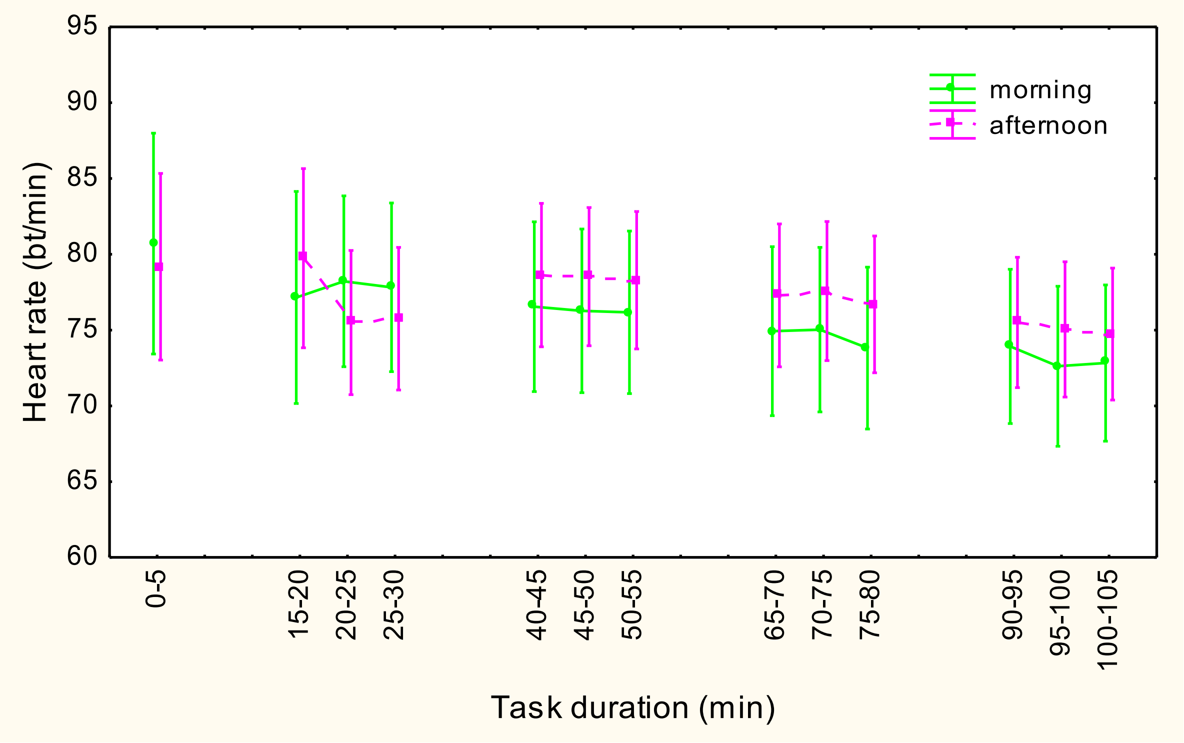

Figure 38: Change in heart rate over time for subjects tested in the morning and subjects tested in the afternoon sessions. Error bars depict 95% confidence interval.

EFFECT OF SECONDARY TASK

The following section assessed the change in both performance and physiological variables in response to the secondary task. The intervals before, during and after the secondary task were considered in each of the four instances, and the experimental groups were compared in terms of the changes they elicited. Again, while gender and time of day effects were considered as covariates, they were considered separately at the end of the section.

Table II: Summary of significant secondary task-related effects for dependent variables; where **TASK** = change in parameters elicited by the secondary task interval in general; **GROUP** = difference in reaction to secondary task between the three experimental groups; **TASK over time** = change in effect elicited by the secondary task over the four task instances (X denotes a significant difference where $p < 0.05$).

	TASK	GROUP	TASK over time
PERFORMANCE PARAMETERS			
Mean deviation	X		
Reaction time			
Info capacity	X		
Steering alteration		X	X
CARDIOVASCULAR PARAMETERS			
Heart rate	X	X	X
RMSSD	X	X	X
PNN30			X
HF power	X	X	
HF cf	X	X	X
LF power	X	X	
LF cf		X	
LF component of (LF+HF) power		X	
OCULOMOTOR PARAMETERS			
Pupil	X	X	X
Blink frequency	X	X	
Blink duration			
Short fixation duration		X	X
% short fixations		X	
Medium fixation duration			X
% med fixations			
Long fix duration			
% long fixations			
Saccade duration			
Saccade amplitude			
Saccade speed			

From Table II it can be seen that parameters in both the performance and physiological measures depicted significant change elicited by the secondary task interval. The majority of the measures presented a specific group effect, showing that the effect elicited by the task was due to a specific group. A significant change in the effect of the secondary task over time was evident for steering alteration frequency, heart rate and time-domain HRV parameters, HFcf, pupil diameter and short and medium fixation durations.

Performance parameters

For the secondary task section, driving performance as well as the performance of the secondary tasks was considered.

Driving performance

Mean deviation was significantly affected by the addition of a secondary task (p = 0.03), with deviation decreasing during the secondary task (Figure 39).

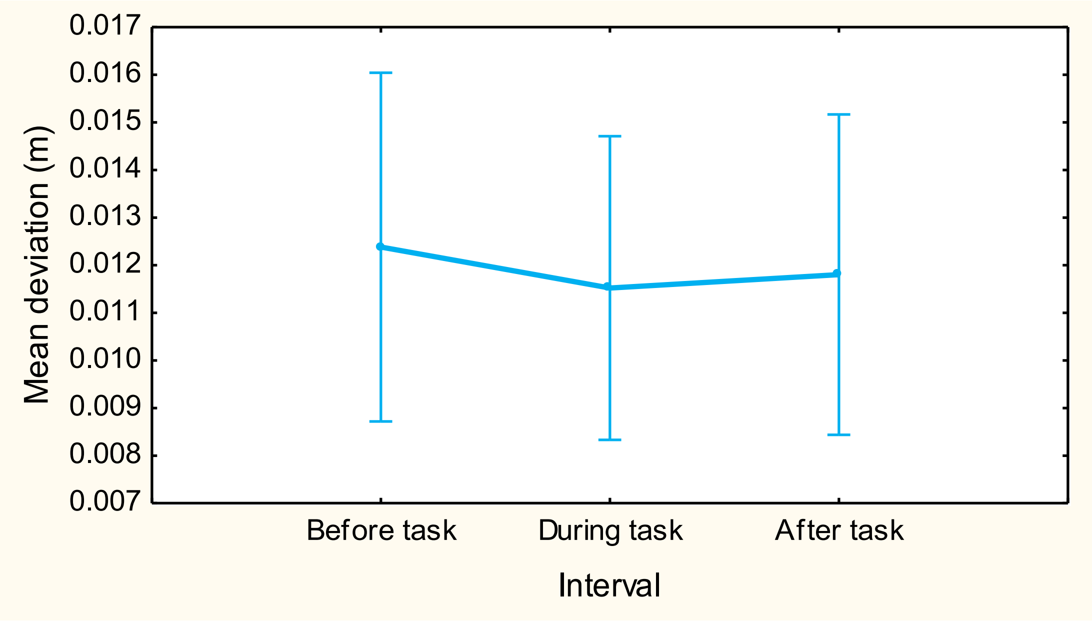

Figure 39: Change in mean deviation during secondary task performance; average over the four task instances. Error bars depict 95% confidence interval.

Steering alteration frequency was significantly affected by the group (p = 0.04), with the memory task increasing the frequency and choice RT reducing the frequency with which steering alterations were made (Figure 40). Steering alteration frequency also showed a significant change over time between the intervals during which the secondary task was performed (p < 0.01). While the frequency decreased during task performance in the initial period, during the second and fourth periods the addition of the secondary task resulted in an increased in steering alteration frequency. Further post-hoc analysis revealed that this change was only significant for the memory span group (Figure 41).

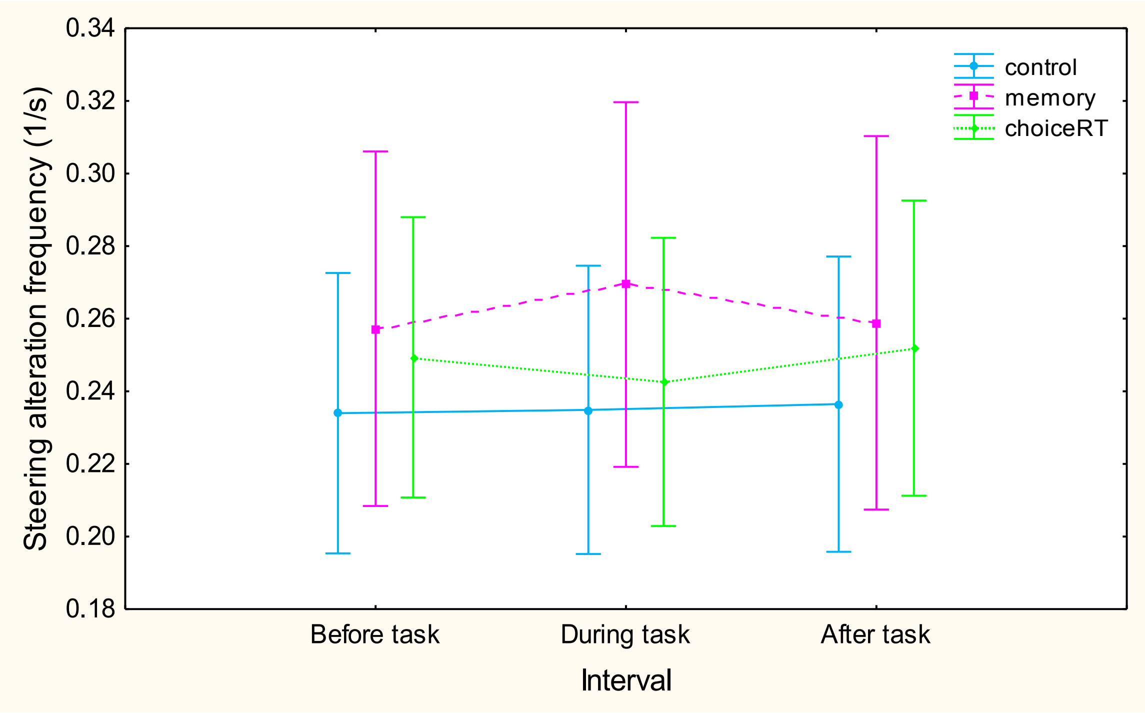

Figure 40: Average change in steering alteration frequency during secondary task performance: difference between the three experimental groups. Error bars depict 95% confidence interval.

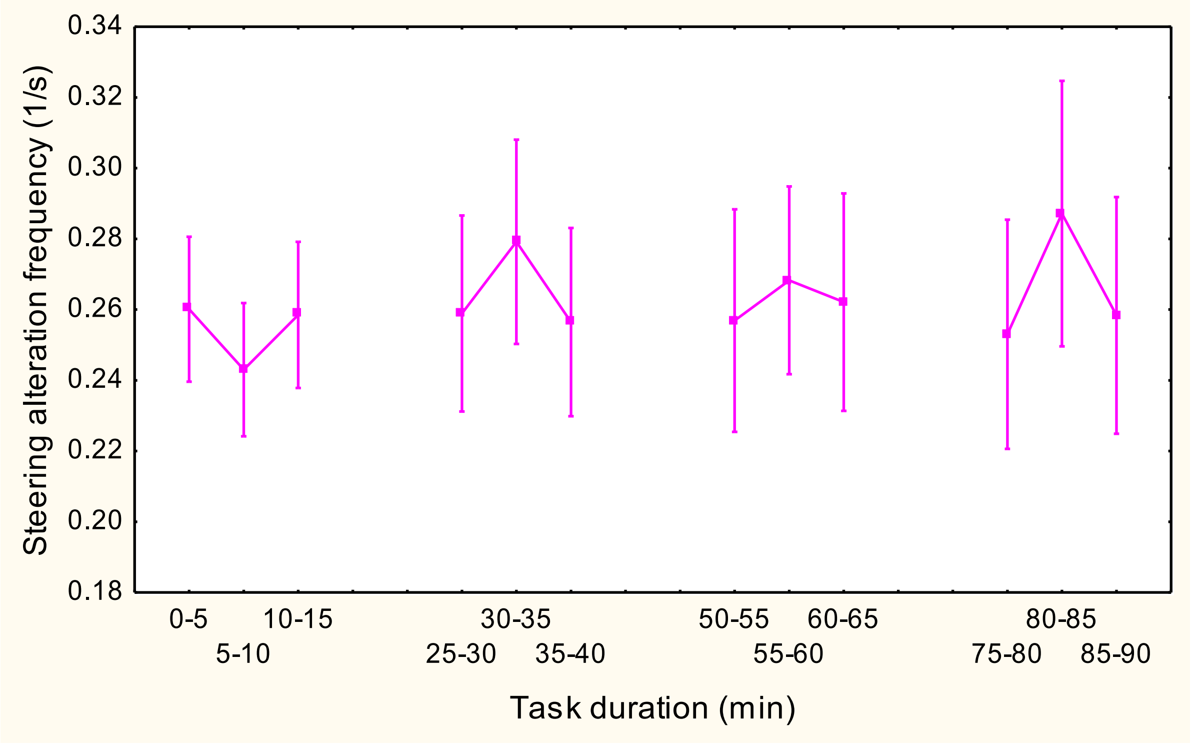

Figure 41: Change in steering alteration frequency before, during and after the memory task for the four task instances. Error bars depict 95% confidence interval.

Performance of memory task over time

While the average memory span did not show any significant change over the four secondary task periods, post-hoc analysis did reveal a significant difference between the first and fourth instances of the memory task, with the final memory task resulting in a significantly higher average memory span than the first memory task (see Figure 42).

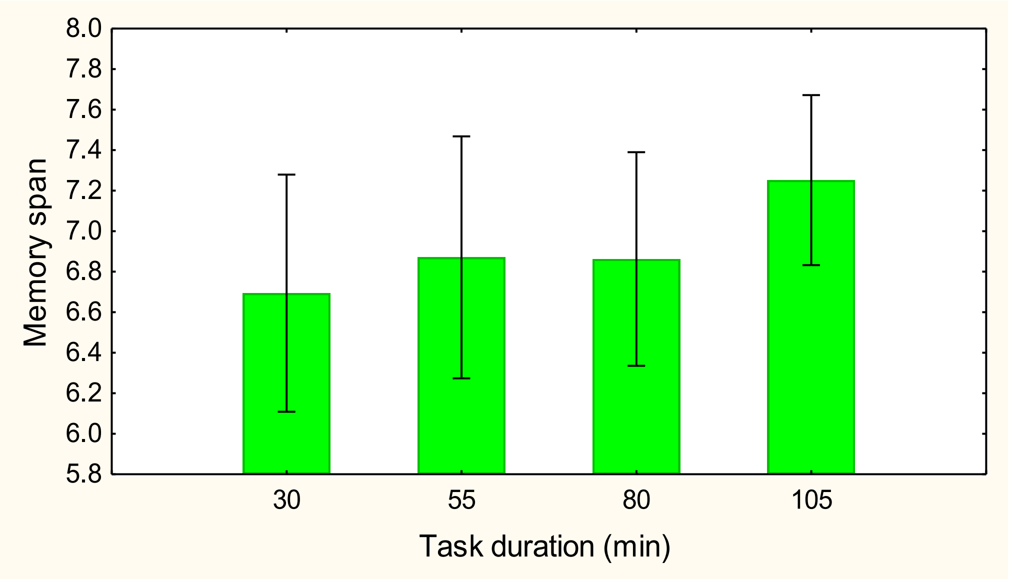

Figure 42: Change in memory span over time. Error bars depict 95% confidence interval.

Performance of choice reaction task over time

No significant change in response time was evident between the four choice RT task instances.

Cardiovascular responses

Heart rate frequency

Only the memory task had a significant effect on heart rate ($p < 0.01$), showing a significant increase in heart rate, followed by a significant decline thereafter. A significant change in this effect was evident over time ($p < 0.01$), with the increase becoming less significant by the final task interval (see Figure 43).

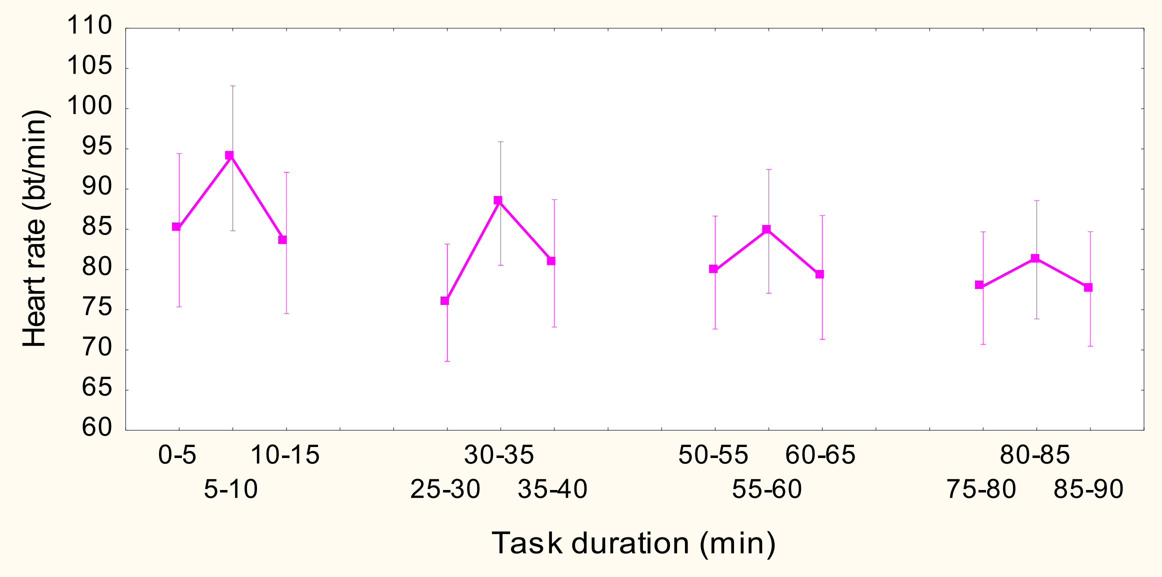

Figure 43: Change in heart rate before, during and after performance of memory task over the four task instances. Error bars depict 95% confidence interval.

Heart rate variability: Time-domain analyses

The RMSSD variable showed a significant response ($p < 0.01$) to the secondary task – subjects in the memory group experienced a significantly higher RMSSD value during the time the memory task was performed.

As with the heart rate results, the effect of the memory task on RMSSD changed over time ($p = 0.01$), with post-hoc analyses revealing a significant increase only for the first time the memory task was performed (Figure 44).

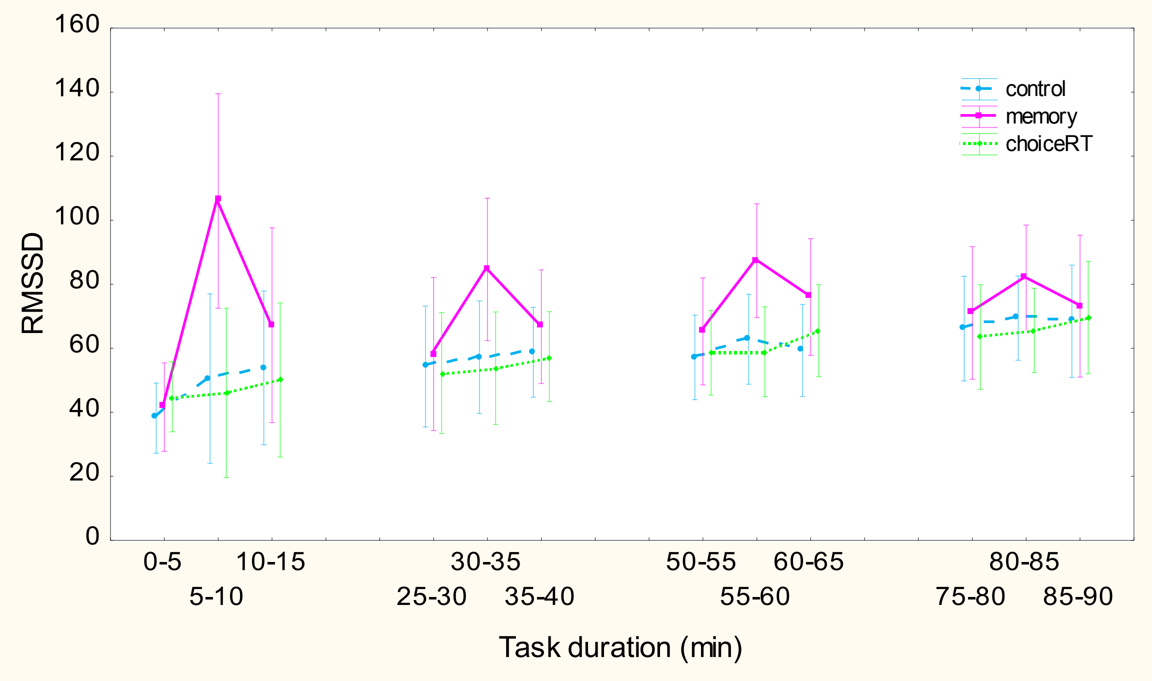

Figure 44: Change in RMSSD before, during and after secondary task performance over time for the three experimental groups. Error bars depict 95% confidence interval.

Heart rate variability: Frequency-domain analyses

Both LF and HF power variables showed a significant task effect ($p < 0.01$ and 0.04 respectively), again localised to the group performing the memory span task, where the power variables increased during the memory task interval (Figure 45a and b). From Figure 45 it can be seen that the LF power variable produced a stronger reaction to the memory task than the HF power variable. The memory span task also resulted in a significant increase in the LF component of the (LF+HF) power variable ($p = 0.02$; Figure 45c).

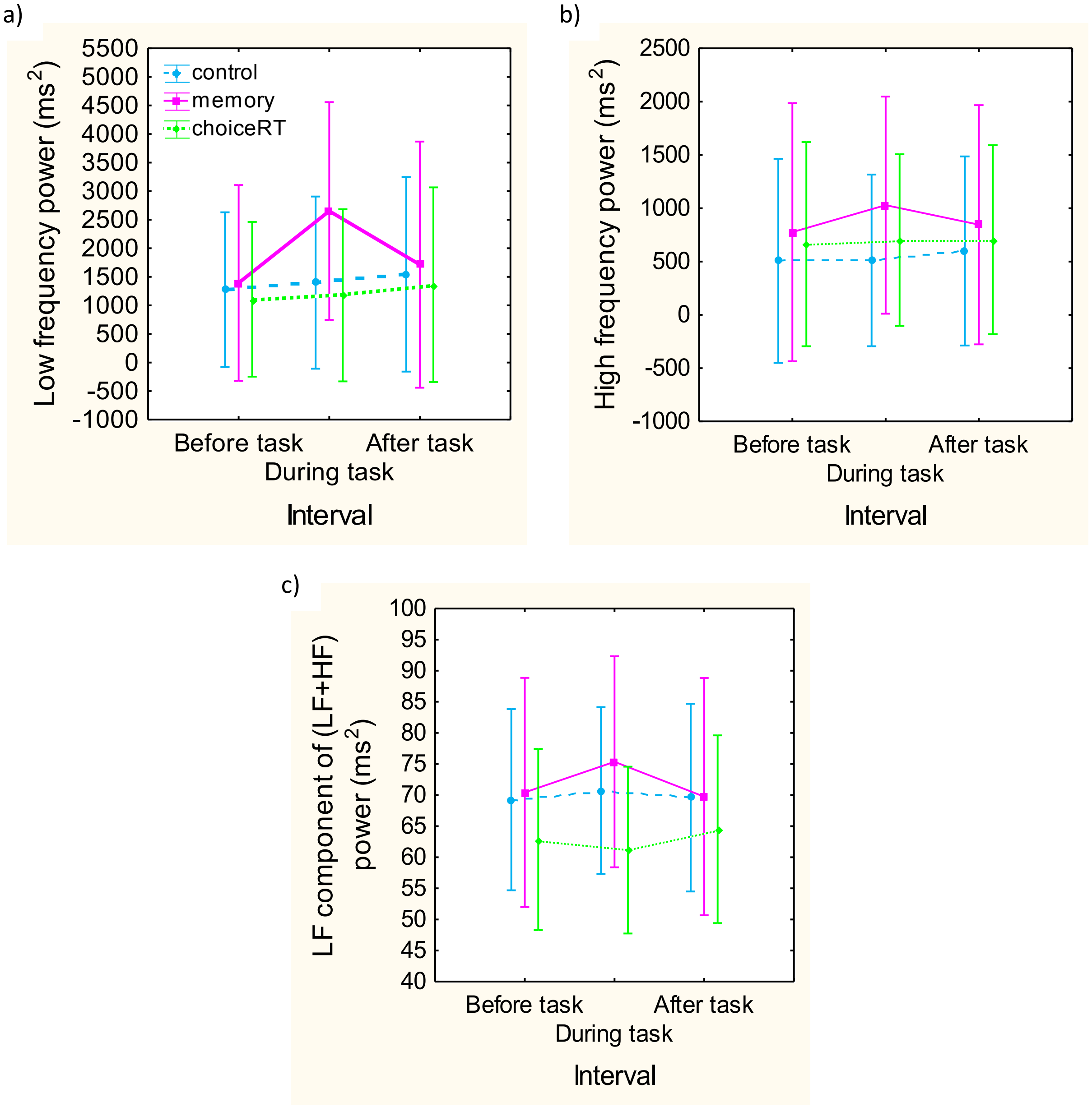

Figure 45: Average change in HRV power spectra during secondary task performance: a) low frequency power; b) high frequency power; c) low frequency component of (LF+HF) power. Error bars depict 95% confidence interval.

When considering the centre frequencies, the change in LFcf due to the secondary task was not found to be significant, while the HFcf showed a significant decrease ($p = 0.01$) during performance of the task. Post-hoc analyses again attributed this decrement to the memory span group (see Figure 46).

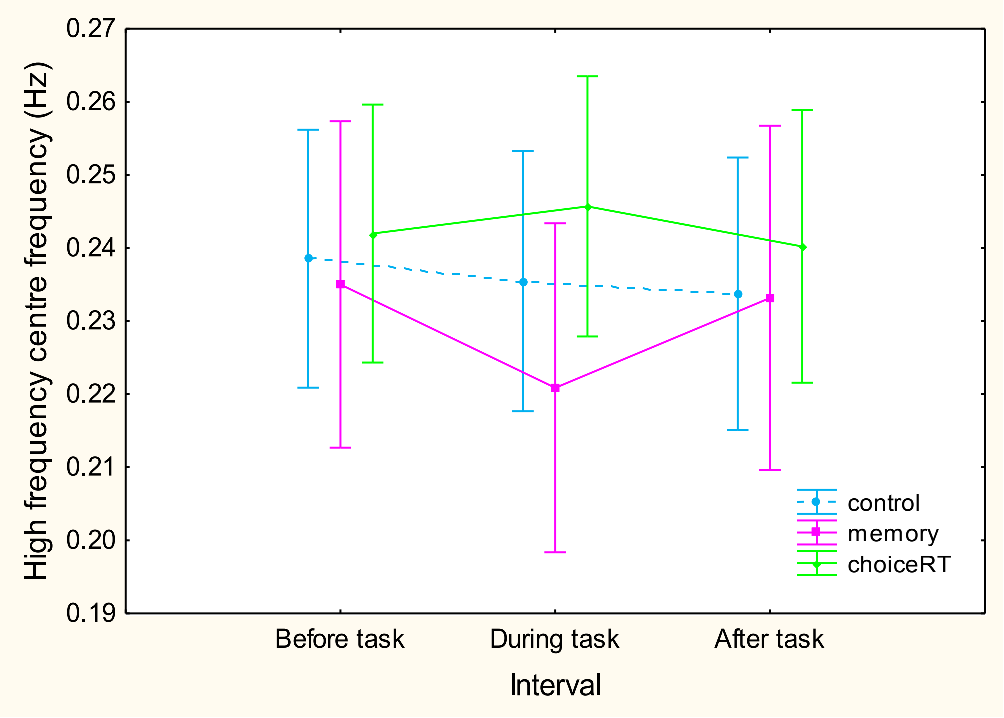

Figure 46: Change in HF centre frequency during secondary task performance, comparing the three experimental groups. Error bars depict 95% confidence interval.

Oculomotor parameters

As with the eye data in the *Time-on-Task Effects* section, all eye movement measures will be expressed as a ratio value, relative to the initial values obtained during the first five minute driving period.

Pupil dilation

Pupil diameter showed a significant increase ($p < 0.01$) during performance of the secondary task when compared to pre- and post-secondary task intervals. This increase was attributed to the memory group only, with post-hoc analysis showing no significant change in diameter for the control and choice RT groups during the secondary task intervals.

A change in pupil dynamics over time was noted ($p < 0.01$) however no group effect was found to be significant. In general (i.e. for all three groups combined), the initial increase in pupil diameter was insignificant and becomes more significant over the four secondary task instances. Post-hoc analysis, however, revealed that the increase in pupil diameter due to the memory span task was significant throughout the four task periods (see Figure 47).

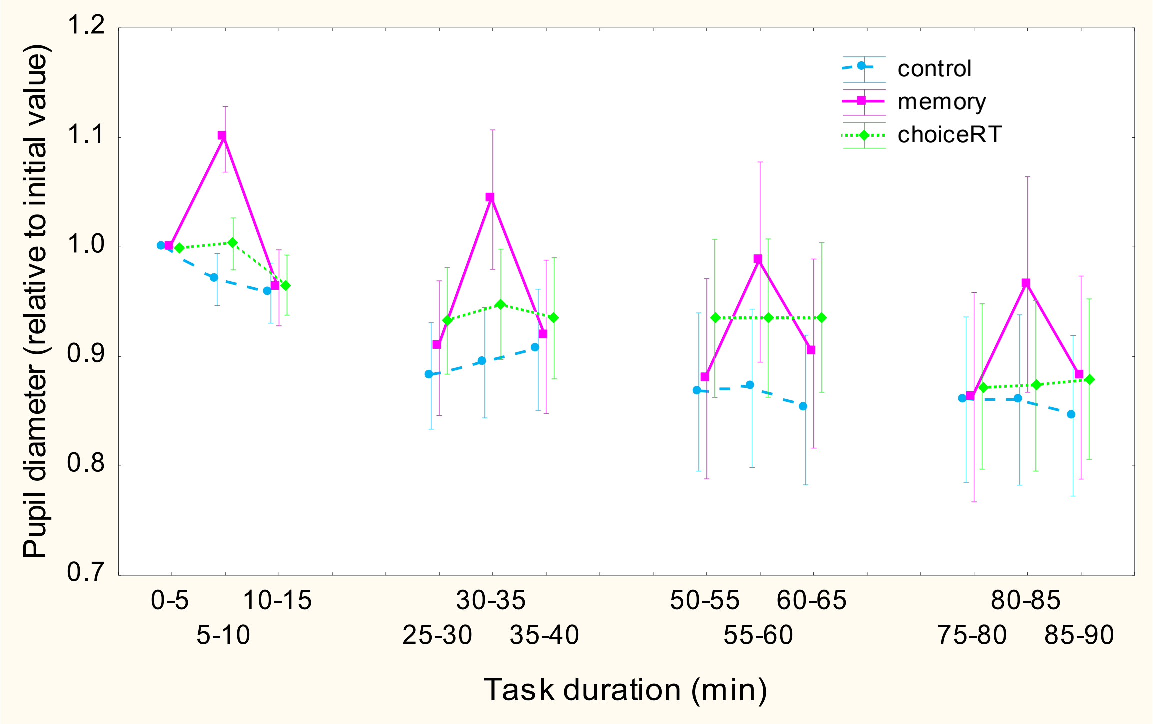

Figure 47: Change in pupil diameter before, during and after secondary task over time for the three experimental groups. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Blink frequency and duration

Only blink frequency produced a significant task effect, with an increase in blink frequency occurring during the secondary task interval (p = 0.04). Post-hoc analyses revealed that this effect was due to the group performing the memory span task, with a significant increase in blink frequency during the memory task evident where no change was observed within the control or choice RT groups (p < 0.01; Figure 48).

No significant change in the task dynamics was noted over the four task instances.

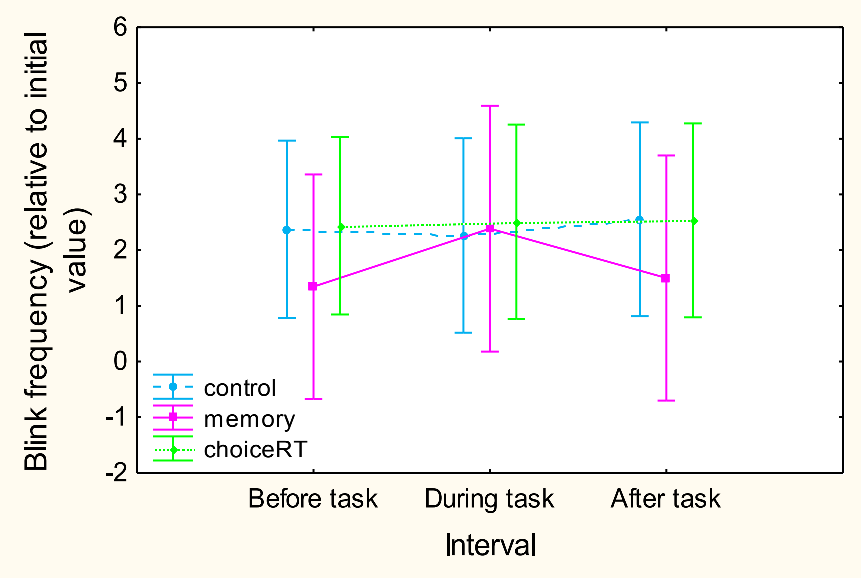

Figure 48: Average effect of secondary task on blink frequency for the three experimental groups. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Fixation duration and percentage time

The effect of the secondary task in general had no significant effect on short, medium or long fixation parameters. The addition of the memory task did, however, significantly affect the short fixation parameters, with the task inducing a greater number of short fixations ($p = 0.03$), with a significantly shorter duration ($p = 0.03$). Short fixation duration showed a group effect with regards to the interaction of the secondary task over time – the initial memory task significantly reduced the duration of short fixations, followed by a significant increase thereafter (see Figure 49).

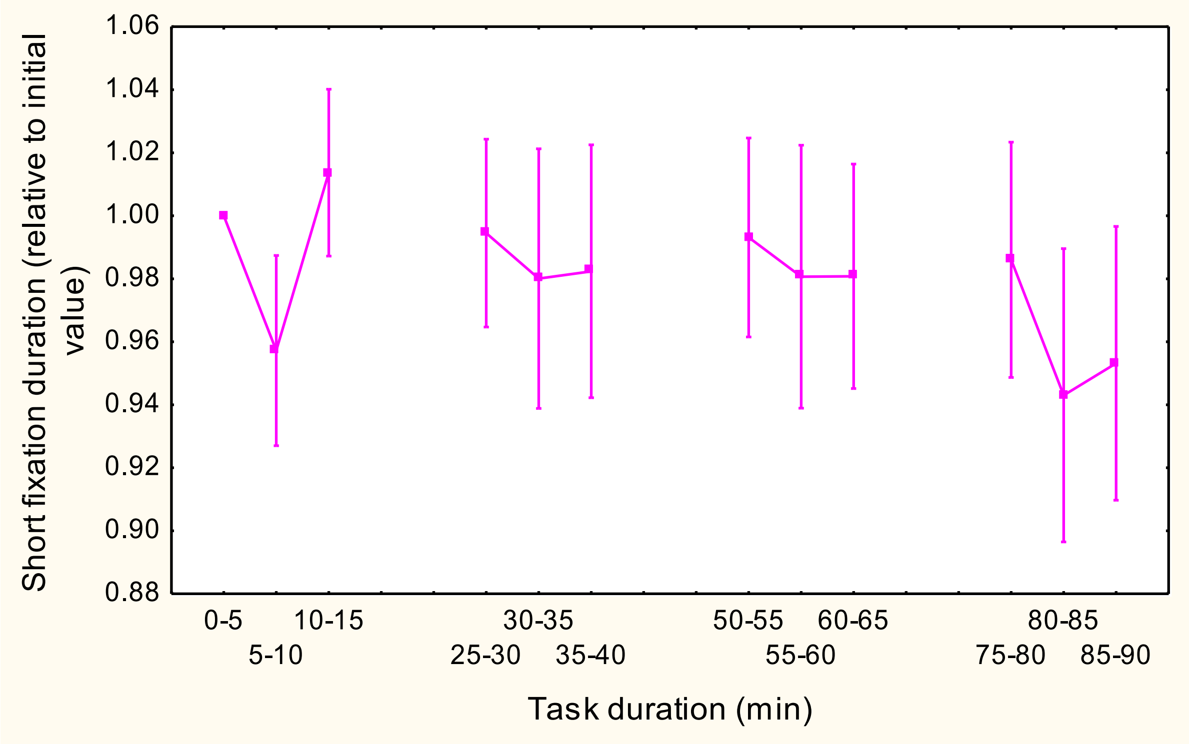

Figure 49: Change in short fixation duration during memory task over the four task instances. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Saccades

None of the saccadic parameters showed any significant effects of the secondary task.

Gender effect

None of the driving parameters produced a general gender effect.

The change in the effect of the memory task on heart rate over time was significantly different between male and female subjects (p = 0.03): the increase in heart rate was significant for the first three instances for females, and insignificant for the last, while for male subjects only the first application of the memory task produced a significant increase in heart rate (see Figure 50). The impact of memory on the HFcf measure was also affected by gender (p = 0.04), with only the females in the memory group showing a significant decline in HFcf during performance of the task (Figure 51).

Figure 50: Change in HR over time during memory span task intervals for males and females. Error bars depict 95% confidence interval.

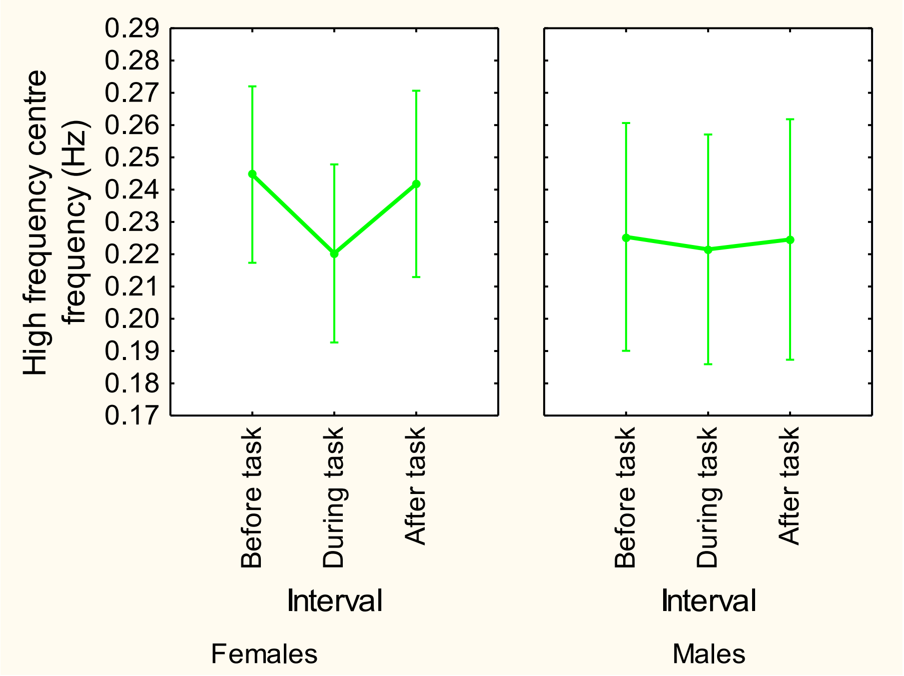

Figure 51: Average change in HFcf during memory task performance for males and females. Error bars depict 95% confidence interval.

None of the oculomotor parameters showed any gender effects of interest.

Time of day effect

None of the driving performance parameters indicated a significant difference between the times of day that testing took place. The memory span data showed the time of day to have a general effect, with subjects testing during the afternoon having a higher average memory span than the subjects tested during the morning sessions (p = 0.01; Figure 52).

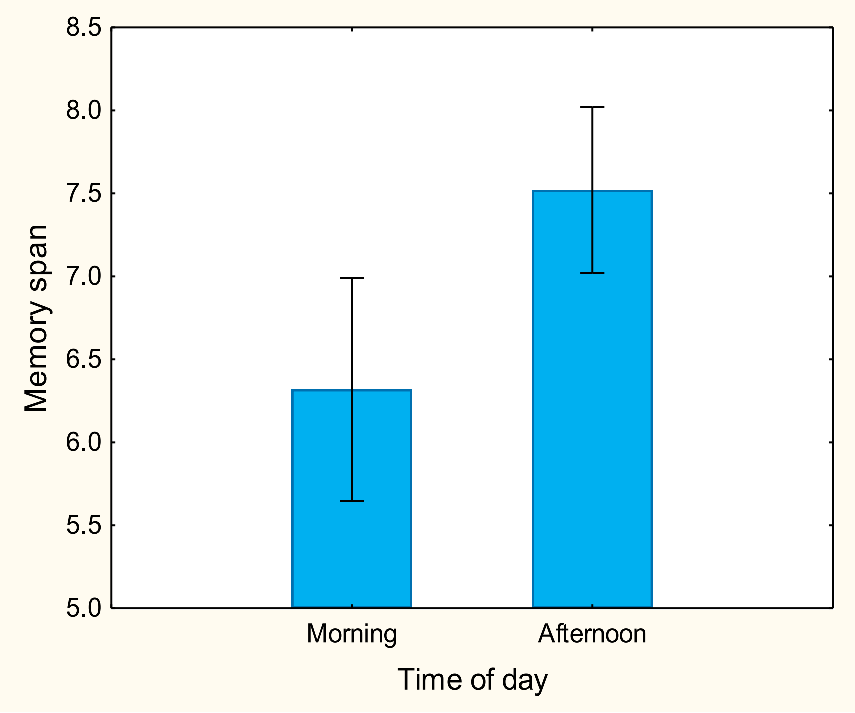

Figure 52: Difference in average memory span performance between subjects tested in the morning and subjects tested in the afternoon. Error bars depict 95% confidence interval.

When considering cardiovascular parameters, only LF power was affected by the time that testing took place (Figure 53). LF power showed an interaction between the task and the time of day the test was performed (p < 0.01), with the memory task resulting in a significant increase in LF power only for the subjects who were tested in the morning session.

None of the oculomotor parameters showed time of day to have any significant effect.

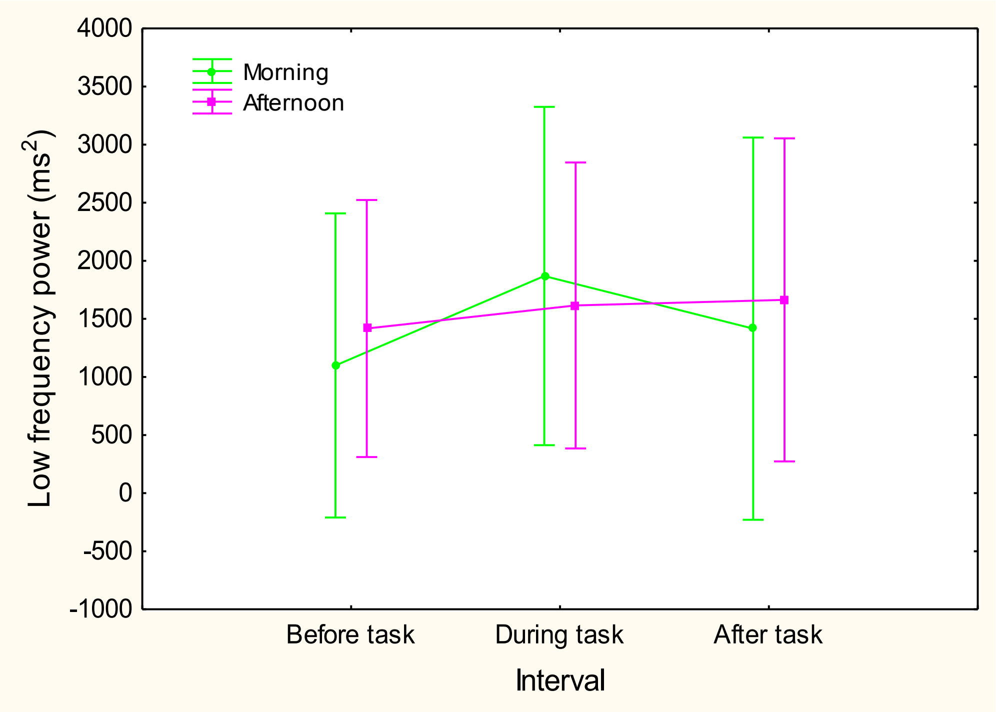

Figure 53: Average change in low frequency power during secondary task interval for subjects tested in the morning and subjects tested in the afternoon. Error bars depict 95% confidence interval.

EFFECT OF MUSIC

The addition of a two-minute music stimulus at the end of the experiment was an attempt to evaluate whether the effects induced by the task could be labelled as “fatigue”, or whether it was more of a down-regulation effect induced by the monotony and prolonged nature of the task. It was hypothesized that if the measures returned to their previous level after the music stimulus that fatigue had been induced; whereas if the fatigue effect was reduced during the music interval and remained at a lower level thereafter the effect could rather be due to a down-regulation.

Performance parameters

Driving performance

Mean deviation decreased significantly during the music interval, and increased significantly thereafter ($p < 0.01$). The post-music deviation was, however still significantly lower than the pre-task deviation. A significant increase in steering alteration frequency was also observed ($p = 0.03$), but no significant decrease occurred after the music. The effect of music on both driving parameters is shown in Figure 54. Both of these effects occurred independent of any group, gender or time of day influences

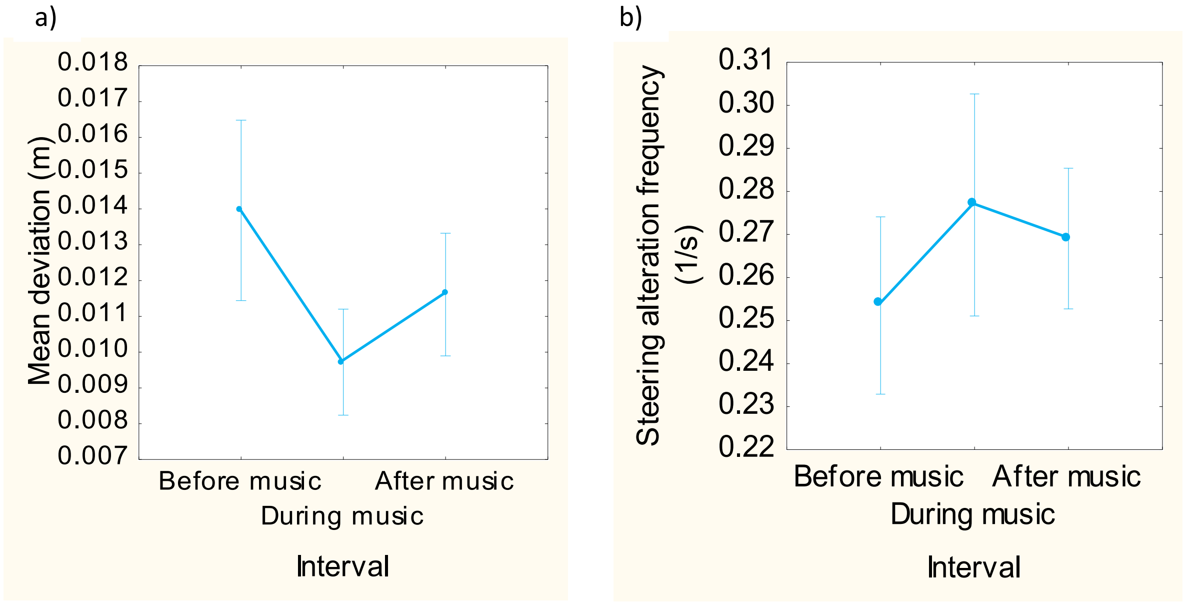

Figure 54: Effect of music on driving parameters; a) mean deviation and b) steering alteration frequency. Error bars depict 95% confidence interval.

Cardiovascular responses

Heart rate frequency

Heart rate decreased significantly during the music interval and increased again thereafter ($p < 0.01$; Figure 55). No covariate effects were observed.

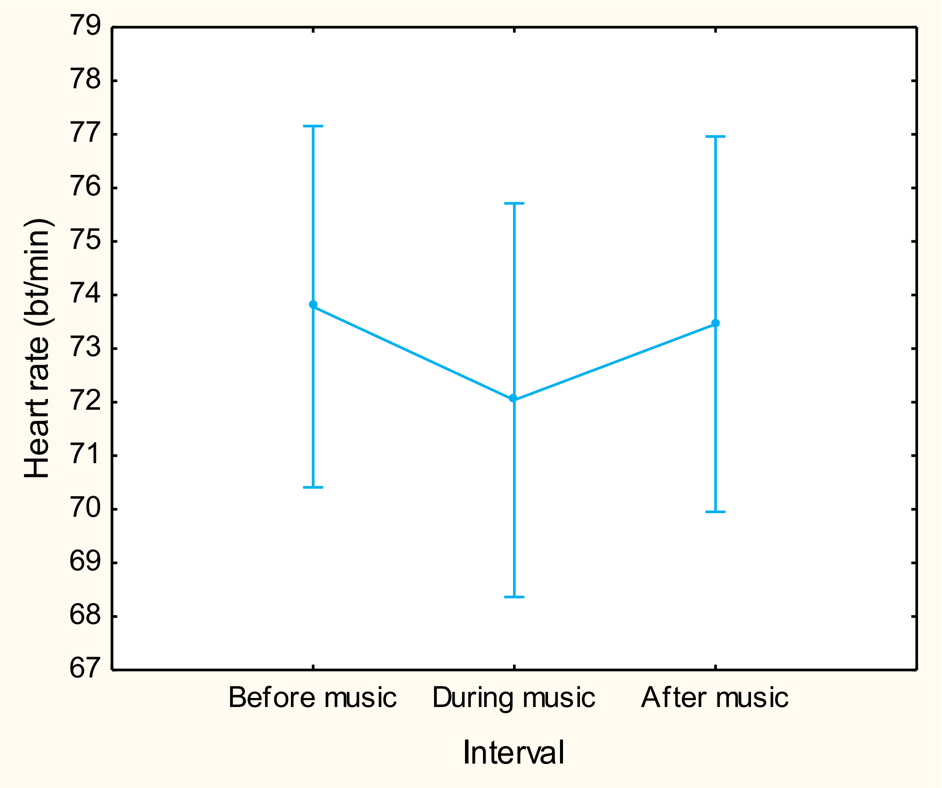

Figure 55: Effect of music on heart rate for all subjects. Error bars depict 95% confidence interval.

Heart rate variability: Time-domain analyses

The music interval had no significant effect on RMSSD ($p = 0.48$). The PNN30 measure did, however, show a significant music effect ($p < 0.01$), increasing significantly during the music interval and decreasing significantly thereafter (Figure 56). No significant difference was noted between pre- and post-music intervals.

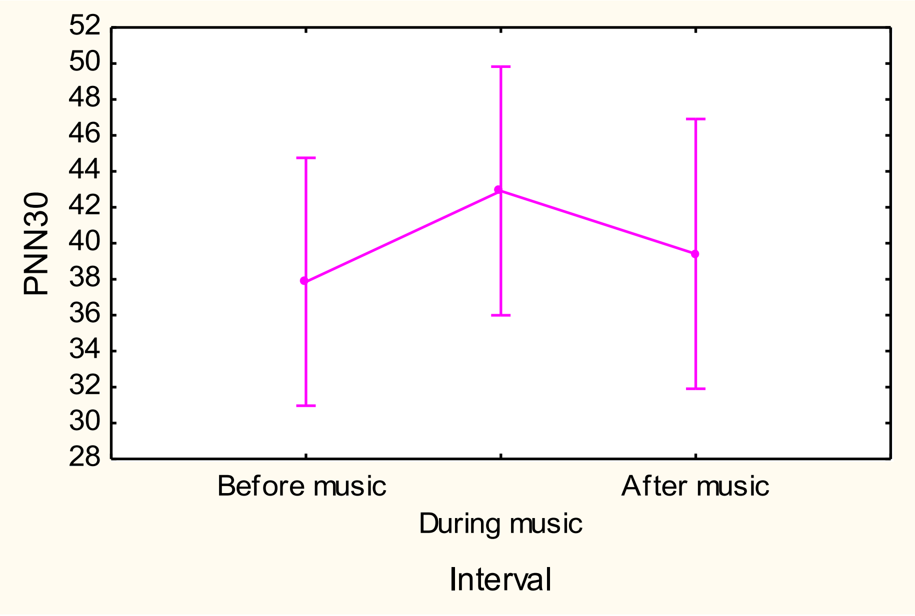

Figure 56: Effect of music on PNN30 for all subjects. Error bars depict 95% confidence interval.

Heart rate variability: Frequency-domain analyses

Both the LF and HF power spectra did not depict a significant effect with regards to the music interval. The LF component of the (LF+HF) power did, however, show a significant decline during the music interval, as well as increasing significantly thereafter ($p < 0.01$; Figure 57). No significant difference was found between pre- and post-music intervals.

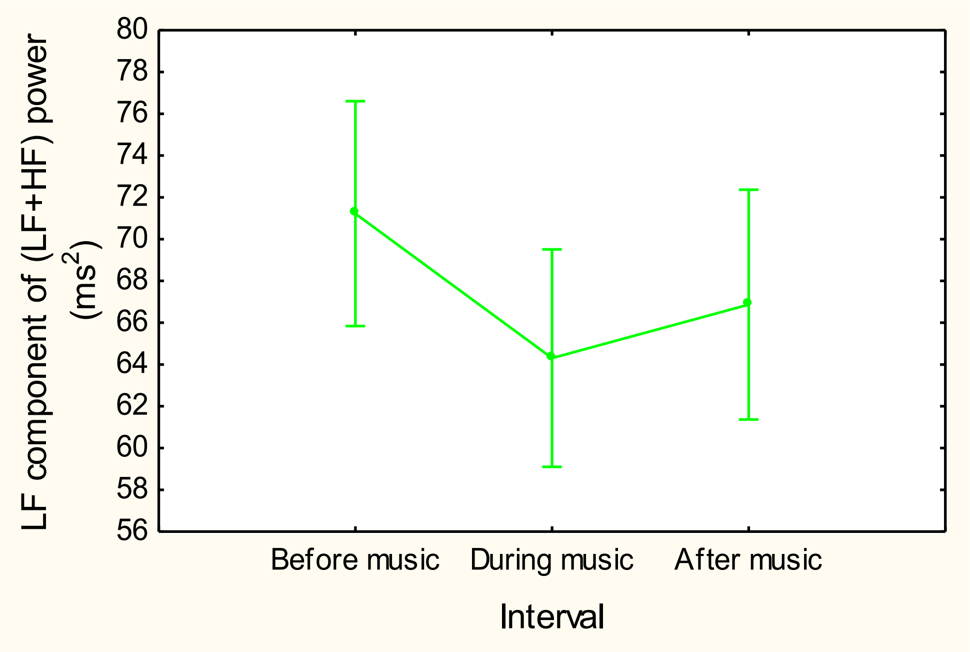

Figure 57: Effect of music on the low frequency component of the (LF+HF) power for all subjects. Error bars depict 95% confidence interval.

With regards to the centre frequency HRV measures, only the HFcf depicted a significant increase during the music interval, with a significant decline thereafter ($p < 0.01$; Figure 58a). No group effect was found. While the LFcf did not reveal a significant effect of the interval itself ($p = 0.07$), it did identify that the effect of the music was dependent on the experimental group ($p = 0.01$) - and therefore affected by the secondary task - but post-hoc analyses failed to locate the significant occurrences. Figure 58b shows an increase in LFcf for both the control and choice RT groups, while LFcf of the memory span group decreased during the music interval.

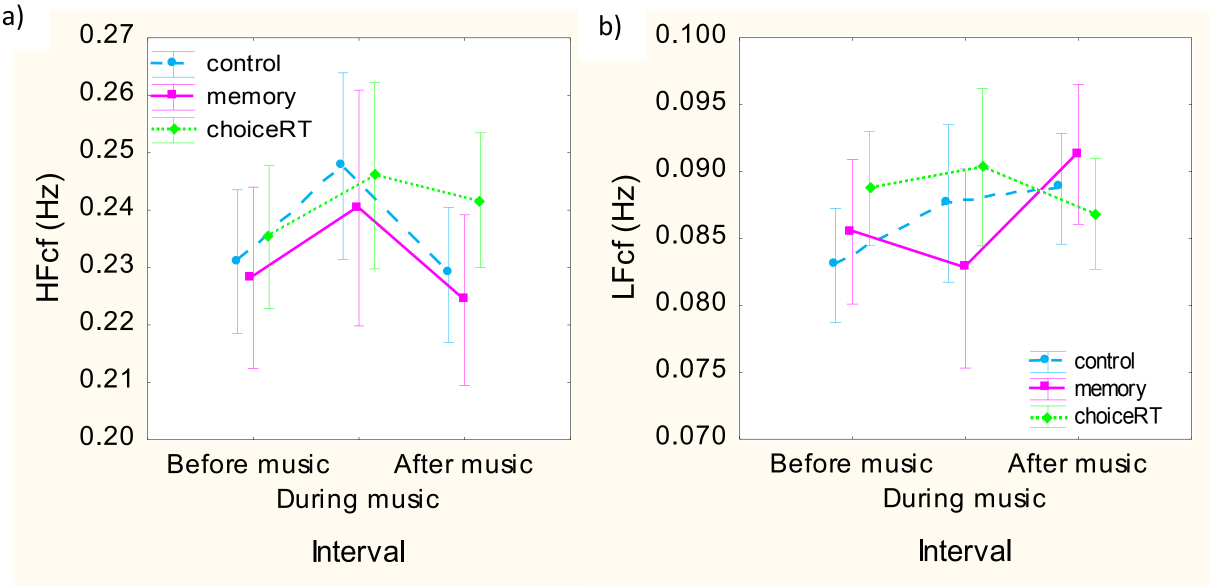

Figure 58: Effect of music on the a) high frequency and b) low frequency centre frequencies for the three experimental groups. Error bars depict 95% confidence interval.

Oculomotor parameters

Pupil dilation

A significant increase in pupil diameter was noted during the music interval ($p < 0.01$), followed by a significant decline thereafter. No significant difference between pre- and post-music intervals was observed.

While the effect of the secondary tasks on the reaction of the pupil to the music stimuli did not yield an overt significance, it may be relevant to note that post-hoc analysis of this interaction revealed a significant change only in the control and choice RT groups (Figure 59).

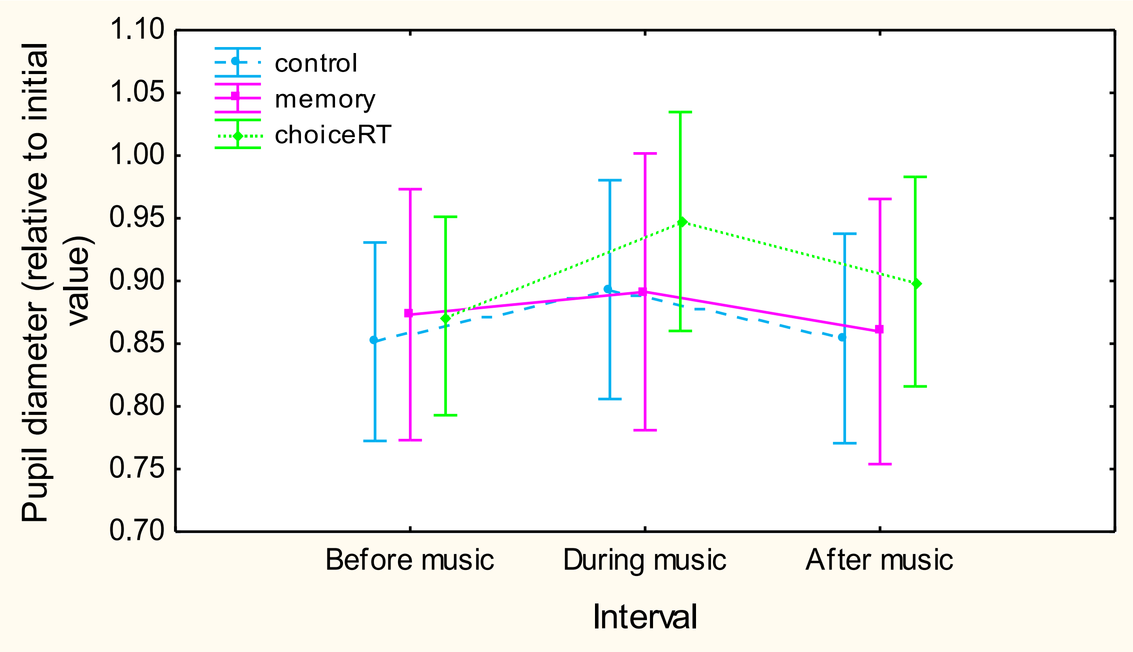

Figure 59: Effect of music on pupil diameter for the three experimental groups. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Blink frequency and duration

Effects induced by the music interval were observed for both blink frequency ($p < 0.01$) and blink duration ($p = 0.01$), with both variables decreasing from the pre-music interval (see Figure 60). While the graphs pertaining to this effect show the measures to increase again during the post-music interval, this increase was not found to be significant.

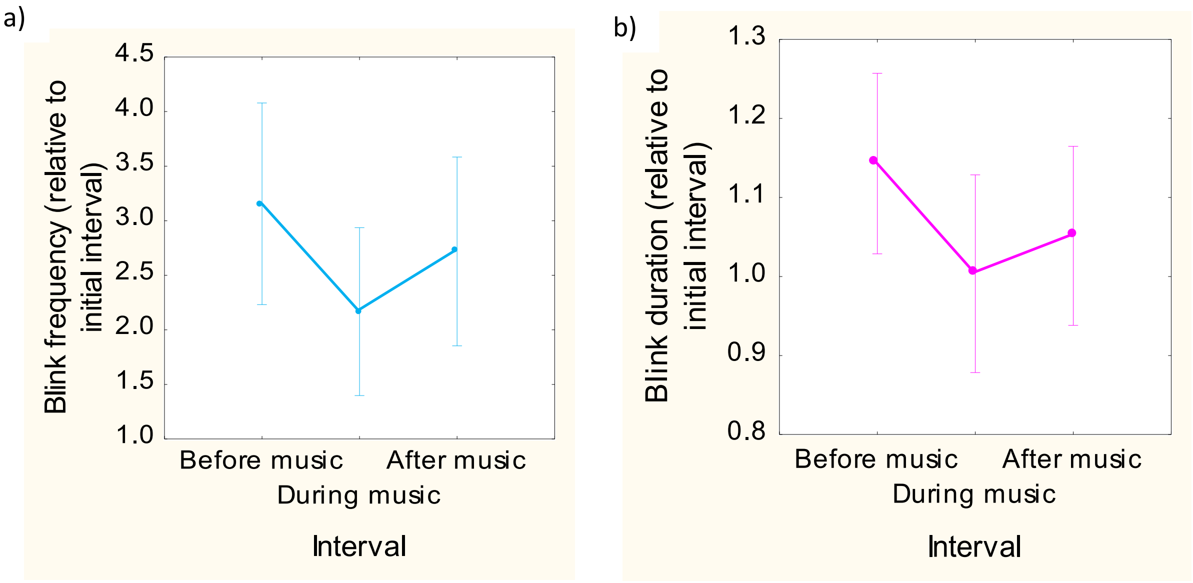

Figure 60: Effect of music interval on a) blink frequency and b) blink duration. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Fixation duration and percentage time

The long fixation parameters did not yield any significant results with regards to the music stimuli. The duration of short fixations, while not presenting a significant change during the music interval, did produce a general group effect ($p = 0.04$), where subjects in the choice RT group produced short fixations of significantly shorter duration than subjects in the memory span group.

The duration of medium fixations increased significantly during the music interval and decreased again thereafter ($p < 0.01$; Figure 61). No significant difference was observed between pre- and post-music intervals, and no group effect was observed.

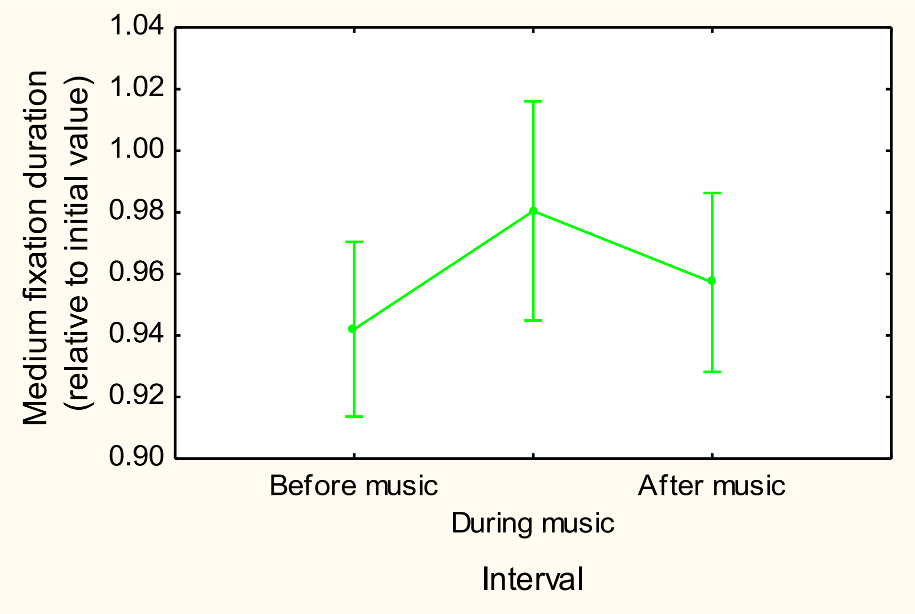

Figure 61: Effect of music on the duration of medium length fixations for all subjects. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

The percentage of short and medium fixations showed the opposite trend as compared to the effects observed both over time and during the secondary task intervals. The percentage of short fixations was significantly reduced during the music interval ($p < 0.01$), reciprocated by a significant rise in the percentage of medium fixations ($p < 0.01$) (see Figure 62). No significant change was evident following the music interval, with post-music values remaining significantly lower (for short fixations) and significantly higher (for medium fixations) than the values obtained during the pre-music interval.

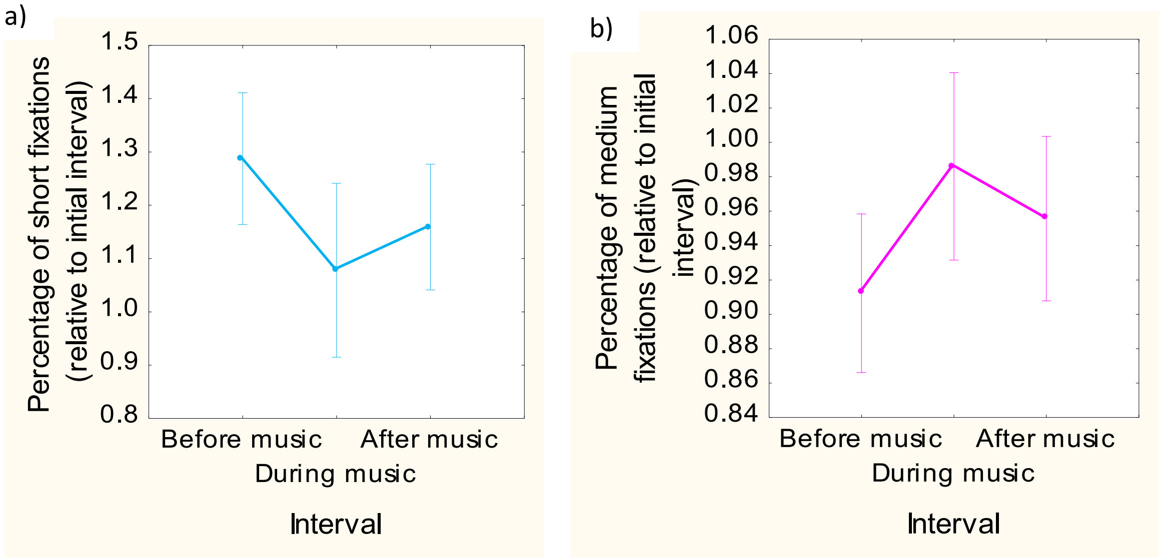

Figure 62: Change in percentage of a) short fixations, and b) medium fixations caused by music stimulus for all subjects. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Saccades

All three saccadic parameters showed a significant effect of the music interval ($p < 0.01$ for all three parameters), resulting in a significant decrease from pre-music interval but no significant increase thereafter (see Figure 63). A significant difference between pre- and post-music intervals was therefore also evident for all three measures. Only saccade duration revealed a significant group effect ($p = 0.03$), with subjects in the choice RT group producing saccades of significantly longer duration than those in the control group. When considering change induced by the music interval, saccade speed showed a significant reduction only for the choice RT group (Figure 63c).

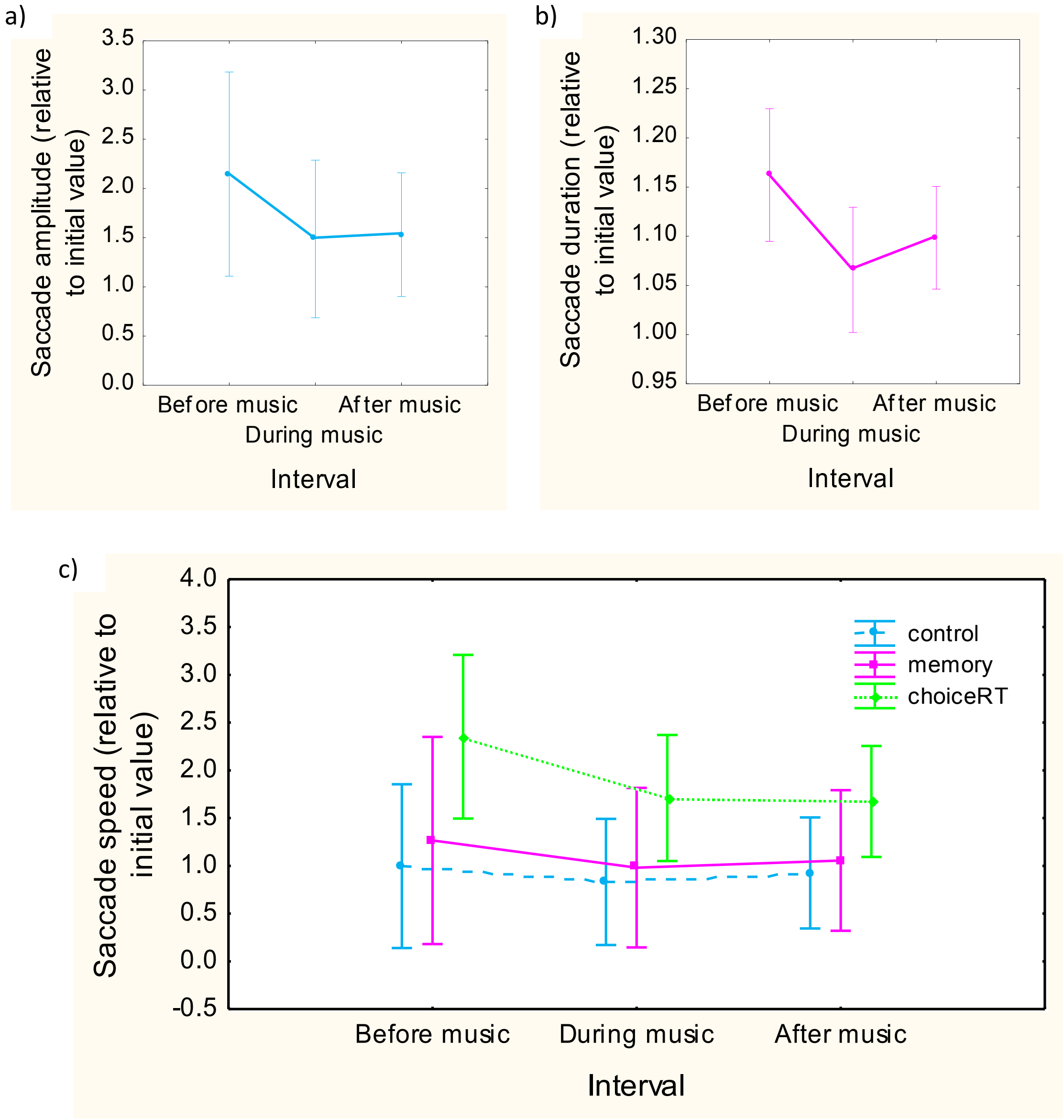

Figure 63: Change in saccadic parameters during music interval: a) change in saccade amplitude for all subjects; b) change in saccade duration for all subjects; c) change in saccade speed for the three experimental groups. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Gender effect

None of the driving or cardiovascular parameters produced a significant gender effect during the music interval.

Figure 64 shows the difference in reaction of saccade speed between the male and female subjects, where a more significant decline in saccade speed during the music interval was noted for female subjects (p = 0.02).

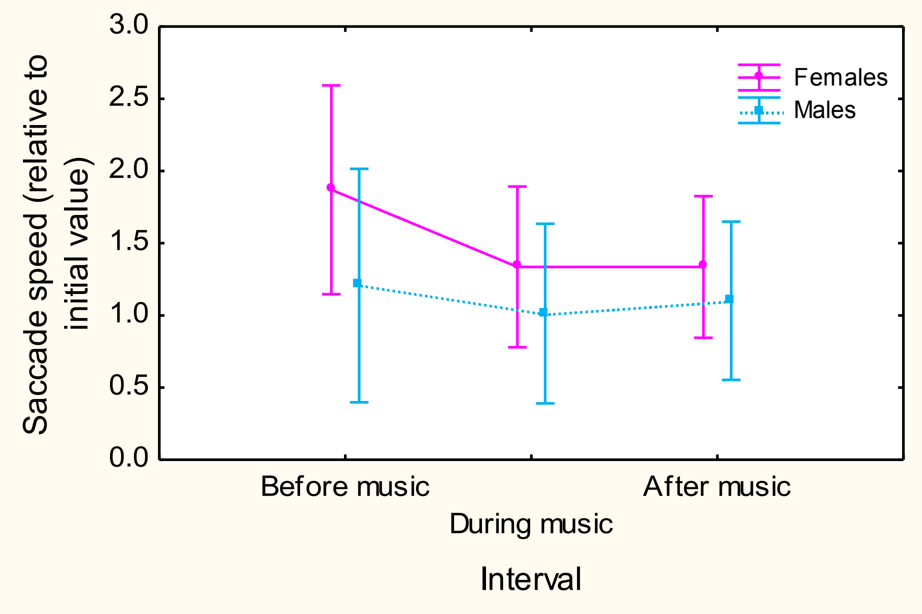

Figure 64: Effect of music on saccade speed: difference between male and female subjects. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

Time of day effect

None of the driving parameters produced a significant time of day effect during the music interval.

RMSSD showed a significant interaction between the time of day of testing and the effect of the music (p = 0.03); post-hoc analyses could not identify where this discrepancy lay; however Figure 65 shows that RMSSD increased during the music interval during morning testing sessions, and decreased during afternoon testing sessions. The time of day of testing also interacted significantly with the LF component of (LF+HF) power, with post-hoc analyses showing a significant change due to the music only within subjects testing in the afternoon (p = 0.01; Figure 66).

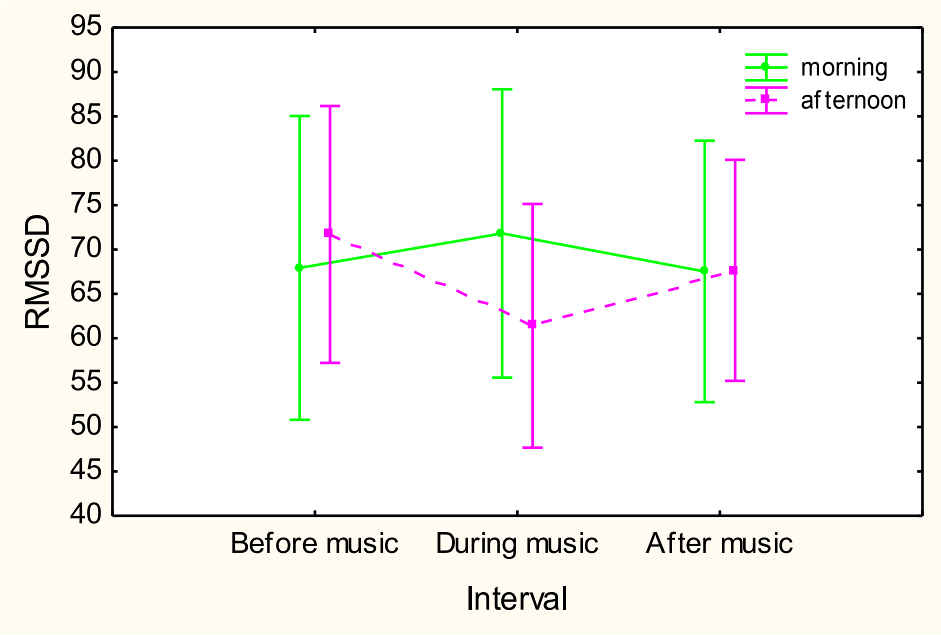

Figure 65: Change in RMSSD during the music interval for morning and afternoon testing sessions. Error bars depict 95% confidence interval.

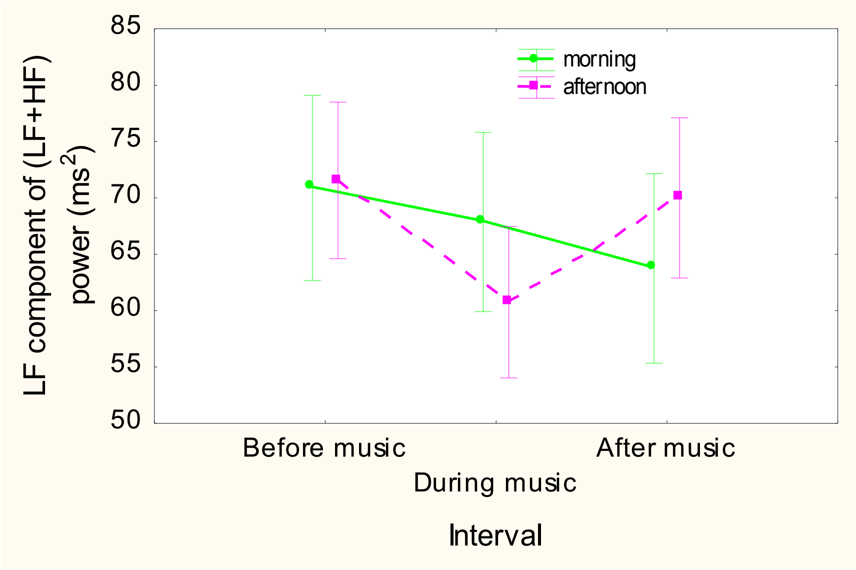

Figure 66: Change in the low frequency component of the (LF+HF) power measure during the music interval; difference between subjects tested in the morning, and those tested in the afternoon. Error bars depict 95% confidence interval.

Both saccade amplitude and saccade speed showed a significant time of day effect (p = 0.02 and 0.00 respectively), again with the most significant changes occurring in the afternoon testing sessions (Figure 67).

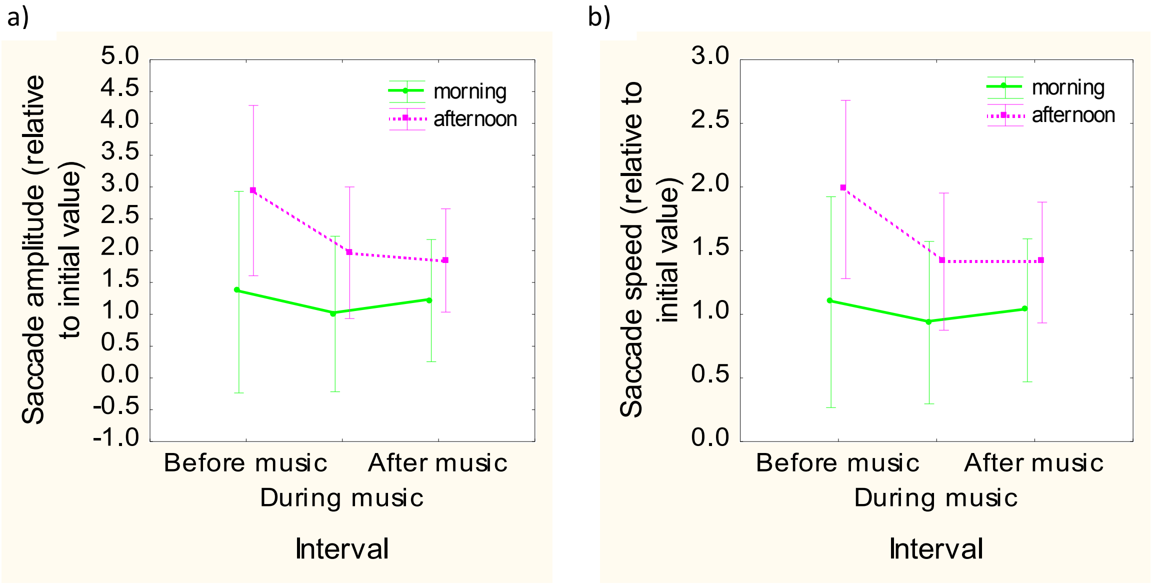

Figure 67: Change in a) saccade amplitude and b) saccade speed during music interval for subjects tested in the morning and the afternoon. Values relative to the initial five minute interval; error bars depict 95% confidence interval.

SUMMARY OF RESULTS

Time-on-task effects

Performance declined over time. This decline was independent from any group effect, however gender showed an interaction with time-on-task, where males performance declined significantly while females tended to maintain a more stable performance.

Heart rate frequency decreased over time, and baseline HR was significantly lower post-task compared to pre-task. Time-domain HRV parameters increased significantly over the testing period, and a higher value for both parameters was found for the post-task baseline compared to the pre-task measurement. LF power and the LF component of (LF+HF) power both increased significantly over time.

Baseline measures of these two variables were also found to be higher post-task – the increase in LF power was noted only for individuals in the memory and choice RT groups. LF and HF centre frequency measures declined over time, and the LFcf baseline was significantly lower for the post-task measurement.

Pupil diameter decreased with time-on-task, and females showed a greater decline over time than their male counterparts. Blink frequency increased with time, independent of any group or covariate influence. While blink duration did not show a time-on-task effect, when considering only the blinks between 50-300 ms the duration was shown to increase over time.

Over time, a greater number of short fixations were performed, and a shorter duration was evident. Both the duration and the number of medium fixations decreased significantly over the test period, with the percentage of medium fixations showing both a group (choice RT group produced a significant decrease) and gender (males decreased to a greater extent) interaction with time-on-task. The long fixation parameters did not show a significant time-on-task effect.

All three saccadic parameters increased over time; saccade amplitude and saccade speed showed a group effect where the increase was localised within the choice RT group.

Effect of secondary task

Neither the memory span nor the choice RT performance changed significantly between the four secondary task instances. A general time of day effect was noted for subjects performing the memory task, with individuals tested in the afternoon having a higher average memory span than those tested in the morning. Driving deviation was positively affected by the secondary task interval, however post-hoc analysis could not attribute this change to a specific group. Steering frequency produced a significant group effect both on the secondary task interval in general and for the change over time. In general, the memory task seemed to increase the frequency, while the choice RT task reduced the frequency of steering alterations. The change over time was attributed to the memory group.

Heart rate frequency increased significantly during performance of the memory span task, with the effect becoming less prevalent over time. The memory span task also caused a significant increase in the RMSSD measure. When considering this effect over the four secondary task intervals, RMSSD followed a similar pattern to heart rate frequency, with post-hoc analysis revealing a significant increase only for the first instance of the memory span task, whereafter the increase was not significant. With regards to the frequency-domain parameters of HRV, all power spectra measures (LF power, HF power, LF component of (LF+HF) power) increased during performance of the memory task, while the HFcf decreased. HFcf showed a significant change over time, again with only the first memory task performance producing a significant effect.

Both pupil diameter and blink frequency increased significantly during the secondary task intervals, again with this effect being evident only for the group performing the memory span task. The general secondary task effect over time increased in significance for pupil diameter, however when considering only the memory span task pupil diameter was found to increase significantly throughout all four instances.

Short fixation parameters were significantly affected by the memory span task, with an increase in the number of short fixations and a decrease in the duration. Again, the decrease in short fixation duration was most significant during the initial memory task performance, whereafter the effect became less evident.

No change in saccadic parameters was noted during performance of the secondary tasks.

Effect of music

Mean driving deviation decreased during the music interval and returned to the pre-music level in the interval following the stimulus. Steering alteration frequency increased during the music stimuli, and remained significantly higher thereafter.

The music interval elicited a significant decline in heart rate frequency, with the measure increasing again thereafter. While the RMSSD measure was not affected by the music interval, PNN30 increased significantly and decreased for the interval following the music. LF and HF power variables were unaffected by the music, but the LF component of the (LF+HF) power declined significantly during the music and increased thereafter. HFcf increased significantly and decreased following the music interval, while the LFcf was unaffected.

Pupil diameter increased significantly during the music interval and decreased significantly thereafter. Both blink frequency and blink duration decreased significantly during the music interval, maintaining a lower level in the interval thereafter. The percentage of short fixations declined during the music interval, reciprocated by an increase in the percentage of medium fixations. This effect was also maintained following the music interval. The duration of medium fixations increased significantly during the music interval, followed by a significant decrease thereafter. A reduction in all three saccadic parameters was evident during the music interval, with a lower level being maintained thereafter. The change in both saccade speed and saccade duration occurred for subjects in the choice RT group only.

CHAPTER V

DISCUSSION

INTRODUCTION

This study posed a number of hypotheses with regards to fatigue and mental workload. Firstly, the manifestation of fatigue over time was considered regarding changes in performance and physiological parameters as well as the subjective difficulty incurred during prolonged task performance. Secondly, an attempt to differentiate between the concepts of active and passive fatigue was made by intermittently introducing an additional load requiring either the same mental resources as the primary task, or resources unused by the primary task. Finally the study aimed to decipher whether the effects observed could be attributed to task-related fatigue or if it was rather the nature of the task that resulted in a down-regulation which could easily be counteracted by a novel stimulus.

TIME-ON-TASK EFFECTS

In terms of the time-on-task effects, three hypotheses were constructed. The first hypothesis was that performance of the primary task would decline over time. A decline in performance is often seen as a characteristic of fatigue with a continuous workload, most commonly associated with a slowing of sensorimotor performance (Mascord and Heath, 1992; Zhang *et al.,* 2009). This was true for mean deviation (Figure 7), while no change in steering alteration frequency was observed. Steering alteration frequency may be considered as an indicator of the general driving behaviour adopted by the subjects. The lack of change in this measure suggests that subjects did not choose to change their strategy of driving even when performance began to decline.

The second hypothesis was that the subjects in the control group (i.e. the group where no secondary task was performed) may show either a more rapid or a more detrimental decrement in terms of performance. The performance characteristics show, however, that the declines observed were noted as a general characteristic for all three experimental groups, with no significant effect elicited by either of the secondary tasks.

The third hypothesis questioned whether the time-on-task would elicit significant responses from physiological variables, and whether the responses would correspond to fatigue literature. Time-on-task was found to elicit a change in almost all physiological measures (see Table III).

Table III: Significant changes in physiological parameters over time.

	Time-on-task effect	Possible cause
CARDIOVASCULAR PARAMETERS		
Heart rate	Decrease	Fatigue/↓ arousal
RMSSD	Increase	↓arousal/↓workload
PNN30	Increase	↓arousal/↓workload
HF power	-	-
LF power	Increase	↓arousal/↓workload
LF component of (LF+HF) power	Increase	↓arousal/↓workload
HF cf	Decrease	-
LF cf	Decrease	-
OCULOMOTOR PARAMETERS		
Pupil	Decrease	Fatigue/↓ arousal
Blink frequency	Increase	↓attentional resources
Blink duration	-	-
Short fixation duration	Decrease	
% short fixations	Increase	↓conscious attention
Medium fixation duration	Decrease	
% med fixations	Decrease	↓cognitive/conscious control
Long fix duration	-	-
% long fixations	-	-
Saccade duration	Increase	↑scanning/↓attention?
Saccade amplitude	Increase	↑scanning/↓attention?
Saccade speed	Increase	↑scanning/↓attention?
Critical Flicker Fusion Frequency	Decrease	Fatigue

With regards to the differentiation between active and passive fatigue, the author contends that passive fatigue could be attributed mainly to a reduction in non-specific arousal (Mascord and Heath, 1992) or activation of the system, while the concept of active fatigue is more stringently linked to the concept of resource allocation/depletion over time. Both active and passive fatigue concepts consider the role of effort. When an individual is under-aroused (as is the case for passive fatigue) Kahneman (1973) attributes the performance degradation to insufficient effort being invested in the task; this can either be determined by the characteristics of the task (where an individual in involuntarily unable to increase effort expenditure), or by the motivation of the subject (van der Hulst *et al,* 2001). During conditions of high workload (as in the case of active fatigue), however, the constant investment of effort for mobilisation of additional resources to maintain performance is limited in terms of the capacity of the individual, and the physiological and psychological costs incurred limit the duration for which this additional energy can be expended (Gaillard, 1993; 2001). When considering these concepts, it is useful to examine the response of the autonomic nervous system – Kahneman (1973) posited that the investment of effort in order to increase the amount of available resources brought with it an increase in sympathetic activation (for example, an increase in heart rate (Mascord and Heath, 1992) and an increase in pupil diameter (Beatty, 1982)). During this experiment an inclination toward parasympathetic activity is indicated by the reduction in heart rate frequency (Figure 8), increase in heart rate variability (HRV) parameters (Figures 10, 11, 13, 14 and 15) and reduction in pupil diameter (Figure 18) over time. An increase in duration of blinks between 50-300 ms was also observed – prolonged blink duration is considered to reflect deactivation and the slowing down of several physiological processes (Schleicher *et al.,* 2008). One may therefore conclude that the increased parasympathetic activity implicated in the current results demonstrates the presence of a more passive form of fatigue.

This theory could be challenged, however, by questioning whether an active fatigue would not produce the same results once an individual's limit for additional energy investment has been reached. Granholm *et al.* (1964; cited in Sirevaag and Stern, 2000) for example, related changes in pupil diameter to resource availability: they concluded that pupil diameter increases as a function of load until the limit of available resources is reached; after this point they found dilation to plateau and then decline as the resource capacity was exceeded. Similarly, the increase in blink frequency observed during fatigue has been attributed to a reduction in attentional capacity, where attentional resources are required for blink inhibition (Stern *et al.,* 1995). While Figure 18 depicts a steady decline in pupil diameter over time, Figure 47 shows pupil diameter to increase during secondary task performance – this strengthens the argument against resource depletion, as an additional load was still able to elicit a pupillary response.

A further consideration is the change in strategy for effort expenditure that may have occurred – Hockey (1997) noted that during prolonged task performance, fatigue may have a general adaptive role in shifting one's behaviour to a strategy that requires less effort. Here, the individuals may have chosen to expend less energy (at the cost of a reduction in performance) because they were aware that they would not be able to continue performance of the task for the whole two-hour period at their current level of effort. In this concept, effort would be reduced without prior indications of impending resource depletion, mimicking a passive fatigue response. This theory is brought into question by the unresponsiveness of the steering alteration frequency parameter; however it is possible that a change in strategy for effort expenditure may not be reflected by this measure. The role of motivation also needs to be considered, with the possibility of subjects reducing the effort they expend as aversion to the task increased over time.

An increase in eye movements over time was indicated by fixation and saccadic data. A general decline in fixation duration over time was observed (Figures 21 and 23) as well as an inclination for more short fixations and fewer fixations of medium length (Figures 20 and 22 respectively). These shorter fixations were accompanied by larger and faster saccades (Figures 24-26). Schleicher *et al.* (2008) proposed that short fixations were possibly indicative of reflexive, unconscious aspects of behavioural control, while fixations of medium length reflected the more cognitively-controlled aspects. The increase in eye movement could be indicative of increased scanning in an attempt to stay awake or prevent boredom, while the reduction in cognitive fixations in favour of shorter, reflexive fixations could then possibly indicate a withdrawal of conscious attention and/or effort monitoring.

It is possible, as stated by Schmidt *et al.* (2009) that such a task could integrate both active and passive fatigue. One could postulate that passive fatigue mechanisms become prevalent prior to the resource depletion that would be incurred during active fatigue in prolonged tasks of this nature. Perhaps a balance between increasing effort expenditure to maintain performance and effort reduction to prolong one's performance exists in order to provide the individual with the ability to maintain acceptable performance without exhausting all resources and risking a complete breakdown.

Intermittently subjects were asked to rate their discomfort, or the difficulty they were encountering in maintaining performance in order to provide a third dimension to the time-on-task analysis. Figure 28 depicts an incremental increase in subjective difficulty over time, which corresponds to the fatigue responses noted in both behavioural and physiological parameters. The NASA-TLX completed after the task implicated mental demand and effort as the highest contributions to the overall workload experienced, followed by the level of frustration induced by the task (Figure 29).

This study further posed the question of whether the tracking task induced an actual "fatigue" state, or whether more of a down-regulation effect occurred instead. If the effect was due to down-regulation rather than fatigue, it was hypothesized that the time-on-task effects observed would dissipate rapidly if a dramatic stimulus were to be presented, or once the subject had disengaged from the task. In considering this, pre- and post-task measures of critical flicker fusion frequency (CFFF) and heart rate were taken; with the post-task measures being taken approximately 10 minutes after the subjects had stopped driving. Again, HR and HRV measures indicated a greater parasympathetic dominance following completion of the task (Figures 9 and 12), showing that the state of fatigue was maintained even after the task had been completed. It is possible, however, that the higher sympathetic activity evident in the pre-task baselines may also be due to emotional factors such as nervousness, anxiety and anticipation of the task ahead. In an attempt to avoid this, subjects were habituated at least one day prior to the test session to ensure that they were comfortable with the equipment and the procedure before the test session. It is impossible to say whether the habituation was sufficient to prevent emotional effects on the day of the experiment, and also highly improbable that all emotional aspects could have been nullified. CFFF was significantly lower post-task for all three experimental groups (Figure 27). A decline in CFFF has also been associated with fatigue and time-on-task (Grandjean, 1979; Hancock *et al.,* 1995; Wilson *et al.,* 2003). While the usefulness of this measure as a fatigue indicator has been greatly protested, within this context and in conjunction with both behavioural and physiological measures indicating fatigue, it seems that CFFF is a valid measure for fatigue in this type of sustained attention task. The reactivity of the cardiovascular and CFFF measures together, however, provides a more solid argument for the fatigue theory and the author is inclined to negate the emotional aspects of the HRV.

The music stimulus presented near the end of the driving task was a further attempt to counteract the down-regulation that may have occurred. It was hypothesized that if the stimulus could improve performance and counteract the physiological debts incurred over time, and this effect could be maintained following cessation of the stimulus, then the time-on-task effect could be considered more of a down-regulation rather than classifying it as a genuine fatigue response. If, however, the effect was transient and performance and physiological measures returned to the state prior to implementation of the music, the state induced could be considered as fatigue.

The introduction of the music interval produced conflicting results with regards to this hypothesis. When considering the driving performance parameters, mean deviation improved during the music stimulus but returned to the pre-music level in the five minute period following cessation of the stimulus (Figure 54a). Steering alteration frequency, on the other hand, increased during the music and remained at an elevated level thereafter (Figure 54b) – this could indicate that even though performance declined after the stimulus, subjects remained more aware of their performance and made a more concentrated attempt to perform well. It is also possible that motivation of the subjects increased during the music interval, as they were aware that the task was near completion when the music was introduced.

Physiological measures also produced some confounding results during the music stimulus. All cardiovascular parameters returned to their previous level following the music stimulus, favouring the fatigue concept rather than down-regulation. During the music interval, however, the dissociation of these measures produced many questions. While HR was expected to increase (as the stimulus was expected to increase arousal), instead a decline in HR was observed (Figure 55), suggesting that the music had a relaxing effect on the subjects rather than waking them up. As with previous results for both time-on-task and secondary task effects, a decline in HR was expected to be accompanied by an increase in HRV. This was true for the time-domain PNN30 variable (Figure 56); however the frequency-domain parameters were less reactive. Both LF and HF power variables failed to produce a significant effect, and the LF component of the (LF+HF) power variable decreased significantly (Figure 57). A decrease in HRV (especially in the low frequency spectrum) is considered an indication of increased workload or effort (Fairclough *et al.,* 2005). This was supplemented by an increase in pupil diameter during the music stimulus (Figure 59), also indicative of an increase in workload and/or effort (Beatty, 1982; Marshall, 2000; Sirevaag and Stern, 2000). As mentioned previously, in conjunction with the increase in arousal elicited by the music stimulus, an increase in motivation due to the near-completion of the task may have prompted subjects to invest more effort in the task, which would explain the decline in the frequency-domain measure. The question remains, however, that if an increase in motivation and/or effort was the case, would that not also result in an increase in HR and decline in PNN30? One may also question why the other power variables were non-reactive, considering their significant change during both the time-on-task and the secondary task analyses.

The centre frequency HRV measures were also questionable: only the HFcf produced a significant effect, with HFcf increasing during the music interval (Figure 58a). While the change in LFcf was not significant, the groups were found to elicit different effects on this variable. Figure 58b shows that while the music stimulus increased LFcf for both the control and choice RT groups, a decline in LFcf was found for subjects in the memory span group. Again, the interpretation of this finding is difficult, especially due to the fact that no other measures showed the memory span group to have different reactions during the music stimulus.

The other oculomotor measures tended to retain the effect produced by the music interval rather than return to pre-music levels. A decline in both blink frequency and blink duration was observed (Figure 60) – this is considered by numerous authors to occur during increased task demand to reduce the likelihood of missing relevant information during a visual task (Wilson and Eggemeier, 1991; Brookings *et al.,* 1996; Fairclough *et al.,* 2005). With regards to fixation parameters, the opposite effect compared to the time-on-task change was observed, with an increase in medium fixations and a consequent decline in short fixations occurring (Figure 62). This is consistent with the above findings of an increase in cognitive demand or attention, as medium-length fixations are considered to reflect more conscious cognitive processing (Schleicher *et al.,* 2008). Saccadic parameters indicated a decline in eye movement (Figure 63), again possibly indicating a more focussed approach to the task when subjects realised they were near the end of the experiment.

SECONDARY TASK EFFECTS

Significant effects relating to the secondary task were evident only for the memory span task. The purpose of the secondary tasks was to determine whether the tasks would function to increase arousal (thereby improving performance and physiological state) or whether they would overextend the individual in terms of resource capacity, resulting in a performance decrement. It is important to note that the two tasks used cannot be compared in terms of the mental workload that they induce as they are structurally different, requiring different information processing channels and using different resources. The choice RT task was applied as it utilizes the same visuo-motor resources as the primary task, so this was considered a means to test whether there was spare capacity within these resources, or if the resources were becoming depleted over time. Because driving performance was unaffected during the choice RT task, one could assume that there was still sufficient capacity for the subjects to perform both tasks concurrently.

The other purpose of the secondary task was to determine whether the addition of another task to the driving could function to increase arousal and improve performance – again, the choice RT task did not demonstrate an increase in arousal, both with regards to driving performance and with regards to the physiological measures. It is possible that the choice RT task was not demanding enough (in terms of resource requirements and/or task engagement) to elicit the desired responses. It should also be noted that while the provision of knowledge of results for the secondary tasks was avoided as much as possible, the memory span task would have inadvertently provided knowledge of results in that if the subject had the wrong answer the number string would be shorter for the next one, and if they were correct the following string would be longer. The choice RT task, on the other hand, had no such feedback.

The memory task was applied in order to increase task engagement and therefore increase arousal, and it was designed to use auditory, memory and verbal resources that were somewhat dormant (or unused) during the primary task. Driving performance improved during concurrent performance of the memory span task (Figure 39) and steering frequency increased (Figure 40). The increase in steering frequency suggests that the subjects were attempting to stay on the line more accurately during this period. In this context it may be relevant to consider that during the initial memory span interval (where the subject would not yet have been fatigued) steering frequency decreased, whereafter an increase during the memory span intervals was noted (Figure 41). This change in steering behaviour may be either a habituation to the concurrent task performance, or an alteration in driving strategy with the onset of fatigue.

The physiological measures hypothesized to depict an increase in mental loading during the memory span task produced ambiguous results. Figures 43 and 47 show an increase in HR and pupil diameter respectively. This is consistent with literature, considering such reactions being indicators of an increased cognitive load (Brookings *et al.,* 1996; Wilson and Russell, 2003; Beatty, 1982; Marshall, 2000; Lin *et al.,* 2008). An increase in mental load was expected to decrease measures of HRV (Mascord and Heath, 1992; Lin *et al.,* 2008). The memory task in this situation, however, resulted in a significant increase in RMSSD (Figure 44) as well as in the HF power, LF power and LF component of the (LF+HF) power variables (Figure 45a, b and c). One possible factor that may compound HRV results is the vocal nature of the memory span task, as the HF component has been said to reflect momentary respiratory influences (Jorna, 1992; Lin *et al.,* 2008). Jorna (1992) notes that speaking produces a wide respiratory spectrum with a large range of frequencies present, therefore the effect may have been included in the low frequency measures as well. Fairclough and Houghton (2004) posed the question of whether HRV was more reactive to task-related or state effort (see Chapter II, or Mulder, 1986): The current research may suggest that HRV is reactive to the type of effort that is most prevalent for the given task. For Fairclough and Houston's (2004) experiment, perhaps the task-related effort was higher than that of state effort; however for the current results the increase in task-related effort posed by the memory span task is perhaps less significant than the relief from the state effort (required to maintain attention on a monotonous or fatiguing task (Thackray, 1981)) that the secondary task provides, therefore HRV increases instead of decreasing as one would expect.

A significant increase in blink frequency was also noted for the intervals during which the memory span task was performed (Figure 48). While a reduction in blink rate during increased cognitive demand has been documented by numerous authors (Wilson and Eggemeier, 1991; Brookings *et al.,* 1996; Fairclough *et al.,* 2005; Ha *et al.,* 2006), this is usually attributed to an increase in visual demand, where blinks are inhibited to reduce the likelihood of missing visual information (Ha *et al.,* 2006). In this context, a reduction in blink frequency should have been evident during the choice RT task due to the increase in visual demand, but again this task did not elicit any significant results. The opposing finding of increased blink frequency (as found during the memory span task) has also been given much attention – Wilson and Eggemeier (1991) posit that a higher blink rate may be due to an increased rate of information intake, as individuals tend to blink following information acquisition. Various authors in Stern *et al.* (1984) have reported a significant effect on blink rate when vocalisation was required by a task – significant increases in blink rate have been noted for tasks requiring vocalisation of a result, while the same tasks performed silently resulted in either no change in blink rate or a decreased blink rate. Stern *et al.* (1984) pose the question as to whether an increase in blink rate is secondary to speech or motor activity, or whether the increase reflects a more generalised activation function, as an increase in blink rate has also been observed during dual-task performance when compared to single-task performance without verbalisation. Recarte *et al.* (2008) propose that the inhibition of blinks during a visual task requires attentional resources, and therefore the increase in resources required to perform an additional mental task would interfere with the resources needed for blink inhibition, resulting in an increased blink rate. Because the increase in blink frequency was only observed during the memory span task, the concept of vocalisation affecting the results cannot be ruled out for both blink frequency and the HRV measures.

Fixations and saccades have been implicated in workload studies where the task is primarily visual, therefore the response of these measures to the auditory memory task were minimal. The intervals during which the memory span task was performed produced a significant decline in the duration of short fixations (Figure 49) as well as an increase in the number of short fixations while no significant change was noted for saccadic parameters.

GENDER AND TIME OF DAY EFFECTS

The covariate effects of gender and the time of day that testing took place were assessed in order to determine whether they had significant influence on the results obtained above. In general, females did not perform the primary task as well as males did; however they tended to maintain their level of performance, while the males' performance declined to a greater extent over time (Figure 30). The females' pupil diameter produced a stronger decline over time (Figure 31); possibly indicating that the initial effort invested was higher for females and became less as they became more accustomed to the task. Males tended to produce more frequent eye movements, with a higher percentage of short fixations and a greater increase in saccades over time (Figures 32-36). This inclination for more short fixations was again evident in the analysis of the intervals surrounding the music stimulus.

With regards to the time of day that testing took place, cardiovascular measures seemed to be more reactive during the morning testing sessions (Figures 37 and 38). Subjects tested in the afternoon were found to have a higher average memory span than those tested in the morning (Figure 52).

It should be noted that only a few of the measures showed significant effects for these two covariates, and the variables that did show a significant difference did not correlate in a coherent manner. The effects are therefore considered more arbitrary than providing much relevant information with regards to the main effects that are the focus of the thesis.

In conclusion, it can be said that the tracking task produced a significant fatigue response, indicated by performance, physiological and subjective data. The effect elicited is considered a fatigue rather than a down-regulation due to both the response of the post-task measures taken approximately 10 minutes after completion of the task, as well as the rapid return of the majority of measures to the fatigued state following the upregulation (music) stimulus. It is, however, apparent that motivation may play a large role in this type of research and may compound interpretation of physiological measures; a number of physiological variables reflected an increased effort or cognitive functioning following the music task and it is hypothesized that this was due to the subjects knowledge that the experiment was almost over.

In addition to the increase in parasympathetic activity over time, implementation of the secondary tasks suggests that task disengagement rather than resource depletion may be responsible for the results observed. It is, however, difficult to interpret the secondary task results, as the choice RT task and the memory span task both have their downfalls in terms of functionality – the choice RT task may have been insufficient in terms of demand to elicit an appropriate response, while the vocalisation required by the memory task compounded the physiological interpretation. From the results obtained during performance of the memory span task it is evident that an increase in mental workload (in this case, short term memory) functions to increase primary task engagement, as seen by improved driving performance and more frequent steering alterations. It is also possible that this type of secondary task may reduce the expenditure of “state effort”, or the effort required to prevent fatigue during a prolonged monotonous task.

Once again, while the concept of passive fatigue is favoured by many of the physiological responses it is highly possible, as suggested by Schmidt *et al.* (2009), that an interplay between both active and passive fatigue symptoms exists. While a monotonous situation may seem to invoke a passive form of fatigue, it is perhaps possible that the passive fatigue mechanisms are activated to prevent the total breakdown in performance that would occur should an individual become actively fatigued. During a task where prolonged performance is required it may be feasible to reduce effort expenditure (at the risk of decreased performance) in favour of preventing resource depletion and increasing one’s ability to maintain performance over a longer period.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The concept of task-related fatigue is still not well understood. The aim of this study was to induce a task-related fatigue through prolonged performance of a simplistic tracking task requiring sustained attention in order to investigate and clarify the mechanisms surrounding active and passive fatigue concepts. Physiological responses were studied in order to determine whether a differentiation between active and passive fatigue could be achieved in this manner.

SUMMMARY OF PROCEDURES

The current research considered performance, physiological and subjective measures in order to provide a holistic picture of fatigue manifestation. The protocol consisted of a tracking task in the form of simplistic driving in a simulator performed for approximately 115 minutes in total. Three groups were formed: The control group performed the tracking task only, while the two experimental groups involved performance of a concurrent choice RT or memory span task intermittently throughout the protocol. Near the end of the task a loud music stimulus was introduced in order to counteract any down-regulation that may have occurred due to the monotonous nature of the task. After this sequence subjects continued the task for five more minutes. Each group consisted of fourteen subjects equal in gender distribution and matched as evenly as possible for age, driving and videogame experience as well as experience with the driving simulator. Subjects were tested either between 9:00-11:30am or 2:30-5:00pm to avoid circadian influences.

Baseline measures of heart rate and critical flicker fusion frequency were taken both before and after the driving protocol. Measures of driving performance, heart rate, heart rate variability and eye movements were taken throughout the protocol and analysed in five minute intervals, with gender and the time of day that testing took place considered as covariates. Performance of the secondary tasks was measured as average response time for the choice RT task, and average memory span for the memory span task. Subjective fatigue was recorded via the Borg CR-10 scale after every 25 minutes of driving, and the NASA-TLX was completed after the task to provide an index of mental workload.

SUMMARY OF RESULTS

Time-on-task had a significant effect on performance, physiological and subjective measures. Over time, performance was shown to decline – this effect was independent of whether or not a secondary task was performed. Heart rate declined over time, while heart rate variability measures increased over time with the exception of the decreasing centre frequency measures. Pupil diameter also declined over time. An increase in blink frequency was noted, along with an inclination for larger and more frequent eye movements. Subjective ratings of difficulty increased over the testing period.

Measures of baseline heart rate and heart rate variability as well as critical flicker fusion frequency reflected fatigue (consistent with existing literature) following completion of the task. The induction of an upregulation interval (via loud music) was shown to have a transient effect on the majority of performance and physiological measures, indicating that the task induced a fatigue response rather than a mere down-regulation. Some of the effects of the music were longer lasting, namely the eye movement parameters and change in driving behaviour. These were considered to reflect the increase in motivation that occurred at this time due to the subjects' knowledge that the task was nearing completion.

With regards to the secondary tasks, only the memory span task elicited a significant response within the performance and physiological measures. These effects included an increase in heart rate, heart rate variability parameters, pupil diameter and blink frequency. The parasympathetic reaction of physiological parameters over time in conjunction with the sympathetic reaction of both heart rate and pupil diameter during performance of the memory span task are indicative of a passive fatigue response to the task, as this indicates both an increase in arousal and that spare processing capacity was available for performance of the secondary task throughout the experiment. The increase in heart rate variability and blink parameters was compounded by the need for vocalisation during the memory span task, as well as the interplay between task-related effort and state effort, which is required to maintain performance in a state of reduced arousal.

CONCLUSIONS

The protocol used in this study was found to elicit fatigue responses. While the results are inclined to demonstrate a more passive form of fatigue, this can only be tentatively accepted, due to the loose theoretical framework surrounding these concepts as well as the lack of physical evidence for the existence of two completely separate fatigue responses. In general, the fatigue elicited was accompanied by an increase in parasympathetic activity, with an increase in sympathetic activity occurring when an extra task aimed at increasing general task engagement was introduced.

The measures which produced similar results throughout the experiment were driving performance, heart rate and pupil diameter, which declined over time and increased during secondary task performance, synonymous with literature regarding fatigue and workload studies. Heart rate variability and blink parameters increased both over time and during increased workload. It is possible that these measures were affected by the vocal nature of the memory span task, or that they reflected alternative aspects of effort regulation compared to heart rate and pupil diameter.

Eye movement parameters (i.e. fixation and saccadic parameters) reflected a decline in general attention (or, possibly, an inclination toward cognitive distraction) throughout the protocol regardless of secondary task implementation. This may indicate that while the memory span task functioned to alleviate the fatigue response to some extent, the general attentional resources utilised were expended regardless. In this respect it should be noted that a secondary task may be able to alleviate some of the monotony induced by such a task, but there still exists a depletion of resources that cannot be dismissed and may still be implicated in dangerous behaviour when fatigued.

In general, both cardiovascular and oculomotor responses are useful in depicting fatigue and mental workload; however dissociation of measures as well as contamination due to aspects such as vocalisation makes interpretation of the measures difficult. An important consideration for future research is whether these measures can still predict the onset of fatigue in a more realistic situation where individuals are able to interact more naturally with the environment.

From the results obtained in this study, one can conclude that an intermittent secondary task that is unrelated to the primary task in terms of both resource utilisation and cognitive processing may be useful in reducing the negative effects of fatigue during prolonged performance of a monotonous task. The overall level of fatigue is, however, unaffected by such a task and therefore a secondary task is no substitute for adequate rest breaks during long work hours. It is also important to carefully consider the type of task applied, as general attention resources may be further depleted or withdrawn from the primary task, leading to errors or accidents.

RECOMMENDATIONS

Future investigations into the effects of task-related fatigue should consider the following recommendations in terms of the research methodology employed:

1. The use of a single group of subjects for all conditions should be considered, as this may reduce the individual variability experienced within this research. The role of motivation for this type of study is, however, important and it should be noted that a substantial degree of task aversion as well as habituation would be experienced in subsequent sessions that may affect performance and physiological data. A larger sample size as well as more accurate matching of subjects within the groups would also assist in reducing some of the individual variability.
2. More detailed analysis of data, for example, analysis of the variance within each interval may be useful in order to describe fatigue responses by a general (performance) decline and/or by more irregular performance, identifying more short-term breakdowns. In this way it may be possible to use physiological changes to identify to onset of fatigue prior to the more detrimental performance decrement.
3. The secondary tasks implemented should also be carefully reconsidered. In order to determine whether the resources utilised by the primary task are becoming depleted, a task such as the choice RT task is important; however the task needs to be reconsidered both in terms of the cognitive stimulation

invoked as well as the intrusiveness of such a task. If a task such as the memory span task is used, the effect of vocalisation on the various physiological measures needs to be seriously considered. For example, a matching of breathing rate to HRV measures may provide a clearer picture of the role played by the vocalisation. Measurement of the secondary task separately may allow one to distinguish the effect of the task from the effect observed during dual-task performance on physiological measures. If tasks requiring different resources are to be compared it is necessary to consider more carefully the demand imposed by each task as well as the type of cognitive processing required, as both the additional activity induced by the task as well as the resources involved will compound the results.

4. The time of testing should be kept constant for all subjects, and more stringent requirements with regards to sleeping habits should be made in order to ensure no circadian influences affect the results.

5. Finally, it should be noted that the driving task used was considered more of a simplistic perceptual-motor task than a realistic driving scenario. In this respect, future research should consider a more realistic driving situation in order to evaluate whether the effects observed during this study can be applied in real life situations. It is, however, important to consider that numerous factors will affect the results in a real-life scenario. For this reason it is suggested that initially as many factors as possible be tested separately; thereafter a combination of factors may be studied. One may also consider the use of professional drivers and the lengthening of the protocol to match the demands placed on such individuals.

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APPENDIX A: General Information

1. Prescreening questionnaire (including Morningness-Eveningness questionnaire)
2. Letter of Information for the subject
3. Consent form

APPENDIX A1

Prescreening Questionnaire

Prescreening Questionnaire **(values in red for scoring not shown to subjects)**

Please note that you are exempt from this study if:

- You do not have a **valid driver's license**
- You wear **glasses** (contact lenses are acceptable)
- You have any **sleep disorders**
- You have a history of **epilepsy**
- You have **ADHD** or similar disorders

Name:

Email:

Cell:

Sex:

Age:

How many years driving experience do you have?

0-2 years	2-5 years	5+ years
1	2	3

How often do you drive long distance (over 1.5hours)?

Never	Less than once a month	More than once a month
0	1	2

Have you had any experience with the HKE driving simulator? If yes, how much?

No experience	Less than 1hr experience	More than 1hr experience
0	1	2

How often do you play video games?

Daily	A few times a week	Less than once a week	Never
3	2	1	0

How long do you play video games for at a time on average?

N/A	Less than 1 hour	1 – 3 hours	More than 3 hours
0	1	2	3

Morningness-eveningness Questionnaire

Read each question carefully and select the most appropriate answer

1. If you were entirely free to plan your evening and had no commitments the next day, at what time would you choose to go to bed.?

1. 20:00 – 21:00	5
2. 21:00 – 22:15	4
3. 22:15 – 00:30	3
4. 00:30 – 01:45	2
5. 01:45 – 03:00	1

2.You have to do 2 hours physically hard work. If you were entirely free to plan your day, in which of the following periods would you choose to do the work?

1. 08:00 – 10:00	4
2. 11:00 – 13:00	3
3. 15:00 – 17:00	2
4. 19:00 – 21:00	1

3. For some reason you have gone to bed several hours later than normal, but there is no need to get up at a particular time the next morning. Which of the following is most likely to occur?

1. Will wake up at the usual time and not fall asleep again	4
2. Will wake up at the usual time and doze thereafter	3
3. Will wake up at the usual time but will fall asleep again	2
4. Will not wake up until later than usual	1

4. You have a 2 hour test to sit which you know will be mentally exhausting. If you were entirely free to choose, in which of the following periods would you choose to sit the test?

1. 08:00 – 10:00	4
2. 11:00 – 13:00	3

3. 15:00 – 17:00	2
4. 19:00 – 21:00	1

5. If you had no commitments the next day and were entirely free to plan your own day, what time would you get up?

1. 05:00 – 06:30	5
2. 06:30 – 07:45	4
3. 07:45 – 09:45	3
4. 09:45 – 11:00	2
5. 11:00 – 12:00	1

6. A friend has asked you to join him twice a week for a work-out in the gym. The best time for him is between 10pm - 11pm. Bearing nothing else in mind other than how you normally feel in the evening, how do you think you would perform?

1. Very well	1
2. Reasonably well	2
3. Poorly	3
4. Very poorly	4

7. One hears about 'morning' and 'evening' types of people. Which of these types do you consider yourself to be ?

1. Definitely morning type	6
2. More a morning than an evening type	4
3. More an evening than a morning type	2
4. Definitely an evening type	0

Morningness - Eveningness Scale

1. Definitely morning type ....32 - 28
2. Moderately morning type ....27 - 23
3. Neither type ....22 - 16
4. Moderately evening type........15 - 11
5. Definitely evening type...........10 - 6

Thank you for your time! I will get hold of you either via email or SMS to set up a time for testing!

If you have any questions, please don't hesitate to get hold of me!! ☺

Casey

0782843796

g06d0667@campus.ru.ac.za

APPENDIX A2

LETTER OF INFORMATION FOR THE SUBJECT

Dear ______________________________,

Thank you for your interest in participating in this study, your assistance in completing this investigation is greatly appreciated. This letter explains the aims of the project, as well as the potential risks and benefits involved. Please read it carefully and sign the accompanying consent form.

AIM OF THE STUDY

This study is focused on the effect of mental workload and fatigue on the performance of sustained attention tasks, using driving as a special case scenario in the driving simulator. The aim of the study is to assess the effects of underload, monotony and/or fatigue on continuous driving performance as well as how various physiological variables react to this type of work. Throughout the course of the testing protocol, heart rate as well as eye movements will be measured, and a subjective feeling of fatigue will also be taken periodically. This will provide an indication of the mental capacity required to perform a task involving sustained attention, and hopefully provide some insight into the use of physiological measures to predict the likelihood of performance failure before it occurs.

PROCEDURES

You will be required to attend two laboratory sessions at the Human Kinetics and Ergonomics Department. In the initial session (lasting no longer than 30 minutes) you will be introduced to the equipment (heart rate monitor and eye tracker) and procedures, and allowed to practice driving on the driving simulator until you feel comfortable enough to perform the task. Any questions or concerns you have about the testing protocol are welcome.

The second session will entail driving on the driving simulator continuously for approximately two hours. The heart rate monitor and eye tracker will be attached and worn throughout the procedure. [Choice RT group: A choice reaction task will be introduced periodically while you are driving, to which you will be required to respond to with the buttons on the steering wheel.] [Memory span group: An auditory memory task will be introduced periodically while you are driving, to which you will be required to respond verbally.] A perceived effort/fatigue rating will also be asked periodically, where you will be asked to rate the difficulty of performing the task on a scale of 1 (very easy/alert) to 10 (very hard/struggling to maintain performance).

RISKS AND BENEFITS

It is unlikely that you will experience any injuries during this study, as the procedures are not considered harmful in any way. Due to the length of the protocol, however, there is a possibility of “simulator sickness”, where you may feel slightly dizzy or nauseous. This feeling is transient, and should dissipate once you have stopped the task. If you feel uncomfortable and unable to complete the protocol please note that you may request to stop the test at any point.

In the unlikely event of incurring an injury during the study as a result of either the experimental protocol or equipment used, the Human Kinetics and Ergonomics Department will be liable for any costs which may ensue and will reimburse the subject to the full amount i.e. doctors consultation, etc. The Department will also assist in applying rehabilitation sessions for the injury if need be. The Department will, however, waiver any legal recourse against the researcher or Rhodes University in the event the injury is proved to be self inflicted or due to the negligence of the subject themselves. It is important to reiterate that the likelihood of incurring injury during this protocol is highly unlikely.

Benefits derived from this study include exposure to equipment and technology which may otherwise be difficult to encounter. You will also contribute to an improved understanding of the demands placed on individuals in a wide array of work situations requiring sustained attention, for example long distance driving, in the hopes of preventing the dangerous performance failures that occur in real-life situations. This will ultimately to make the work environment a safer and better place.

OTHER

All data collected will be coded, and thus you will remain anonymous with regards to your data and results. If at any stage you wish to withdraw from the study you may do so without any adverse consequences to you. If there are any queries involving the testing procedures or any other concerns you may have, the researcher's details are provided at the end of this letter.

PLEASE TAKE NOTE OF THE FOLLOWING REQUIREMENTS BEFORE YOUR TESTING SESSION:

- At least 6 hours sleep the night before testing
- No alcohol 24 hours prior to testing
- No coffee/caffeine at least 1 hour prior to testing, and no more than 2 cupes within the last 12 hours
- No (strenuous) exercise 12 hours prior to testing

Please contact the researcher if you are unsure of any of these requirements (e.g. what constitutes strenuous exercise) and inform the researcher if you were not able to comply with these requirements before testing begins.

Thank you for your time and co-operation.

Yours Sincerely

Casey De Gray Birch (BScHons)

HKE Masters student

0782843796

g06d0dd7@campus.ru.ac.za

APPENDIX A3

Consent Form

I, ____________________________, do hereby consent to participate in the study entitled:

"**The effects of sustained attention, workload and task-related fatigue on physiological measures and performance during a tracking task**".

I agree that I have been fully informed, both verbally and in writing, of the procedures involved in this study. I have also been made aware of any potential risks associated with the protocol.

By voluntarily consenting to participate in this research I waive any legal recourse against the researcher, or against Rhodes University, in the event of any personal injuries sustained due to negligence on my behalf. This waiver shall be binding upon my heirs and legal representatives. I am aware, however, that the Human Kinetics and Ergonomics Department is liable for any injuries caused by either the experimental protocol or equipment that are brought to the attention of the researcher in due course of the experiment. I will inform the researcher immediately if at any point I experience distress or abnormality, and am fully aware that I may withdraw from participation in this study at any time without any adverse consequences.

I am aware that whilst my anonymity will be protected at all times, my results may be published or used for scientific and statistical purposes. I understand the conditions with which I am expected to comply for the duration of the tests, and any queries I have with regards to this have been answered to my satisfaction.

I have read and understood the above information, as well as the information provided in the letter accompanying this form.

Signed at the Department of Human Kinetics and Ergonomics, Rhodes University, on _____ (Date) 2011.

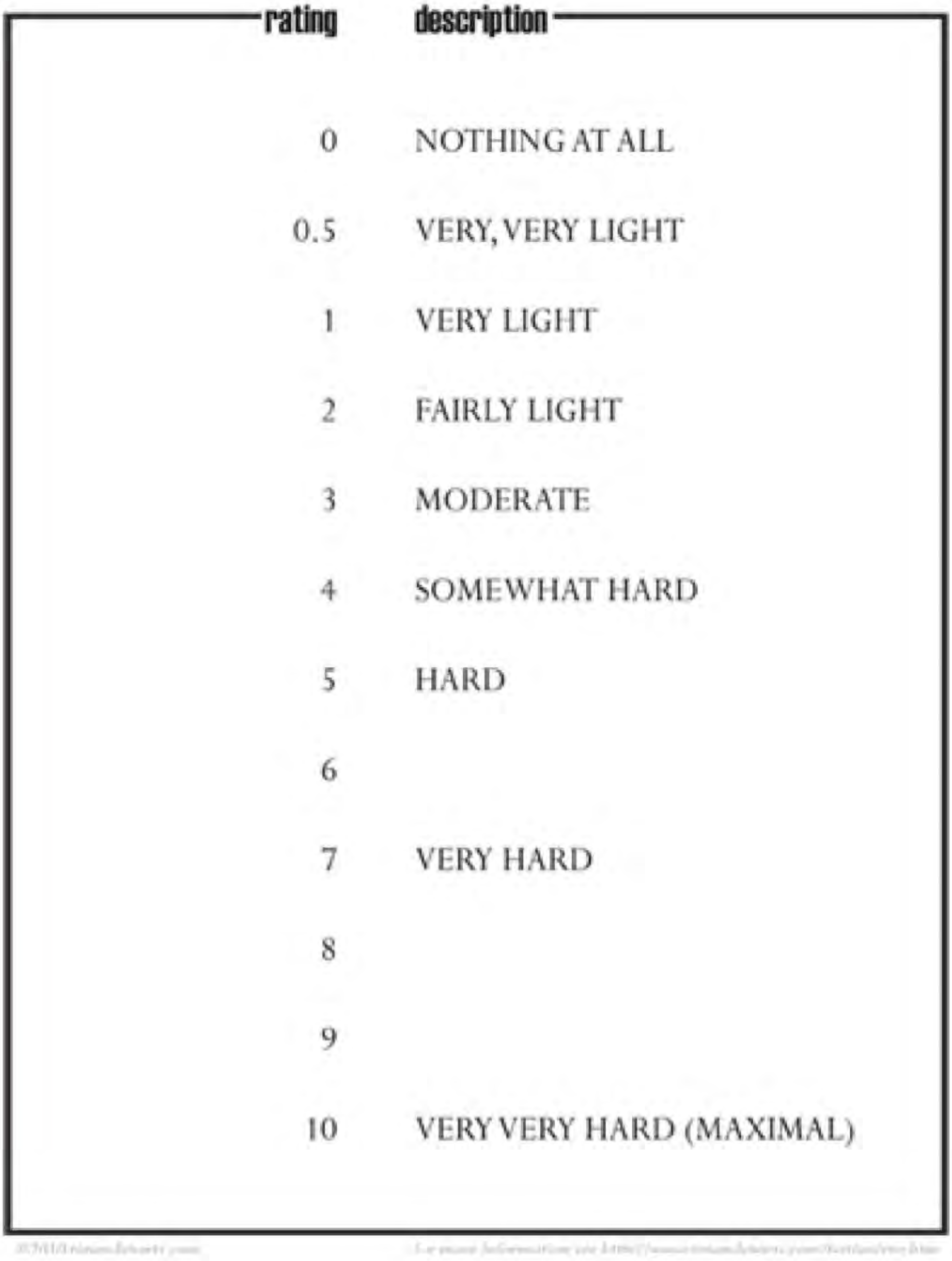
SUBJECT:__________________________ **(SIGN)**_____________________

WITNESS:__________________________ **(SIGN)**_____________________

RESEARCHER:______________________ **(SIGN)**_____________________

APPENDIX B

Borg CR-10 Scale



rating	description
0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)

APPENDIX C: Summary Reports

1. Time-on-task effects
    1. Performance parameters
    2. Cardiovascular parameters
    3. Oculomotor parameters
    4. Subjective parameters
2. Secondary task effects
    1. Performance parameters
    2. Cardiovascular parameters
    3. Oculomotor parameters
3. Effect of music
    1. Performance parameters
    2. Cardiovascular parameters
    3. Oculomotor parameters

APPENDIX C1

Time-on-task Effects

Time-on-task effects were analysed with a repeated-measures ANOVA, where "TIME" is the change in variables over the 23 intervals (minus the secondary task intervals, see Chapter III page 58). The covariates analysed include "group" (the experimental group), "gender" (the gender of the subject) and "time" (the time of day that testing took place. Significant effects are highlighted in red.

1. Performance parameters
    a. Mean deviation

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .018

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.06818	1	0.06818	198.800	0.00000
group	0.00049	2	0.00024	0.719	0.49530
gender	0.00068	1	0.00068	1.995	0.16809
time	0.00067	1	0.00067	1.952	0.17259
group*gender	0.00031	2	0.00015	0.464	0.63300
group*time	0.00062	2	0.00031	0.915	0.41131
gender*time	0.00038	1	0.00038	1.113	0.29969
group*gender*time	0.00025	2	0.00012	0.376	0.68958
Error	0.01028	30	0.00034		
TIME	0.00033	12	0.00002	3.321	0.00013
TIME*group	0.00016	24	0.00000	0.818	0.71385
TIME*gender	0.00024	12	0.00002	2.400	0.00536
TIME*time	0.00007	12	0.00000	0.689	0.76155
TIME*group*gender	0.00021	24	0.00000	1.036	0.41733
TIME*group*time	0.00027	24	0.00001	1.370	0.11701
TIME*gender*time	0.00005	12	0.00000	0.512	0.90694
TIME*group*gender*time	0.00027	24	0.00001	1.371	0.11639
Error	0.00305	360	0.00000		

b. Effective reaction time

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .071

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.98168	1	0.98168	194.049	0.00000
group	0.00667	2	0.00333	0.659	0.52439
gender	0.00823	1	0.00823	1.6275	0.21183
time	0.01016	1	0.01016	2.0085	0.16672
group*gender	0.00427	2	0.00213	0.4222	0.65945
group*time	0.01080	2	0.00540	1.0682	0.35633
gender*time	0.00569	1	0.00569	1.125	0.29728
group*gender*time	0.00400	2	0.00200	0.395	0.67692
Error	0.15176	30	0.00505		
TIME	0.00441	12	0.00036	2.297	0.00791
TIME*group	0.00431	24	0.00018	1.123	0.31436
TIME*gender	0.00430	12	0.00035	2.240	0.00977
TIME*time	0.00132	12	0.00011	0.6875	0.76369
TIME*group*gender	0.00477	24	0.00019	1.2415	0.20221
TIME*group*time	0.00430	24	0.00017	1.119	0.31894
TIME*gender*time	0.00091	12	0.00007	0.4778	0.92737
TIME*group*gender*time	0.00381	24	0.00015	0.9929	0.47479
Error	0.05765	360	0.00016		

c. Information processing capacity

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 1.97

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	10641.7	1	10641.7	2734.52	0.00000
group	8.88	2	4.44	1.141	0.33308
gender	8.45	1	8.45	2.171	0.15103
time	3.39	1	3.39	0.871	0.35826
group*gender	2.61	2	1.30	0.335	0.71798
group*time	6.68	2	3.34	0.858	0.43405
gender*time	5.00	1	5.00	1.286	0.26583
group*gender*time	2.79	2	1.39	0.358	0.70179
Error	116.75	30	3.89		
TIME	2.14	12	0.18	2.959	0.00059
TIME*group	1.32	24	0.06	0.913	0.58391
TIME*gender	3.24	12	0.27	4.487	0.00000
TIME*time	0.92	12	0.08	1.279	0.22886
TIME*group*gender	1.51	24	0.06	1.047	0.40397
TIME*group*time	1.98	24	0.08	1.368	0.11808
TIME*gender*time	0.41	12	0.03	0.568	0.86798
TIME*group*gender*time	1.30	24	0.05	0.896	0.60851
Error	21.69	360	0.06		

d. Steering alteration frequency

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .138

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	27.3432	1	27.3432	1433.59	0.00000
group	0.0377	2	0.01885	0.988	0.38397
gender	0.00738	1	0.00738	0.387	0.53848
time	0.00307	1	0.00307	0.161	0.69130
group*gender	0.01077	2	0.00538	0.282	0.75602
group*time	0.04455	2	0.02228	1.168	0.32477
gender*time	0.01881	1	0.01881	0.986	0.32864
group*gender*time	0.00317	2	0.00159	0.083	0.92035
Error	0.5722	30	0.01907		
TIME	0.00866	12	0.00072	1.114	0.34688
TIME*group	0.01423	24	0.00059	0.915	0.58111
TIME*gender	0.00446	12	0.00037	0.573	0.86347
TIME*time	0.00642	12	0.00054	0.827	0.62280
TIME*group*gender	0.01599	24	0.00067	1.029	0.42736
TIME*group*time	0.0091	24	0.00038	0.586	0.94194
TIME*gender*time	0.0081	12	0.00067	1.042	0.40898
TIME*group*gender*time	0.0116	24	0.00048	0.747	0.80221
Error	0.23311	360	0.00065		

2. Cardiovascular parameters

a. Heart rate

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 35.8

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	260712	1	260712	2031.07	0.00000
group	3000	2	1500	1.169	0.32450
gender	1179	1	1179	0.918	0.34562
time	178	1	178	0.139	0.71196
group*gender	1548	2	774	0.603	0.55367
group*time	960	2	480	0.374	0.69125
gender*time	2081	1	2081	1.621	0.21267
group*gender*time	3204	2	1602	1.248	0.30159
Error	38509	30	1284		
TIME	1296	12	108	6.234	0.00000
TIME*group	494	24	21	1.188	0.24852
TIME*gender	137	12	11	0.659	0.79010
TIME*time	397	12	33	1.908	0.03224
TIME*group*gender	624	24	26	1.501	0.06300
TIME*group*time	626	24	26	1.506	0.06151
TIME*gender*time	488	12	41	2.349	0.00652
TIME*group*gender*time	499	24	21	1.199	0.23884
Error	6238	360	17		

b. RMSSD

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 94.3

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	165836	1	165836	186.4834	0.000000
group	2933	2	1466	0.1649	0.848740
gender	2068	1	2068	0.2325	0.63314
time	56	1	56	0.0063	0.937124
group*gender	24988	2	12494	1.4049	0.261065
group*time	28	2	14	0.0016	0.998404
gender*time	11636	1	11636	1.3085	0.261719
group*gender*time	29007	2	14504	1.6309	0.212629
Error	266784	30	8893		
TIME	35100	12	2925	19.7435	0.000000
TIME*group	3069	24	128	0.8633	0.653220
TIME*gender	1480	12	123	0.8323	0.617015
TIME*time	446	12	37	0.2506	0.995280
TIME*group*gender	6783	24	283	1.9076	0.006865
TIME*group*time	5594	24	233	1.5734	0.043840
TIME*gender*time	2746	12	229	1.5447	0.106209
TIME*group*gender*time	4113	24	171	1.1568	0.279377
Error	53334	360	148		

c. PNN30

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 75.5

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	530482.9	1	530482.9	92.93802	0.000000
group	18138.0	2	9069.0	1.58884	0.220860
gender	1611.0	1	1611.0	0.28224	0.599147
time	266.1	1	266.1	0.04661	0.830529
group*gender	11846.8	2	5923.4	1.03775	0.36662
group*time	4626.1	2	2313.0	0.40523	0.670410
gender*time	1183.7	1	1183.7	0.20738	0.652105
group*gender*time	8479.5	2	4239.8	0.74279	0.484334
Error	171237.0	30	5707.9		
TIME	1891.6	12	157.6	2.85253	0.000918
TIME*group	393.9	24	16.4	0.29703	0.999595
TIME*gender	215.7	12	18.0	0.32524	0.984572
TIME*time	721.7	12	60.1	1.08824	0.36870
TIME*group*gender	888.0	24	37.0	0.66957	0.880832
TIME*group*time	364.6	24	15.2	0.27489	0.999795
TIME*gender*time	288.6	12	24.1	0.43521	0.94885
TIME*group*gender*time	1935.3	24	80.6	1.45919	0.077353
Error	19894.3	360	55.3		

d. High frequency centre frequency

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .061

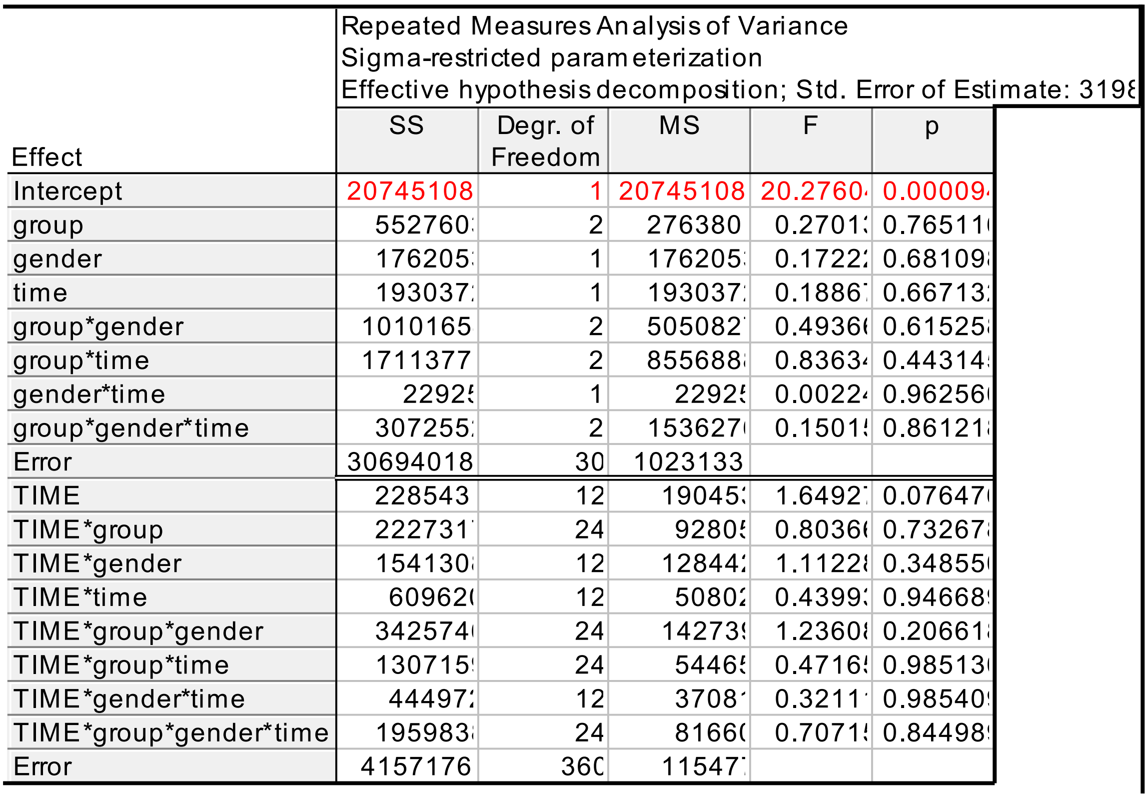
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	24.8390	1	24.8390	6542.83	0.00000
group	0.0044	2	0.0022	0.59	0.56042
gender	0.0099	1	0.0099	2.631	0.11524
time	0.0147	1	0.0147	3.87	0.05827
group*gender	0.0053	2	0.0027	0.711	0.49946
group*time	0.0115	2	0.0057	1.51	0.23609
gender*time	0.0019	1	0.0019	0.50	0.48509
group*gender*time	0.0001	2	0.0001	0.02	0.97509
Error	0.1138	30	0.0038		
TIME	0.0222	12	0.0018	8.48	0.00000
TIME*group	0.0025	24	0.0001	0.48	0.98209
TIME*gender	0.0013	12	0.0001	0.497	0.91621
TIME*time	0.0025	12	0.0002	0.96	0.48254
TIME*group*gender	0.0033	24	0.0001	0.63	0.91028
TIME*group*time	0.0048	24	0.0002	0.921	0.57397
TIME*gender*time	0.0017	12	0.0001	0.65	0.79015
TIME*group*gender*time	0.0041	24	0.0001	0.79	0.74197
Error	0.0786	36	0.0002		

e. Low frequency centre frequency

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .021

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3.35220	1	3.35220	6937.32	0.00000
group	0.00076	2	0.00038	0.791	0.46246
gender	0.00001	1	0.00001	0.03	0.85581
time	0.00099	1	0.00099	2.05	0.16164
group*gender	0.00056	2	0.00028	0.58	0.56387
group*time	0.00057	2	0.00028	0.59	0.56080
gender*time	0.00221	1	0.00221	4.58	0.04043
group*gender*time	0.00053	2	0.00026	0.55	0.58288
Error	0.01449	30	0.00048		
TIME	0.00101	12	0.00008	2.28	0.00821
TIME*group	0.00112	24	0.00004	1.26	0.18527
TIME*gender	0.00097	12	0.00008	2.19	0.01139
TIME*time	0.00038	12	0.00003	0.86	0.58279
TIME*group*gender	0.00092	24	0.00003	1.03	0.42043
TIME*group*time	0.00134	24	0.00005	1.51	0.06038
TIME*gender*time	0.00070	12	0.00005	1.59	0.09129
TIME*group*gender*time	0.00091	24	0.00003	1.031	0.42466
Error	0.01334	36	0.00003		

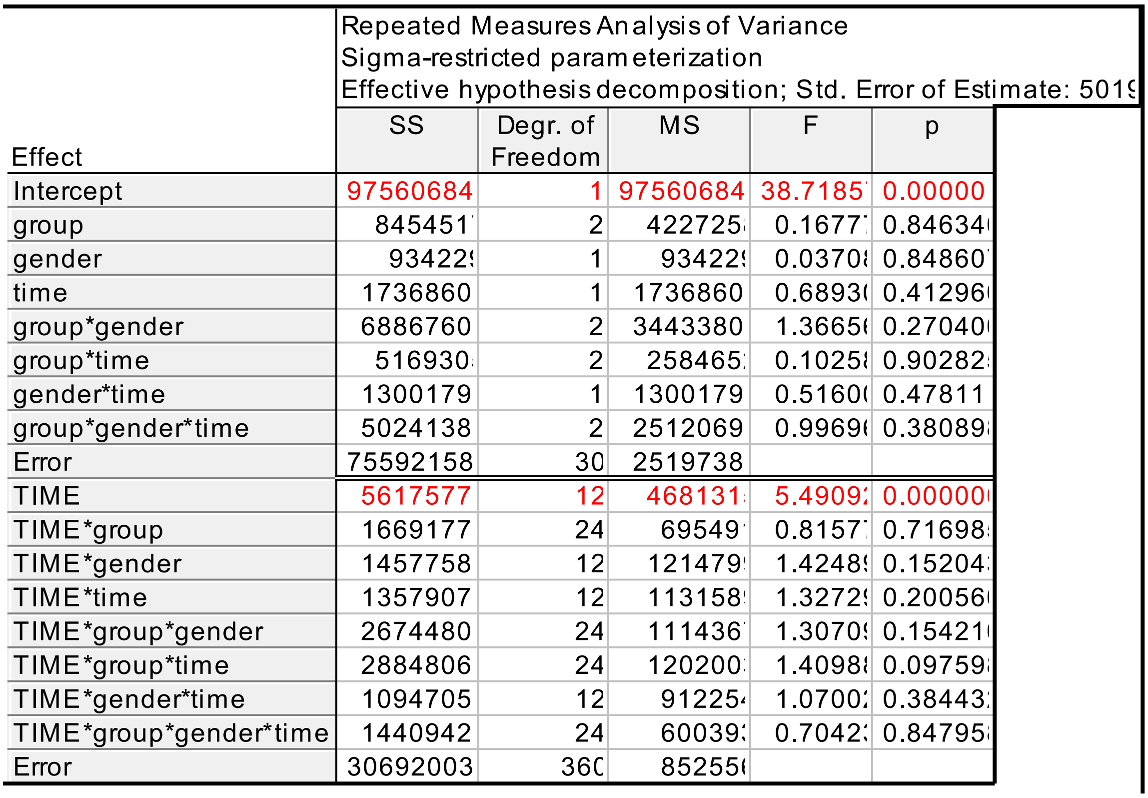
f. High frequency power



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 319

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	20745108	1	20745108	20.2760	0.00009
group	552760	2	276380	0.2701	0.7651
gender	176205	1	176205	0.1722	0.68109
time	193037	1	193037	0.1886	0.66713
group*gender	1010165	2	505082	0.4936	0.61525
group*time	1711377	2	855688	0.8363	0.44314
gender*time	2292	1	2292	0.0022	0.96256
group*gender*time	307255	2	153627	0.1501	0.86121
Error	30694018	30	1023133		
TIME	228543	12	19045	1.6492	0.07647
TIME*group	222731	24	9280	0.8036	0.73267
TIME*gender	154130	12	12844	1.1122	0.34855
TIME*time	60962	12	5080	0.4399	0.94668
TIME*group*gender	342574	24	14273	1.2360	0.20661
TIME*group*time	130715	24	5446	0.4716	0.98513
TIME*gender*time	44497	12	3708	0.3211	0.98540
TIME*group*gender*time	195983	24	8166	0.7071	0.84498
Error	4157176	360	11547		

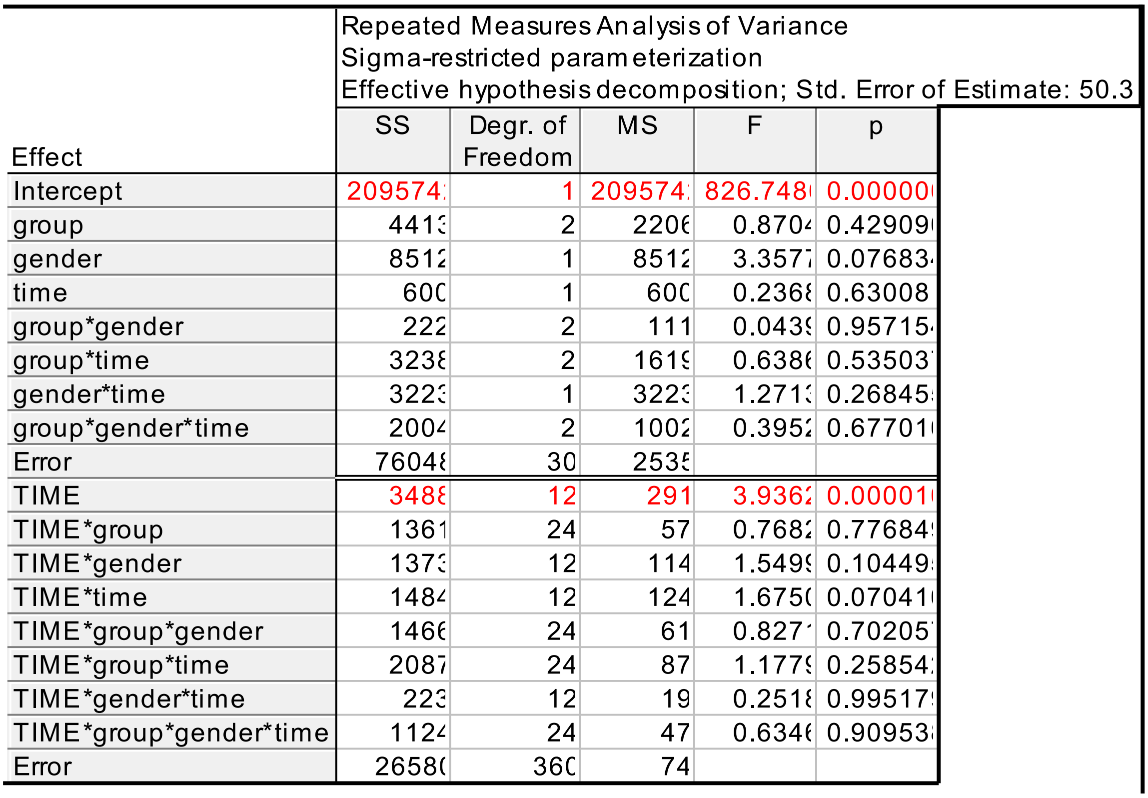
g. Low frequency power



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 501

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	97560684	1	97560684	38.7185	0.00000
group	845451	2	422725	0.1677	0.84634
gender	93422	1	93422	0.0370	0.84860
time	1736860	1	1736860	0.6893	0.41296
group*gender	6886760	2	3443380	1.3665	0.27040
group*time	516930	2	258465	0.1025	0.90282
gender*time	1300179	1	1300179	0.5160	0.47811
group*gender*time	5024138	2	2512069	0.9969	0.38089
Error	75592158	30	2519738		
TIME	5617577	12	468131	5.4909	0.00000
TIME*group	1669177	24	69549	0.8157	0.71698
TIME*gender	1457758	12	121479	1.4248	0.15204
TIME*time	1357907	12	113158	1.3272	0.20056
TIME*group*gender	2674480	24	111436	1.3070	0.15421
TIME*group*time	2884806	24	120200	1.4098	0.09759
TIME*gender*time	1094705	12	91225	1.0700	0.38443
TIME*group*gender*time	1440942	24	60039	0.7042	0.84795
Error	30692003	360	85255		

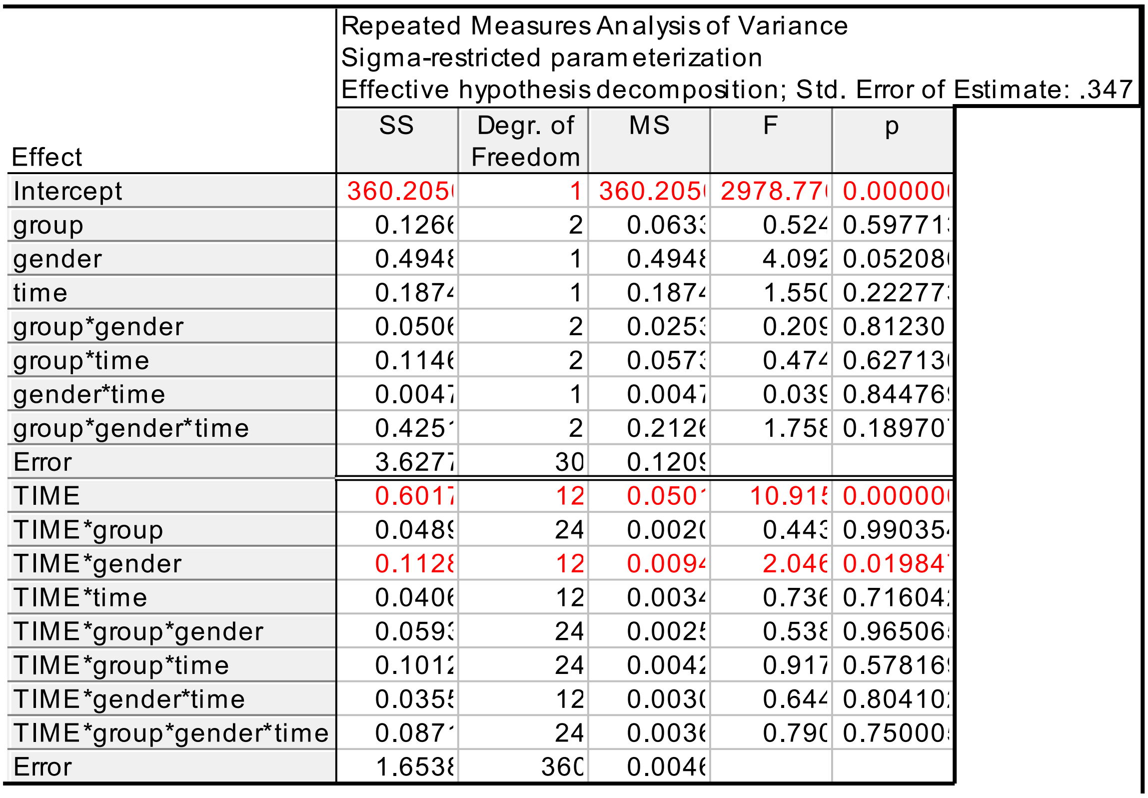
h. Low frequency component of (LF+HF) power



Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 50.3				
	SS	Degr. of Freedom	MS	F	p
Intercept	209574	1	209574	826.748	0.00000
group	441	2	220	0.870	0.42909
gender	851	1	851	3.357	0.07683
time	60	1	60	0.236	0.63008
group*gender	222	2	111	0.043	0.95715
group*time	323	2	161	0.638	0.53503
gender*time	322	1	322	1.271	0.26845
group*gender*time	200	2	100	0.395	0.67701
Error	7604	30	253		
TIME	348	12	291	3.936	0.00001
TIME*group	1361	24	57	0.768	0.77684
TIME*gender	137	12	114	1.549	0.10449
TIME*time	148	12	124	1.675	0.07041
TIME*group*gender	146	24	61	0.827	0.70205
TIME*group*time	208	24	87	1.177	0.25854
TIME*gender*time	22	12	19	0.251	0.99517
TIME*group*gender*time	112	24	47	0.634	0.90953
Error	2658	36	74		

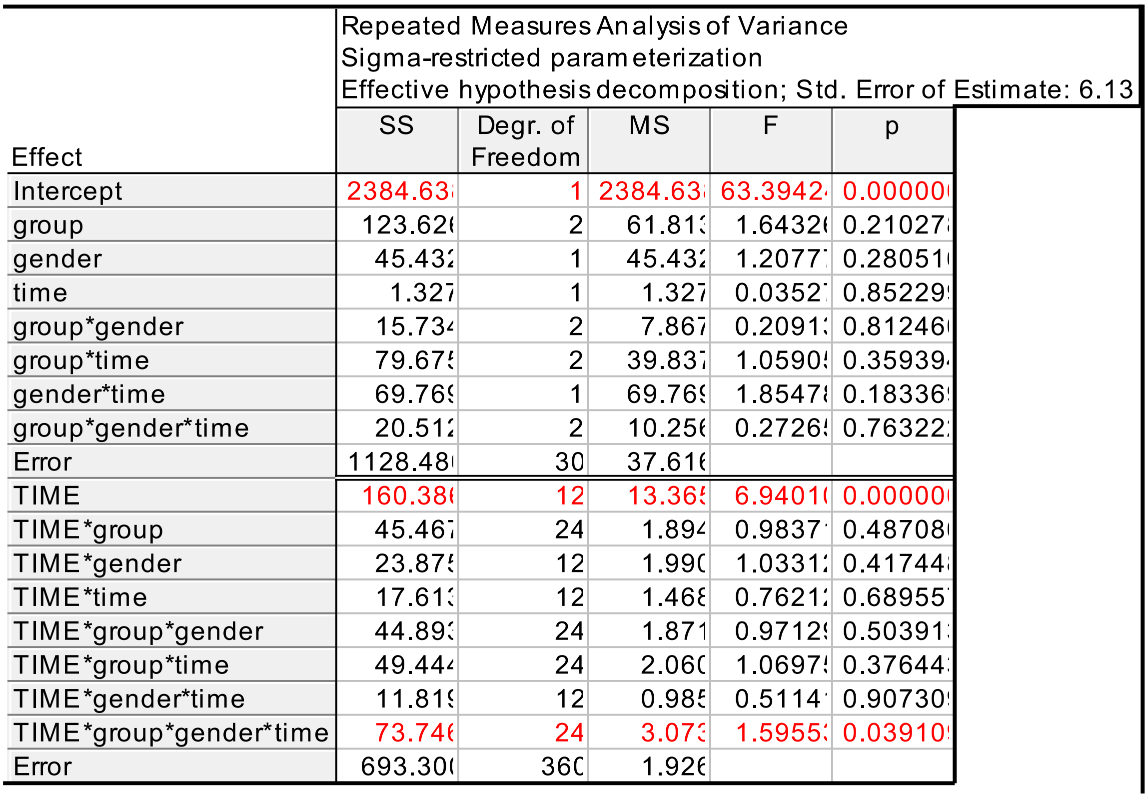
3. Oculomotor parameters

a. Pupil diameter



Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .347				
	SS	Degr. of Freedom	MS	F	p
Intercept	360.205	1	360.205	2978.77	0.00000
group	0.126	2	0.063	0.52	0.59771
gender	0.494	1	0.494	4.09	0.05208
time	0.187	1	0.187	1.55	0.22277
group*gender	0.050	2	0.025	0.20	0.81230
group*time	0.114	2	0.057	0.47	0.62713
gender*time	0.0047	1	0.0047	0.03	0.84476
group*gender*time	0.425	2	0.212	1.75	0.18970
Error	3.6277	30	0.120		
TIME	0.6017	12	0.050	10.91	0.00000
TIME*group	0.048	24	0.002	0.44	0.99035
TIME*gender	0.112	12	0.009	2.04	0.01984
TIME*time	0.040	12	0.003	0.73	0.71604
TIME*group*gender	0.059	24	0.002	0.53	0.96506
TIME*group*time	0.101	24	0.004	0.917	0.57816
TIME*gender*time	0.035	12	0.003	0.64	0.80410
TIME*group*gender*time	0.087	24	0.003	0.79	0.75000
Error	1.653	36	0.004		

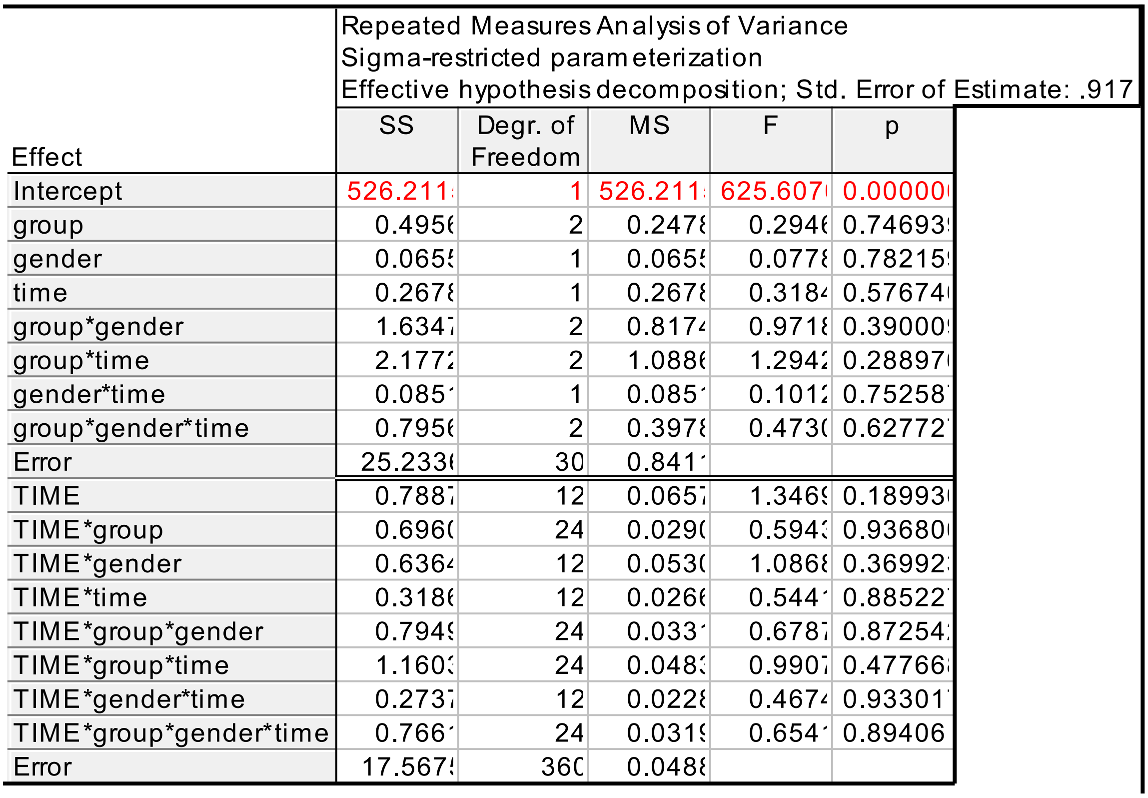
b. Blink frequency



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 6.13

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2384.63	1	2384.63	63.3942	0.00000
group	123.62	2	61.81	1.6432	0.21027
gender	45.43	1	45.43	1.2077	0.28051
time	1.327	1	1.327	0.0352	0.85229
group*gender	15.73	2	7.867	0.2091	0.81246
group*time	79.67	2	39.837	1.0590	0.35939
gender*time	69.76	1	69.76	1.8547	0.18336
group*gender*time	20.51	2	10.25	0.2726	0.76322
Error	1128.48	30	37.61		
TIME	160.38	12	13.36	6.9401	0.00000
TIME*group	45.467	24	1.89	0.9837	0.48708
TIME*gender	23.87	12	1.99	1.0331	0.41744
TIME*time	17.61	12	1.46	0.7621	0.68955
TIME*group*gender	44.89	24	1.871	0.9712	0.50391
TIME*group*time	49.44	24	2.06	1.0697	0.37644
TIME*gender*time	11.81	12	0.98	0.5114	0.90730
TIME*group*gender*time	73.74	24	3.07	1.5955	0.03910
Error	693.30	360	1.92		

c. Blink duration



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .917

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	526.211	1	526.211	625.607	0.00000
group	0.495	2	0.247	0.294	0.74693
gender	0.065	1	0.065	0.077	0.78215
time	0.267	1	0.267	0.318	0.57674
group*gender	1.6347	2	0.817	0.971	0.39000
group*time	2.177	2	1.088	1.294	0.28897
gender*time	0.085	1	0.085	0.101	0.75258
group*gender*time	0.795	2	0.397	0.473	0.62772
Error	25.233	30	0.841		
TIME	0.7887	12	0.0657	1.346	0.18993
TIME*group	0.696	24	0.029	0.594	0.93680
TIME*gender	0.636	12	0.053	1.086	0.36992
TIME*time	0.318	12	0.026	0.544	0.88522
TIME*group*gender	0.794	24	0.033	0.6787	0.87254
TIME*group*time	1.160	24	0.048	0.9907	0.47766
TIME*gender*time	0.2737	12	0.022	0.467	0.93301
TIME*group*gender*time	0.766	24	0.031	0.654	0.89406
Error	17.567	360	0.048		

d. Short fixation duration

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .124

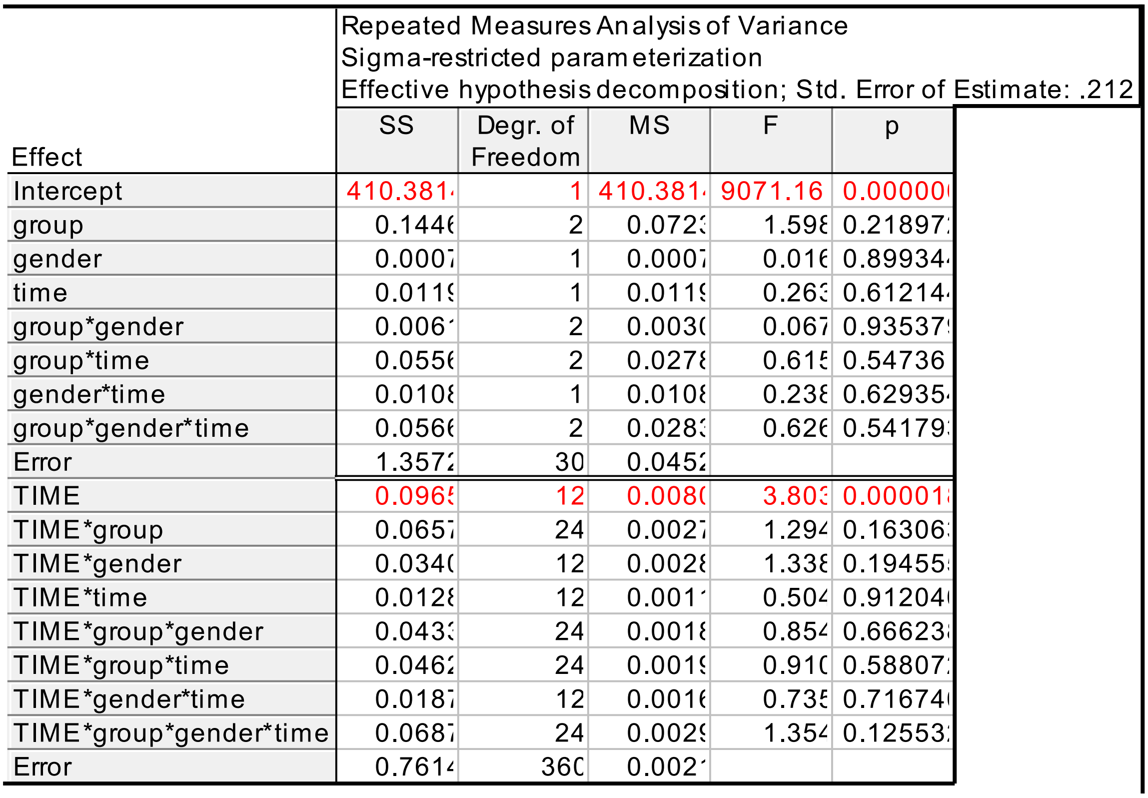
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	428.0110	1	428.0110	27667.35	0.000000
group	0.0988	2	0.0494	3.19	0.055328
gender	0.0933	1	0.0933	6.03	0.020085
time	0.0044	1	0.0044	0.29	0.596152
group*gender	0.0012	2	0.0006	0.04	0.962762
group*time	0.0057	2	0.0028	0.18	0.833837
gender*time	0.0788	1	0.0788	5.09	0.031449
group*gender*time	0.0044	2	0.0022	0.14	0.866827
Error	0.4641	30	0.0155		
TIME	0.0464	12	0.0039	3.33	0.000132
TIME*group	0.0326	24	0.0014	1.17	0.266419
TIME*gender	0.0510	12	0.0043	3.66	0.000033
TIME*time	0.0040	12	0.0003	0.29	0.991048
TIME*group*gender	0.0281	24	0.0012	1.01	0.453415
TIME*group*time	0.0265	24	0.0011	0.95	0.530930
TIME*gender*time	0.0143	12	0.0012	1.03	0.424633
TIME*group*gender*time	0.0342	24	0.0014	1.23	0.214998
Error	0.4184	360	0.0012		

e. Percentage of short fixations

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .970

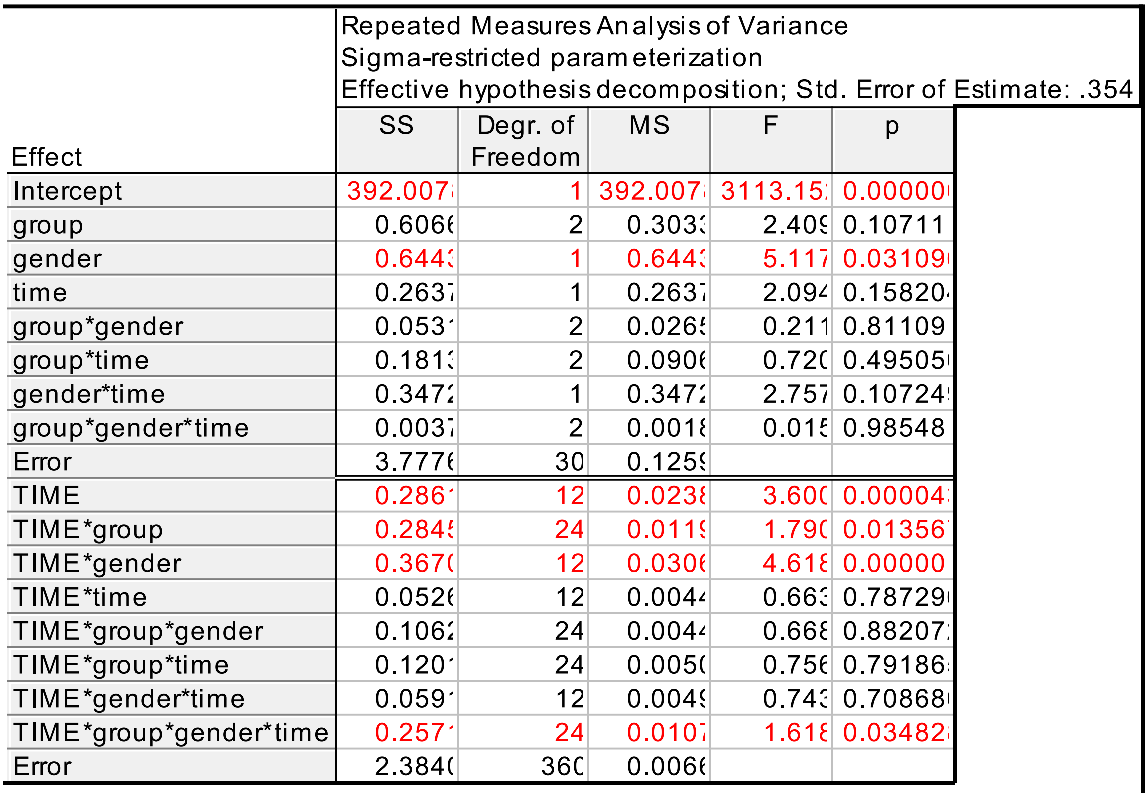
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	625.3945	1	625.3945	663.8860	0.000000
group	2.0799	2	1.0400	1.1040	0.344640
gender	4.2527	1	4.2527	4.5145	0.041962
time	0.6216	1	0.6216	0.6598	0.42302
group*gender	0.0851	2	0.0425	0.0452	0.955912
group*time	0.5116	2	0.2558	0.2715	0.764075
gender*time	0.8168	1	0.8168	0.8671	0.359193
group*gender*time	0.1888	2	0.0944	0.1002	0.904947
Error	28.2606	30	0.9420		
TIME	2.8303	12	0.2359	6.7556	0.000000
TIME*group	1.2070	24	0.0503	1.4405	0.084573
TIME*gender	2.2720	12	0.1893	5.4231	0.000000
TIME*time	0.1281	12	0.0107	0.3058	0.988237
TIME*group*gender	0.7501	24	0.0313	0.8952	0.609154
TIME*group*time	0.7991	24	0.0333	0.9537	0.528070
TIME*gender*time	0.5869	12	0.0489	1.4008	0.163038
TIME*group*gender*time	1.6591	24	0.0691	1.9800	0.004455
Error	12.5687	360	0.0349		

f. Medium fixation duration



Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .212				
	SS	Degr. of Freedom	MS	F	p
Intercept	410.381	1	410.381	9071.16	0.00000
group	0.144	2	0.072	1.59	0.21897
gender	0.000	1	0.000	0.01	0.89934
time	0.011	1	0.011	0.26	0.61214
group*gender	0.006	2	0.003	0.06	0.93537
group*time	0.055	2	0.027	0.61	0.54736
gender*time	0.010	1	0.010	0.23	0.62935
group*gender*time	0.056	2	0.028	0.62	0.54179
Error	1.357	30	0.045		
TIME	0.096	12	0.008	3.80	0.00001
TIME*group	0.065	24	0.002	1.29	0.16306
TIME*gender	0.034	12	0.002	1.33	0.19455
TIME*time	0.012	12	0.001	0.50	0.91204
TIME*group*gender	0.043	24	0.001	0.85	0.66623
TIME*group*time	0.046	24	0.001	0.91	0.58807
TIME*gender*time	0.018	12	0.001	0.73	0.71674
TIME*group*gender*time	0.068	24	0.002	1.35	0.12553
Error	0.761	360	0.002		

g. Percentage of medium fixations



Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .354				
	SS	Degr. of Freedom	MS	F	p
Intercept	392.007	1	392.007	3113.15	0.00000
group	0.606	2	0.303	2.40	0.10711
gender	0.644	1	0.644	5.117	0.03109
time	0.2637	1	0.2637	2.09	0.15820
group*gender	0.053	2	0.026	0.211	0.81109
group*time	0.181	2	0.090	0.72	0.49505
gender*time	0.347	1	0.347	2.757	0.10724
group*gender*time	0.0037	2	0.001	0.01	0.98548
Error	3.777	30	0.125		
TIME	0.286	12	0.023	3.60	0.00004
TIME*group	0.284	24	0.011	1.79	0.01356
TIME*gender	0.367	12	0.030	4.61	0.00000
TIME*time	0.052	12	0.004	0.66	0.78729
TIME*group*gender	0.106	24	0.004	0.66	0.88207
TIME*group*time	0.120	24	0.005	0.75	0.79186
TIME*gender*time	0.059	12	0.004	0.74	0.70868
TIME*group*gender*time	0.257	24	0.0107	1.61	0.03482
Error	2.384	360	0.006		

h. Long fixation duration

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .431				
	SS	Degr. of Freedom	MS	F	p
Intercept	409.0042	1	409.0042	2200.923	0.000000
group	1.5779	2	0.7890	4.246	0.02379
gender	1.3382	1	1.3382	7.201	0.011743
time	0.1075	1	0.1075	0.578	0.452899
group*gender	1.4768	2	0.7384	3.973	0.029457
group*time	0.1412	2	0.0706	0.380	0.687098
gender*time	0.0207	1	0.0207	0.112	0.74075
group*gender*time	0.0125	2	0.0063	0.034	0.966962
Error	5.5750	30	0.1858		
TIME	0.4240	12	0.0353	1.233	0.258460
TIME*group	0.7565	24	0.0315	1.100	0.341100
TIME*gender	0.3999	12	0.0333	1.163	0.308560
TIME*time	0.2128	12	0.0177	0.619	0.826444
TIME*group*gender	0.7071	24	0.0295	1.028	0.428710
TIME*group*time	0.4810	24	0.0200	0.699	0.852985
TIME*gender*time	0.3996	12	0.0333	1.162	0.309390
TIME*group*gender*time	0.7785	24	0.0324	1.132	0.305574
Error	10.3187	360	0.0287		

i. Percentage of long fixations

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 2.66				
	SS	Degr. of Freedom	MS	F	p
Intercept	437.7890	1	437.7890	61.63544	0.000000
group	0.5031	2	0.2516	0.03542	0.965242
gender	0.0247	1	0.0247	0.00348	0.953372
time	4.2103	1	4.2103	0.59276	0.447375
group*gender	2.0697	2	1.0348	0.14569	0.865032
group*time	7.2983	2	3.6492	0.51376	0.603412
gender*time	11.7363	1	11.7363	1.65232	0.208478
group*gender*time	16.1905	2	8.0952	1.13971	0.333374
Error	213.0860	30	7.1029		
TIME	3.8966	12	0.3247	0.54863	0.882014
TIME*group	8.8487	24	0.3687	0.62294	0.918040
TIME*gender	5.8666	12	0.4889	0.82601	0.623578
TIME*time	3.8697	12	0.3225	0.54485	0.884729
TIME*group*gender	10.2598	24	0.4275	0.72228	0.829179
TIME*group*time	9.8873	24	0.4120	0.69606	0.856092
TIME*gender*time	4.6599	12	0.3883	0.65610	0.793207
TIME*group*gender*time	7.3166	24	0.3049	0.51509	0.973353
Error	213.0707	360	0.5919		

j. Saccade amplitude

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 4.68

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1121.19	1	1121.19	51.0195	0.00000
group	119.85	2	59.92	2.7269	0.08163
gender	12.27	1	12.27	0.5585	0.46067
time	40.82	1	40.82	1.8578	0.18301
group*gender	23.07	2	11.53	0.5250	0.59689
group*time	36.76	2	18.38	0.8365	0.44305
gender*time	17.83	1	17.83	0.8117	0.37478
group*gender*time	38.13	2	19.06	0.8675	0.43025
Error	659.27	30	21.97		
TIME	47.38	12	3.94	2.6621	0.00195
TIME*group	59.88	24	2.49	1.6823	0.02465
TIME*gender	9.89	12	0.82	0.5558	0.87675
TIME*time	15.41	12	1.28	0.8660	0.58207
TIME*group*gender	35.69	24	1.48	1.0027	0.46161
TIME*group*time	33.04	24	1.37	0.9283	0.56306
TIME*gender*time	28.30	12	2.35	1.5902	0.09219
TIME*group*gender*time	35.71	24	1.48	1.0032	0.46100
Error	533.96	360	1.48		

k. Saccade speed

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.53

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	691.438	1	691.438	107.648	0.00000
group	34.504	2	17.252	2.686	0.08451
gender	6.508	1	6.508	1.013	0.32216
time	15.682	1	15.682	2.441	0.12864
group*gender	10.620	2	5.310	0.826	0.44719
group*time	7.617	2	3.808	0.593	0.55903
gender*time	8.685	1	8.685	1.352	0.25404
group*gender*time	10.101	2	5.050	0.786	0.46466
Error	192.694	30	6.423		
TIME	10.679	12	0.889	2.386	0.00566
TIME*group	18.969	24	0.790	2.119	0.00189
TIME*gender	2.716	12	0.226	0.607	0.83639
TIME*time	4.378	12	0.364	0.978	0.46906
TIME*group*gender	11.042	24	0.460	1.233	0.20851
TIME*group*time	9.259	24	0.385	1.034	0.42033
TIME*gender*time	8.888	12	0.740	1.986	0.02454
TIME*group*gender*time	11.332	24	0.472	1.266	0.18298
Error	134.256	360	0.372		

I. Saccade duration

	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .367				
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	532.384	1	532.384	3950.47	0.00000
group	1.0101	2	0.505	3.748	0.03525
gender	0.4782	1	0.4782	3.549	0.06931
time	0.100	1	0.100	0.742	0.39577
group*gender	0.0875	2	0.0437	0.325	0.72538
group*time	0.2078	2	0.1039	0.771	0.47148
gender*time	0.0172	1	0.0172	0.127	0.72359
group*gender*time	0.1649	2	0.0825	0.612	0.54893
Error	4.0429	30	0.1348		
TIME	1.2153	12	0.1013	7.817	0.00000
TIME*group	0.2799	24	0.0117	0.900	0.60215
TIME*gender	0.3683	12	0.0307	2.369	0.00604
TIME*time	0.1014	12	0.0084	0.652	0.79695
TIME*group*gender	0.2838	24	0.0118	0.913	0.58475
TIME*group*time	0.1898	24	0.0079	0.610	0.92671
TIME*gender*time	0.1228	12	0.0102	0.790	0.66089
TIME*group*gender*time	0.266	24	0.0111	0.856	0.66366
Error	4.6639	36	0.013		

4. Subjective parameters

a. Borg CR-10

	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 2.94				
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3515.61	1	3515.61	404.556	0.00000
group	7.924	2	3.962	0.4559	0.63791
gender	1.593	1	1.593	0.1833	0.67142
time	0.350	1	0.350	0.0402	0.84231
group*gender	11.085	2	5.543	0.6378	0.53503
group*time	26.713	2	13.356	1.537	0.23048
gender*time	5.894	1	5.894	0.6782	0.41629
group*gender*time	5.391	2	2.696	0.3102	0.73547
Error	278.08	32	8.69		
RPE	218.782	3	72.927	112.177	0.00000
RPE*group	4.432	6	0.739	1.1362	0.34736
RPE*gender	1.411	3	0.47	0.7237	0.54026
RPE*time	0.958	3	0.319	0.491	0.68926
RPE*group*gender	4.485	6	0.748	1.1499	0.33975
RPE*group*time	2.437	6	0.406	0.6248	0.71000
RPE*gender*time	0.265	3	0.088	0.136	0.93834
RPE*group*gender*time	3.243	6	0.54	0.8313	0.54859
Error	62.41	96	0.65		

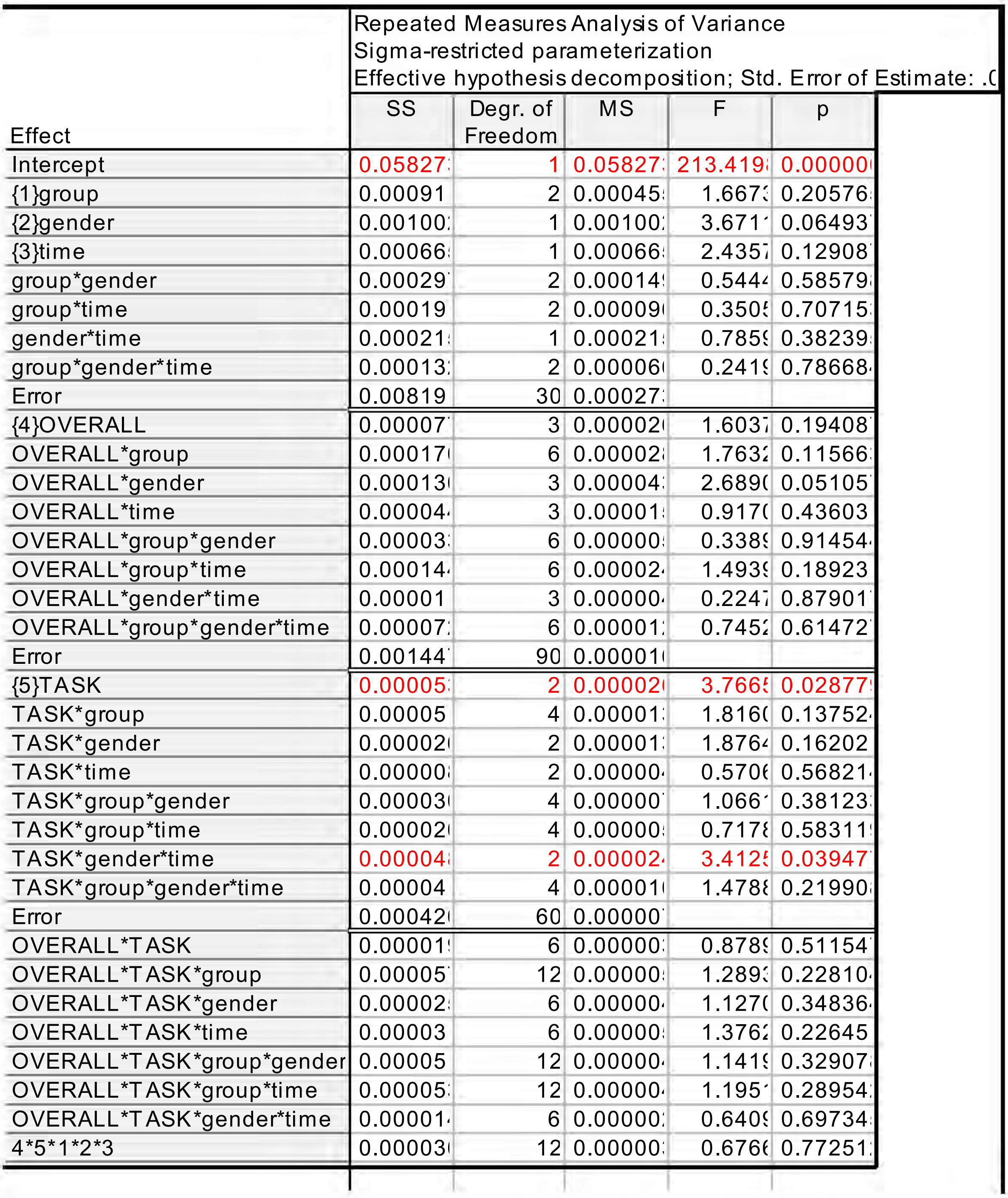
APPENDIX C2

Secondary Task Effects

Secondary task effects were analysed with a repeated-measures ANOVA, where “TASK” refers to the general change in intervals before, during and after the secondary task and “OVERALLxTASK” refers to the change in reaction of the variables over the four instances that the secondary task was performed. The covariates analysed include “group” (the experimental group), “gender” (the gender of the subject) and “time” (the time of day that testing took place. Significant effects are highlighted in red.

1. Performance parameters

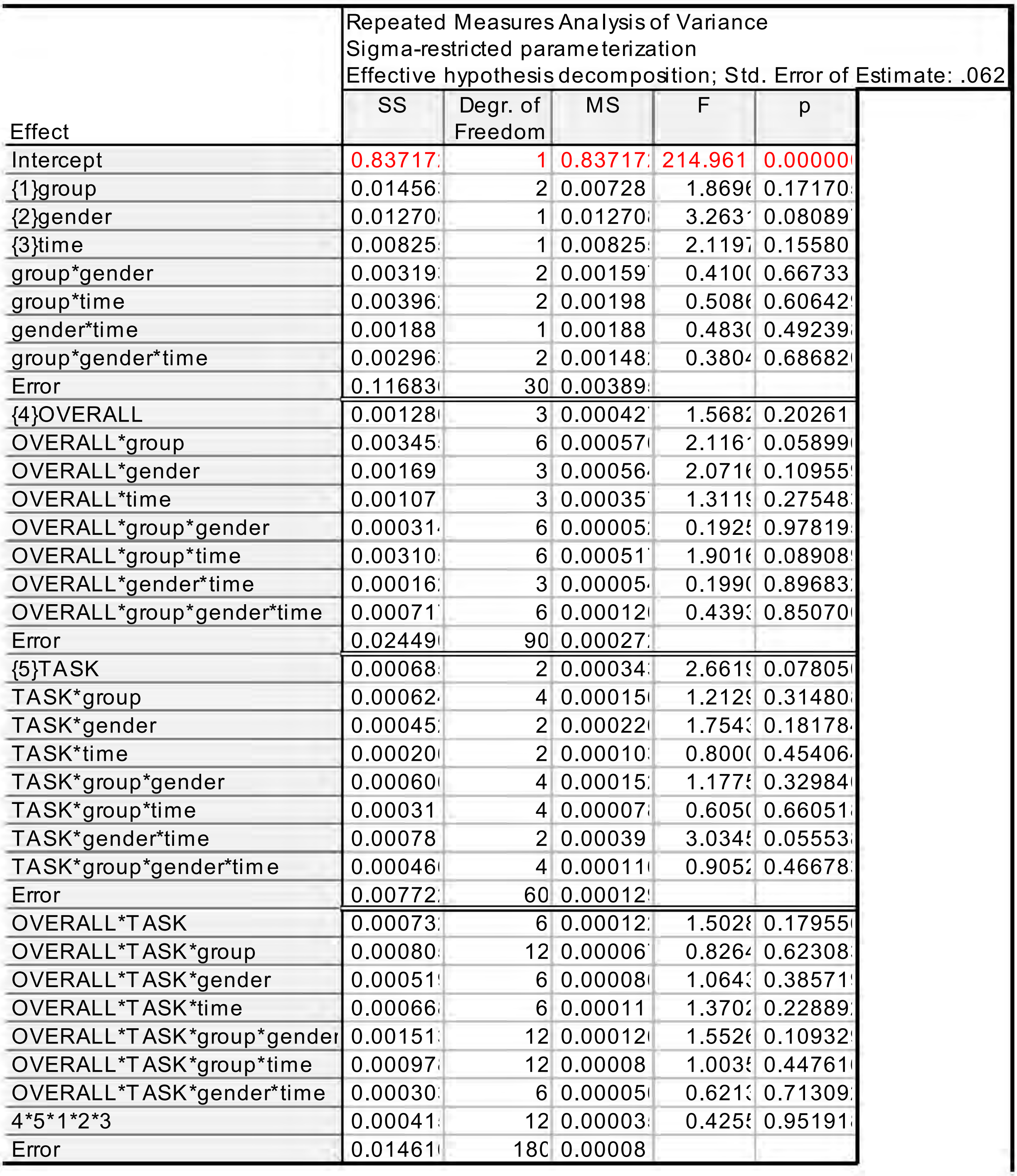
a. Mean deviation



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.05827	1	0.05827	213.419	0.00000
{1}group	0.00091	2	0.00045	1.667	0.20576
{2}gender	0.00100	1	0.00100	3.671	0.06493
{3}time	0.00066	1	0.00066	2.435	0.12908
group*gender	0.00029	2	0.00014	0.544	0.58579
group*time	0.00019	2	0.00009	0.350	0.70715
gender*time	0.00021	1	0.00021	0.785	0.38239
group*gender*time	0.00013	2	0.00006	0.241	0.78668
Error	0.00819	30	0.00027		
{4}OVERALL	0.00007	3	0.00002	1.603	0.19408
OVERALL*group	0.00017	6	0.00002	1.763	0.11566
OVERALL*gender	0.00013	3	0.00004	2.689	0.05105
OVERALL*time	0.00004	3	0.00001	0.917	0.43603
OVERALL*group*gender	0.00003	6	0.00000	0.338	0.91454
OVERALL*group*time	0.00014	6	0.00002	1.493	0.18923
OVERALL*gender*time	0.00001	3	0.00000	0.224	0.87901
OVERALL*group*gender*time	0.00007	6	0.00001	0.745	0.61472
Error	0.00144	90	0.00001		
{5}TASK	0.00005	2	0.00002	3.766	0.02877
TASK*group	0.00005	4	0.00001	1.816	0.13752
TASK*gender	0.00002	2	0.00001	1.876	0.16202
TASK*time	0.00000	2	0.00000	0.570	0.56821
TASK*group*gender	0.00003	4	0.00000	1.066	0.38123
TASK*group*time	0.00002	4	0.00000	0.717	0.58311
TASK*gender*time	0.00004	2	0.00002	3.412	0.03947
TASK*group*gender*time	0.00004	4	0.00001	1.478	0.21990
Error	0.00042	60	0.00000		
OVERALL*TASK	0.00001	6	0.00000	0.878	0.51154
OVERALL*TASK*group	0.00005	12	0.00000	1.289	0.22810
OVERALL*TASK*gender	0.00002	6	0.00000	1.127	0.34836
OVERALL*TASK*time	0.00003	6	0.00000	1.376	0.22645
OVERALL*TASK*group*gender	0.00005	12	0.00000	1.141	0.32907
OVERALL*TASK*group*time	0.00005	12	0.00000	1.195	0.28954
OVERALL*TASK*gender*time	0.00001	6	0.00000	0.640	0.69734
4*5*1*2*3	0.00003	12	0.00000	0.676	0.77251

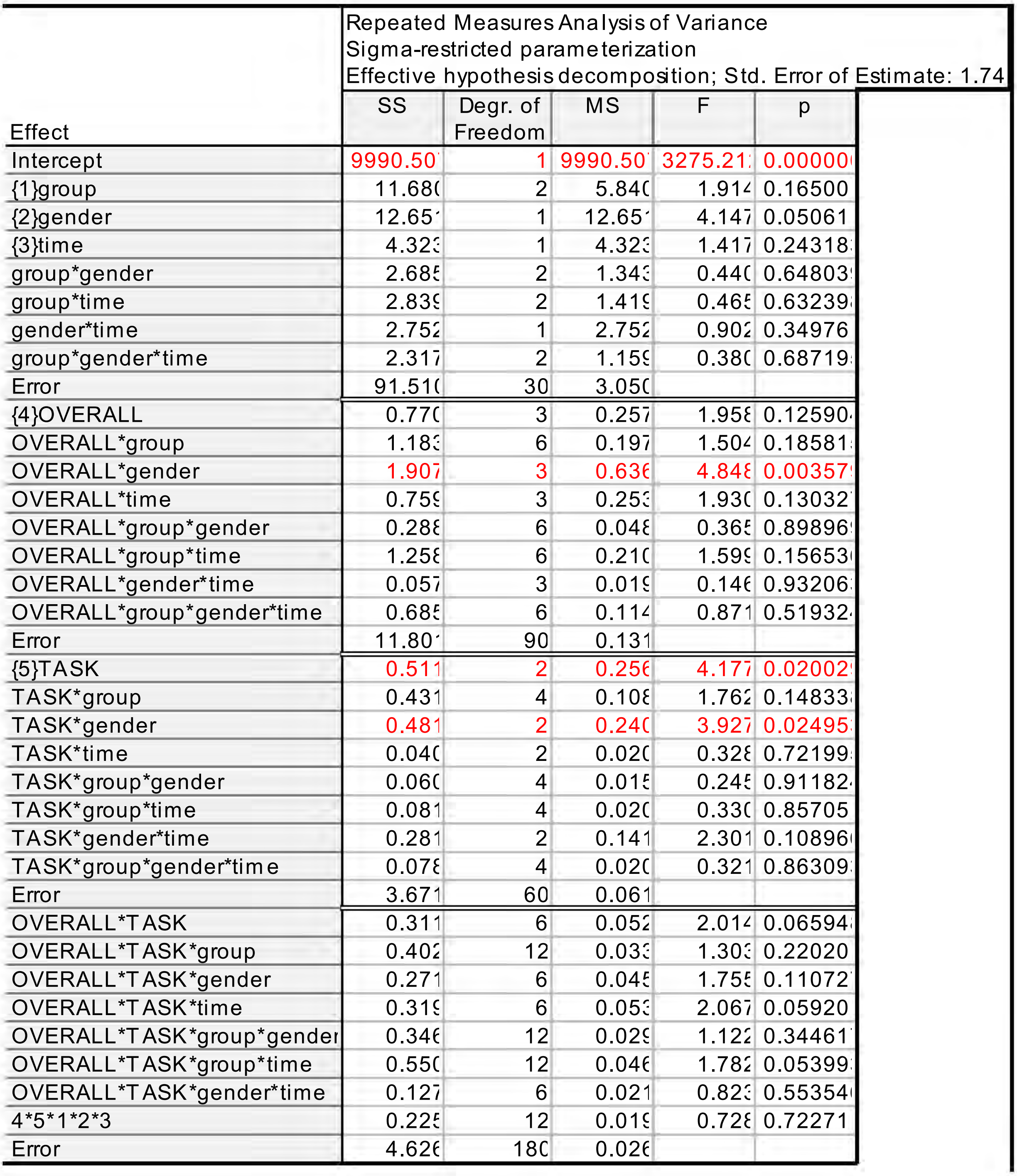
b. Effective reaction time



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .062

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.83717	1	0.83717	214.961	0.00000
{1}group	0.01456	2	0.00728	1.869	0.17170
{2}gender	0.01270	1	0.01270	3.263	0.08089
{3}time	0.00825	1	0.00825	2.119	0.15580
group*gender	0.00319	2	0.00159	0.410	0.66733
group*time	0.00396	2	0.00198	0.508	0.60642
gender*time	0.00188	1	0.00188	0.483	0.49239
group*gender*time	0.00296	2	0.00148	0.380	0.68682
Error	0.11683	30	0.00389		
{4}OVERALL	0.00128	3	0.00042	1.568	0.20261
OVERALL*group	0.00345	6	0.00057	2.116	0.05899
OVERALL*gender	0.00169	3	0.00056	2.071	0.10955
OVERALL*time	0.00107	3	0.00035	1.311	0.27548
OVERALL*group*gender	0.00031	6	0.00005	0.192	0.97819
OVERALL*group*time	0.00310	6	0.00051	1.901	0.08908
OVERALL*gender*time	0.00016	3	0.00005	0.199	0.89683
OVERALL*group*gender*time	0.00071	6	0.00012	0.439	0.85070
Error	0.02449	90	0.00027		
{5}TASK	0.00068	2	0.00034	2.661	0.07805
TASK*group	0.00062	4	0.00015	1.212	0.31480
TASK*gender	0.00045	2	0.00022	1.754	0.18178
TASK*time	0.00020	2	0.00010	0.800	0.45406
TASK*group*gender	0.00060	4	0.00015	1.177	0.32984
TASK*group*time	0.00031	4	0.00007	0.605	0.66051
TASK*gender*time	0.00078	2	0.00039	3.034	0.05553
TASK*group*gender*time	0.00046	4	0.00011	0.905	0.46678
Error	0.00772	60	0.00012		
OVERALL*TASK	0.00073	6	0.00012	1.502	0.17955
OVERALL*TASK*group	0.00080	12	0.00006	0.826	0.62308
OVERALL*TASK*gender	0.00051	6	0.00008	1.064	0.38571
OVERALL*TASK*time	0.00066	6	0.00011	1.370	0.22889
OVERALL*TASK*group*gender	0.00151	12	0.00012	1.552	0.10932
OVERALL*TASK*group*time	0.00097	12	0.00008	1.003	0.44761
OVERALL*TASK*gender*time	0.00030	6	0.00005	0.621	0.71309
4*5*1*2*3	0.00041	12	0.00003	0.425	0.95191
Error	0.01461	180	0.00008		

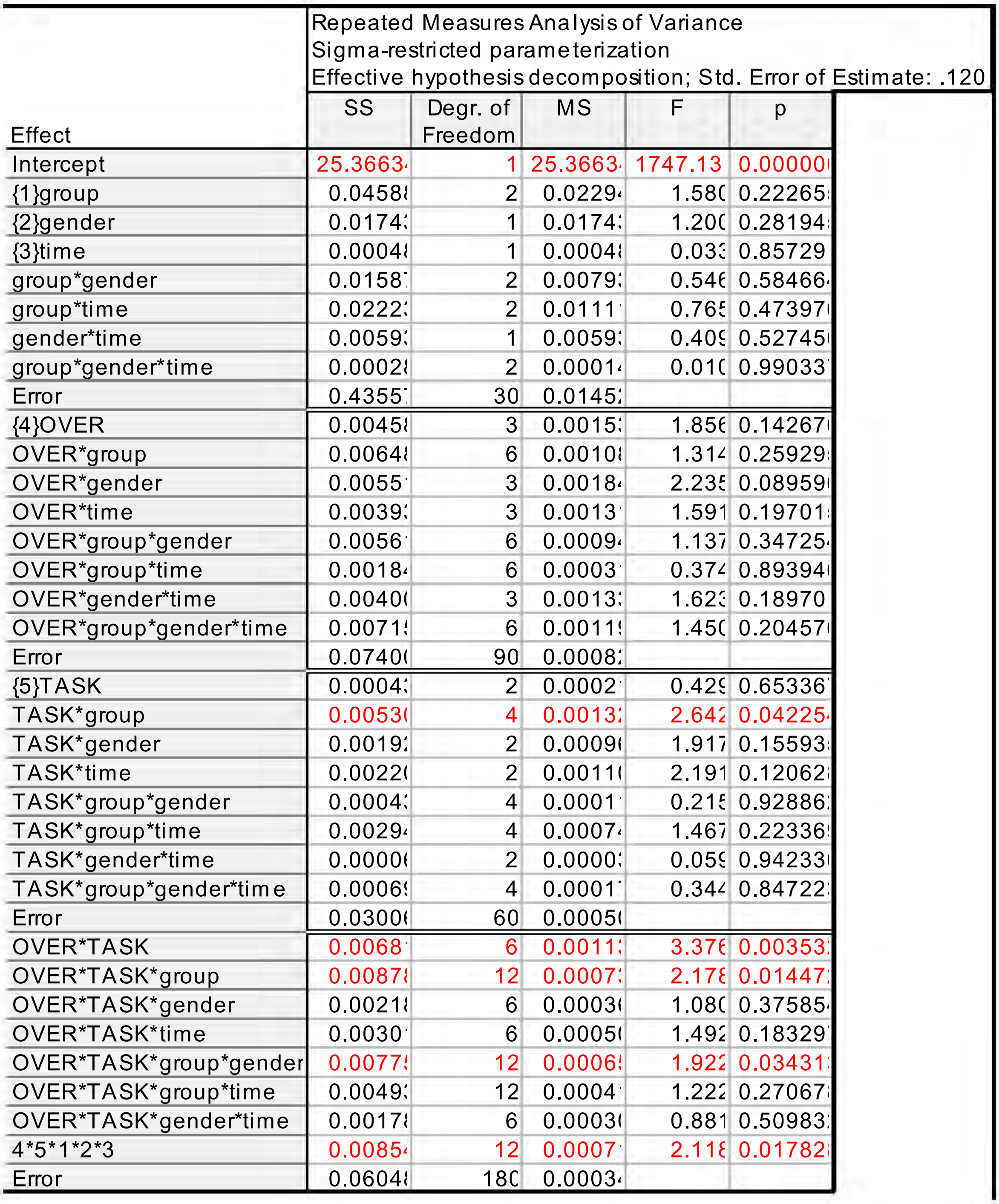
c. Information processing capacity



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 1.74

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	9990.50	1	9990.50	3275.21	0.000000
{1}group	11.680	2	5.840	1.914	0.16500
{2}gender	12.65	1	12.65	4.147	0.05061
{3}time	4.323	1	4.323	1.417	0.24318
group*gender	2.685	2	1.343	0.440	0.64803
group*time	2.839	2	1.419	0.465	0.63239
gender*time	2.752	1	2.752	0.902	0.34976
group*gender*time	2.317	2	1.159	0.380	0.68719
Error	91.510	30	3.050		
{4}OVERALL	0.770	3	0.257	1.958	0.12590
OVERALL*group	1.183	6	0.197	1.504	0.18581
OVERALL*gender	1.907	3	0.636	4.848	0.00357
OVERALL*time	0.759	3	0.253	1.930	0.130327
OVERALL*group*gender	0.288	6	0.048	0.365	0.89896
OVERALL*group*time	1.258	6	0.210	1.599	0.156530
OVERALL*gender*time	0.057	3	0.019	0.146	0.93206
OVERALL*group*gender*time	0.685	6	0.114	0.871	0.51932
Error	11.80	90	0.131		
{5}TASK	0.511	2	0.256	4.177	0.02002
TASK*group	0.431	4	0.108	1.762	0.14833
TASK*gender	0.481	2	0.240	3.927	0.02495
TASK*time	0.040	2	0.020	0.328	0.72199
TASK*group*gender	0.060	4	0.015	0.245	0.91182
TASK*group*time	0.081	4	0.020	0.330	0.85705
TASK*gender*time	0.281	2	0.141	2.301	0.108960
TASK*group*gender*time	0.078	4	0.020	0.321	0.86309
Error	3.671	60	0.061		
OVERALL*TASK	0.311	6	0.052	2.014	0.06594
OVERALL*TASK*group	0.402	12	0.033	1.303	0.22020
OVERALL*TASK*gender	0.271	6	0.045	1.755	0.110727
OVERALL*TASK*time	0.319	6	0.053	2.067	0.05920
OVERALL*TASK*group*gender	0.346	12	0.029	1.122	0.344617
OVERALL*TASK*group*time	0.550	12	0.046	1.782	0.05399
OVERALL*TASK*gender*time	0.127	6	0.021	0.823	0.553540
4*5*1*2*3	0.225	12	0.019	0.728	0.72271
Error	4.626	180	0.026		

d. Steering alteration frequency

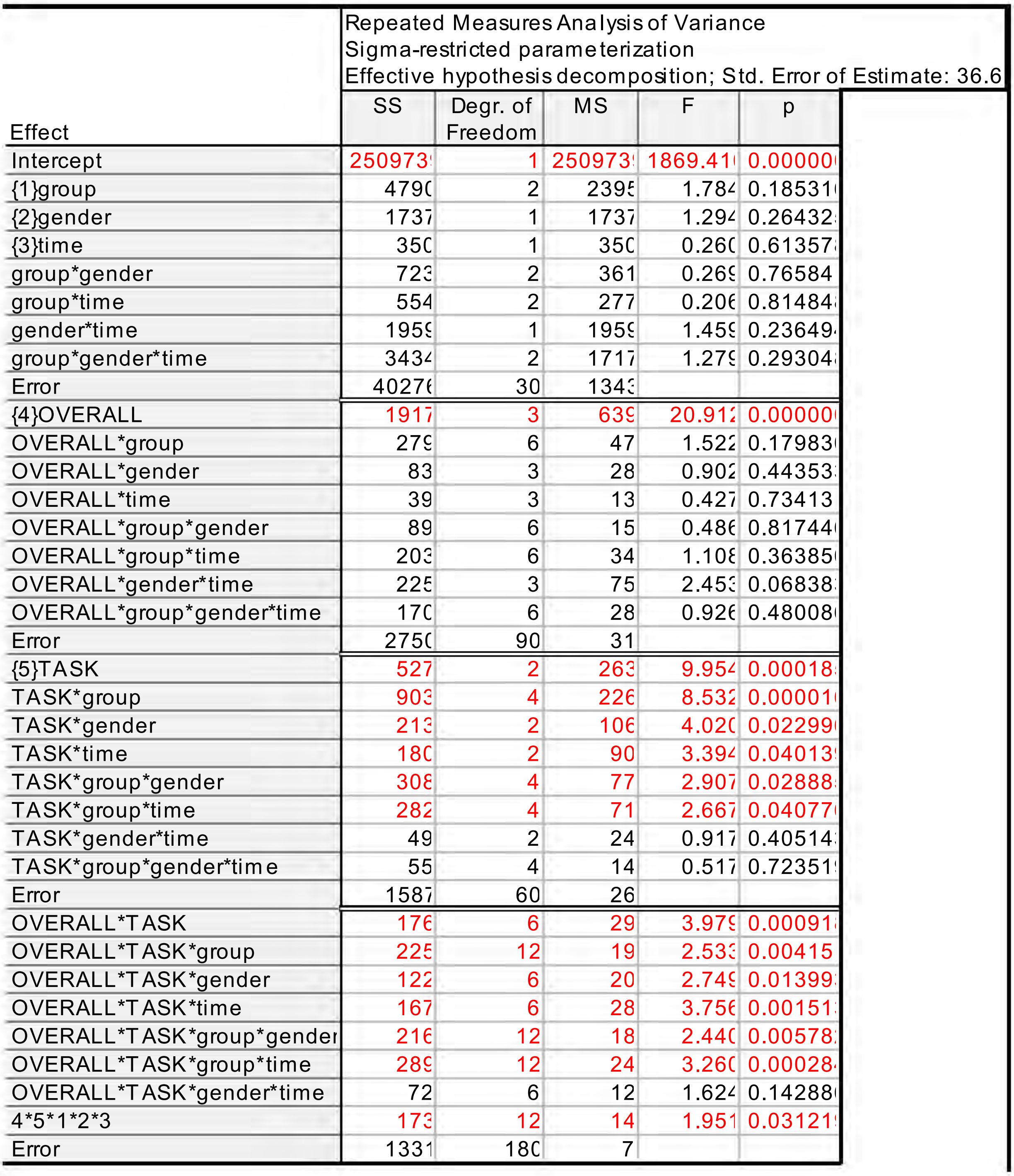


Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .120

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	25.3663	1	25.3663	1747.13	0.00000
{1}group	0.0458	2	0.0229	1.58	0.22265
{2}gender	0.0174	1	0.0174	1.20	0.28194
{3}time	0.0004	1	0.0004	0.03	0.85729
group*gender	0.0158	2	0.0079	0.54	0.58466
group*time	0.0222	2	0.0111	0.76	0.47397
gender*time	0.0059	1	0.0059	0.40	0.52745
group*gender*time	0.0002	2	0.0001	0.01	0.99033
Error	0.4355	30	0.0145		
{4}OVER	0.0045	3	0.0015	1.85	0.14267
OVER*group	0.0064	6	0.0010	1.31	0.25929
OVER*gender	0.0055	3	0.0018	2.23	0.08959
OVER*time	0.0039	3	0.0013	1.591	0.19701
OVER*group*gender	0.0056	6	0.0009	1.137	0.34725
OVER*group*time	0.0018	6	0.0003	0.37	0.89394
OVER*gender*time	0.0040	3	0.0013	1.62	0.18970
OVER*group*gender*time	0.0071	6	0.0011	1.45	0.20457
Error	0.0740	90	0.0008		
{5}TASK	0.0004	2	0.0002	0.42	0.65336
TASK*group	0.0053	4	0.0013	2.64	0.04225
TASK*gender	0.0019	2	0.0009	1.917	0.15593
TASK*time	0.0022	2	0.0011	2.191	0.12062
TASK*group*gender	0.0004	4	0.0001	0.21	0.92886
TASK*group*time	0.0029	4	0.0007	1.467	0.22336
TASK*gender*time	0.0000	2	0.0000	0.05	0.94233
TASK*group*gender*time	0.0006	4	0.0001	0.34	0.84722
Error	0.0300	60	0.0005		
OVER*TASK	0.0068	6	0.0011	3.37	0.00353
OVER*TASK*group	0.0087	12	0.0007	2.17	0.01447
OVER*TASK*gender	0.0021	6	0.0003	1.08	0.37585
OVER*TASK*time	0.0030	6	0.0005	1.49	0.18329
OVER*TASK*group*gender	0.0077	12	0.0006	1.92	0.03431
OVER*TASK*group*time	0.0049	12	0.0004	1.22	0.27067
OVER*TASK*gender*time	0.0017	6	0.0003	0.881	0.50983
4*5*1*2*3	0.0085	12	0.0007	2.11	0.01782
Error	0.0604	18	0.0003		

2. Cardiovascular parameters

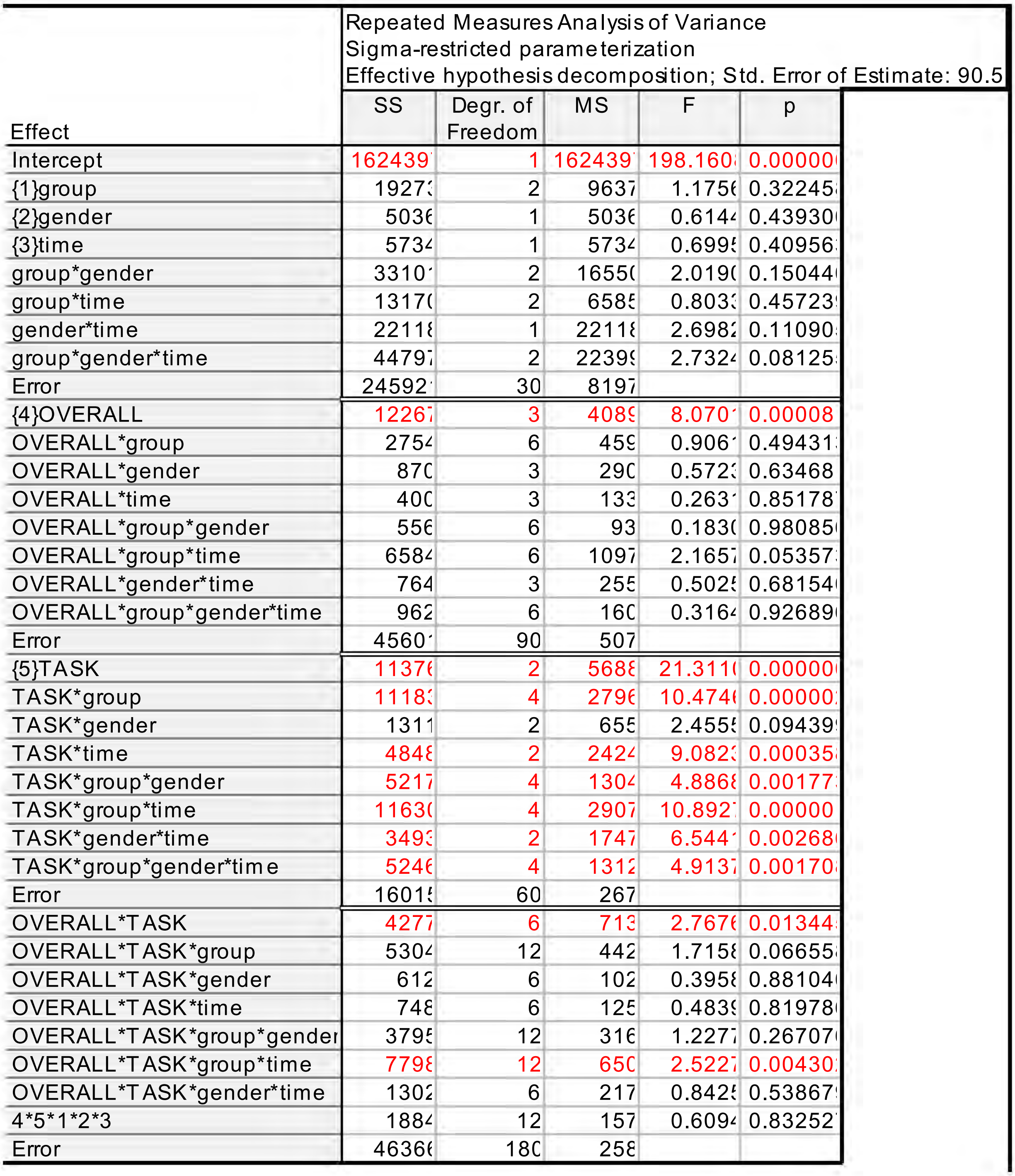
a. Heart rate



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 36.6

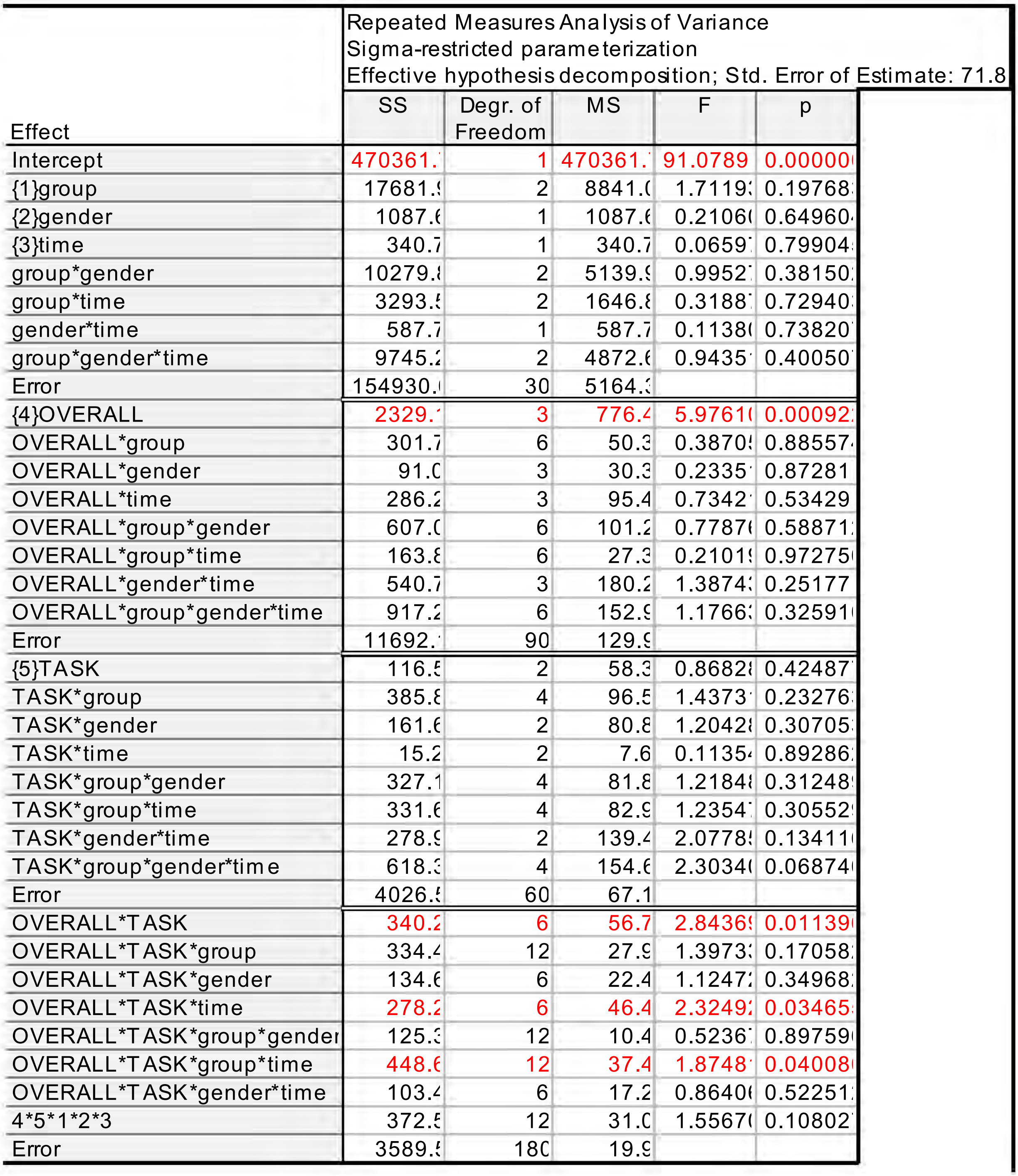
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	250973	1	250973	1869.41	0.00000
{1}group	4790	2	2395	1.784	0.18531
{2}gender	1737	1	1737	1.294	0.26432
{3}time	350	1	350	0.260	0.61357
group*gender	723	2	361	0.269	0.76584
group*time	554	2	277	0.206	0.81484
gender*time	1959	1	1959	1.459	0.23649
group*gender*time	3434	2	1717	1.279	0.29304
Error	40276	30	1343		
{4}OVERALL	1917	3	639	20.912	0.00000
OVERALL*group	279	6	47	1.522	0.17983
OVERALL*gender	83	3	28	0.902	0.44353
OVERALL*time	39	3	13	0.427	0.73413
OVERALL*group*gender	89	6	15	0.486	0.81744
OVERALL*group*time	203	6	34	1.108	0.36385
OVERALL*gender*time	225	3	75	2.453	0.06838
OVERALL*group*gender*time	170	6	28	0.926	0.48008
Error	2750	90	31		
{5}TASK	527	2	263	9.954	0.00018
TASK*group	903	4	226	8.532	0.00001
TASK*gender	213	2	106	4.020	0.02299
TASK*time	180	2	90	3.394	0.04013
TASK*group*gender	308	4	77	2.907	0.02888
TASK*group*time	282	4	71	2.667	0.04077
TASK*gender*time	49	2	24	0.917	0.40514
TASK*group*gender*time	55	4	14	0.517	0.72351
Error	1587	60	26		
OVERALL*TASK	176	6	29	3.979	0.00091
OVERALL*TASK*group	225	12	19	2.533	0.00415
OVERALL*TASK*gender	122	6	20	2.749	0.01399
OVERALL*TASK*time	167	6	28	3.756	0.00151
OVERALL*TASK*group*gender	216	12	18	2.440	0.00578
OVERALL*TASK*group*time	289	12	24	3.260	0.00028
OVERALL*TASK*gender*time	72	6	12	1.624	0.14288
4*5*1*2*3	173	12	14	1.951	0.03121
Error	1331	180	7		

b. RMSSD



Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 90.5 SS	Degr. of Freedom	MS	F	p
Intercept	162439	1	162439	198.160	0.00000
{1}group	19273	2	9637	1.1756	0.32245
{2}gender	5036	1	5036	0.6144	0.43930
{3}time	5734	1	5734	0.6995	0.40956
group*gender	33101	2	16550	2.0190	0.15044
group*time	13170	2	6585	0.8033	0.45723
gender*time	22118	1	22118	2.6982	0.11090
group*gender*time	44797	2	22399	2.7324	0.08125
Error	245921	30	8197		
{4}OVERALL	12267	3	4089	8.0701	0.00008
OVERALL*group	2754	6	459	0.9061	0.49431
OVERALL*gender	870	3	290	0.5723	0.63468
OVERALL*time	400	3	133	0.2631	0.85178
OVERALL*group*gender	556	6	93	0.1830	0.98085
OVERALL*group*time	6584	6	1097	2.1657	0.05357
OVERALL*gender*time	764	3	255	0.5025	0.68154
OVERALL*group*gender*time	962	6	160	0.3164	0.92689
Error	45601	90	507		
{5}TASK	11376	2	5688	21.3110	0.00000
TASK*group	11183	4	2796	10.4746	0.00000
TASK*gender	1311	2	655	2.4555	0.09439
TASK*time	4848	2	2424	9.0823	0.00035
TASK*group*gender	5217	4	1304	4.8868	0.00177
TASK*group*time	11630	4	2907	10.8927	0.00000
TASK*gender*time	3493	2	1747	6.5441	0.00268
TASK*group*gender*time	5246	4	1312	4.9137	0.00170
Error	16015	60	267		
OVERALL*TASK	4277	6	713	2.7676	0.01344
OVERALL*TASK*group	5304	12	442	1.7158	0.06655
OVERALL*TASK*gender	612	6	102	0.3958	0.88104
OVERALL*TASK*time	748	6	125	0.4839	0.81978
OVERALL*TASK*group*gender	3795	12	316	1.2277	0.26707
OVERALL*TASK*group*time	7798	12	650	2.5227	0.00430
OVERALL*TASK*gender*time	1302	6	217	0.8425	0.53867
4*5*1*2*3	1884	12	157	0.6094	0.83252
Error	46366	180	258		

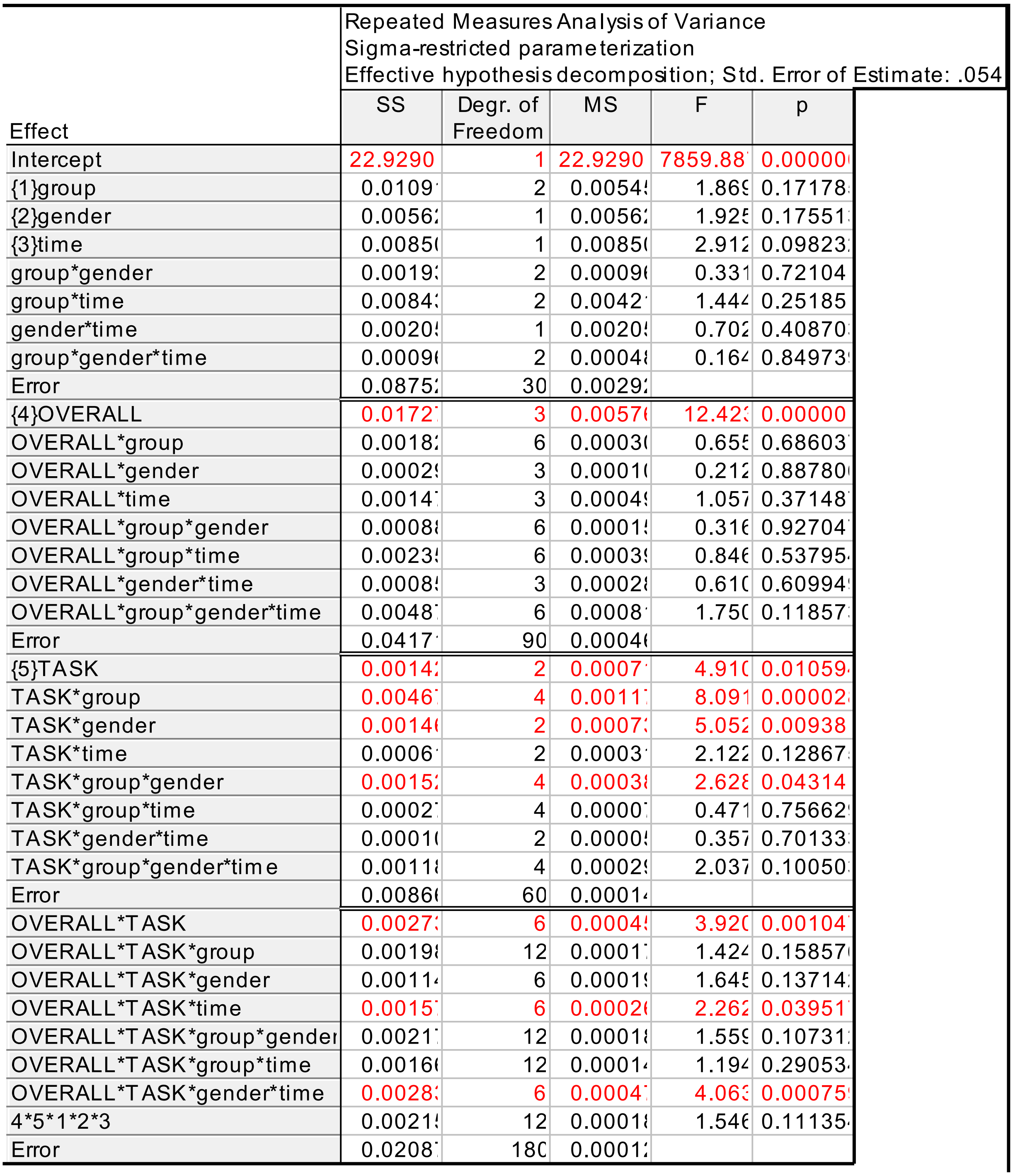
c. PNN30



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 71.8

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	470361.	1	470361.	91.0789	0.00000
{1}group	17681.	2	8841.0	1.7119	0.19768
{2}gender	1087.	1	1087.	0.2106	0.64960
{3}time	340.7	1	340.7	0.0659	0.79904
group*gender	10279.	2	5139.	0.9952	0.38150
group*time	3293.5	2	1646.	0.3188	0.72940
gender*time	587.7	1	587.7	0.1138	0.73820
group*gender*time	9745.2	2	4872.	0.9435	0.40050
Error	154930.	30	5164.		
{4}OVERALL	2329.1	3	776.4	5.9761	0.00092
OVERALL*group	301.7	6	50.	0.3870	0.88557
OVERALL*gender	91.0	3	30.	0.2335	0.87281
OVERALL*time	286.2	3	95.4	0.7342	0.53429
OVERALL*group*gender	607.0	6	101.2	0.7787	0.58871
OVERALL*group*time	163.	6	27.	0.2101	0.97275
OVERALL*gender*time	540.7	3	180.2	1.3874	0.25177
OVERALL*group*gender*time	917.2	6	152.	1.1766	0.32591
Error	11692.1	90	129.		
{5}TASK	116.5	2	58.	0.8682	0.42487
TASK*group	385.	4	96.5	1.4373	0.23276
TASK*gender	161.	2	80.	1.2042	0.30705
TASK*time	15.2	2	7.6	0.1135	0.89286
TASK*group*gender	327.1	4	81.	1.2184	0.31248
TASK*group*time	331.	4	82.	1.2354	0.30552
TASK*gender*time	278.	2	139.4	2.0778	0.13411
TASK*group*gender*time	618.	4	154.	2.3034	0.06874
Error	4026.5	60	67.1		
OVERALL*TASK	340.2	6	56.7	2.8436	0.01139
OVERALL*TASK*group	334.4	12	27.	1.3973	0.17058
OVERALL*TASK*gender	134.	6	22.4	1.1247	0.34968
OVERALL*TASK*time	278.2	6	46.4	2.3249	0.03465
OVERALL*TASK*group*gender	125.	12	10.4	0.5236	0.89759
OVERALL*TASK*group*time	448.	12	37.4	1.8748	0.04008
OVERALL*TASK*gender*time	103.4	6	17.2	0.8640	0.52251
4*5*1*2*3	372.5	12	31.0	1.5567	0.10802
Error	3589.5	180	19.		

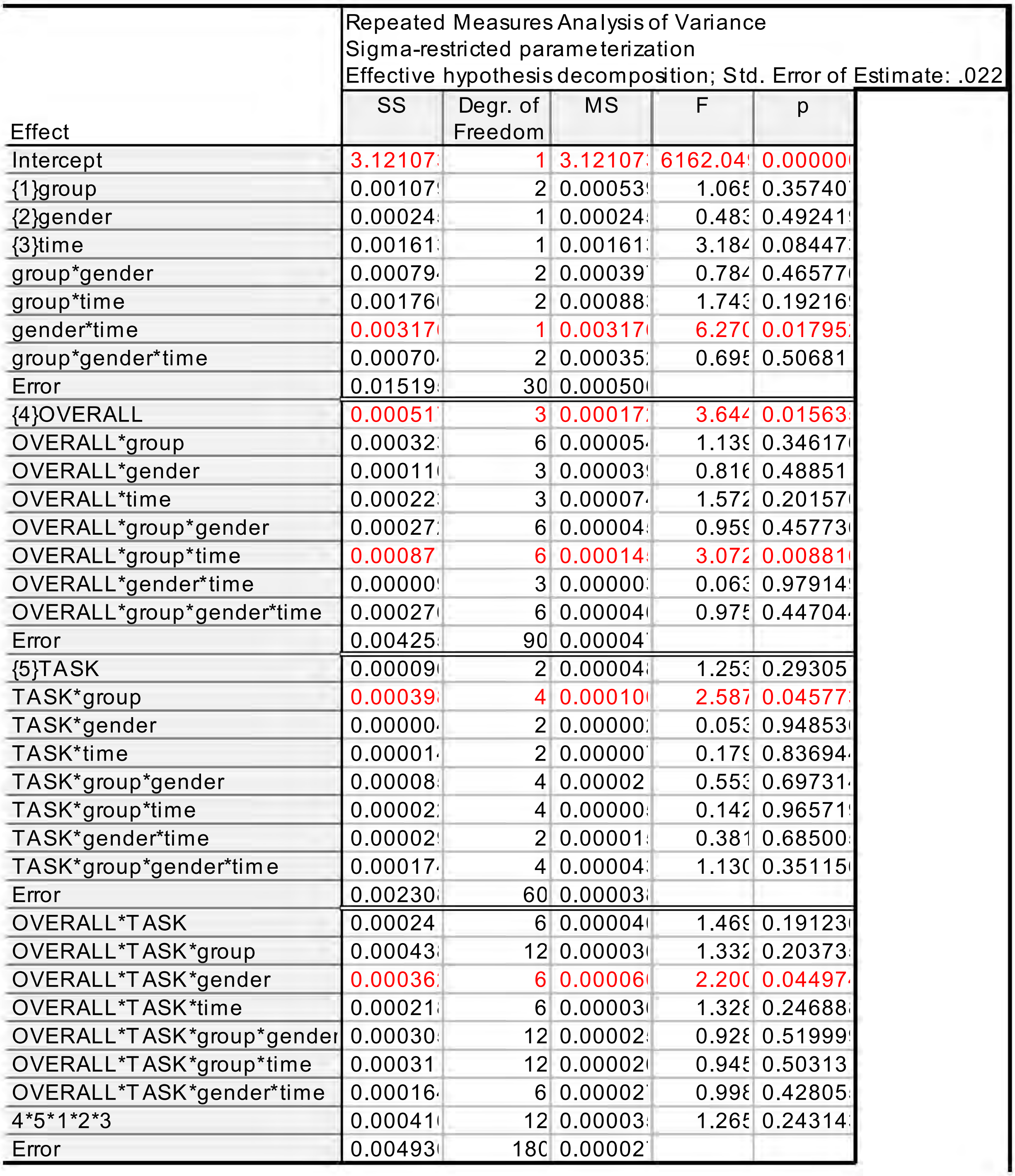
d. High frequency centre frequency



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .054

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	22.9290	1	22.9290	7859.88	0.00000
{1}group	0.0109	2	0.0054	1.86	0.17178
{2}gender	0.0056	1	0.0056	1.92	0.17551
{3}time	0.0085	1	0.0085	2.91	0.09823
group*gender	0.0019	2	0.0009	0.331	0.72104
group*time	0.0084	2	0.0042	1.44	0.25185
gender*time	0.0020	1	0.0020	0.70	0.40870
group*gender*time	0.0009	2	0.0004	0.16	0.84973
Error	0.0875	30	0.0029		
{4}OVERALL	0.0172	3	0.0057	12.42	0.00000
OVERALL*group	0.0018	6	0.0003	0.65	0.68603
OVERALL*gender	0.0002	3	0.0001	0.21	0.88780
OVERALL*time	0.0014	3	0.0004	1.05	0.37148
OVERALL*group*gender	0.0008	6	0.0001	0.31	0.92704
OVERALL*group*time	0.0023	6	0.0003	0.84	0.53795
OVERALL*gender*time	0.0008	3	0.0002	0.61	0.60994
OVERALL*group*gender*time	0.0048	6	0.0008	1.75	0.11857
Error	0.0417	90	0.0004		
{5}TASK	0.0014	2	0.0007	4.91	0.01059
TASK*group	0.0046	4	0.0011	8.091	0.00002
TASK*gender	0.0014	2	0.0007	5.05	0.00938
TASK*time	0.0006	2	0.0003	2.12	0.12867
TASK*group*gender	0.0015	4	0.0003	2.62	0.04314
TASK*group*time	0.0002	4	0.0000	0.471	0.75662
TASK*gender*time	0.0001	2	0.0000	0.357	0.70133
TASK*group*gender*time	0.0011	4	0.0002	2.037	0.10050
Error	0.0086	60	0.0001		
OVERALL*TASK	0.0027	6	0.0004	3.92	0.00104
OVERALL*TASK*group	0.0019	12	0.0001	1.42	0.15857
OVERALL*TASK*gender	0.0011	6	0.0001	1.64	0.13714
OVERALL*TASK*time	0.0015	6	0.0002	2.26	0.03951
OVERALL*TASK*group*gender	0.0021	12	0.0001	1.55	0.10731
OVERALL*TASK*group*time	0.0016	12	0.0001	1.19	0.29053
OVERALL*TASK*gender*time	0.0028	6	0.0004	4.06	0.00075
4*5*1*2*3	0.0021	12	0.0001	1.54	0.11135
Error	0.0208	18	0.0001		

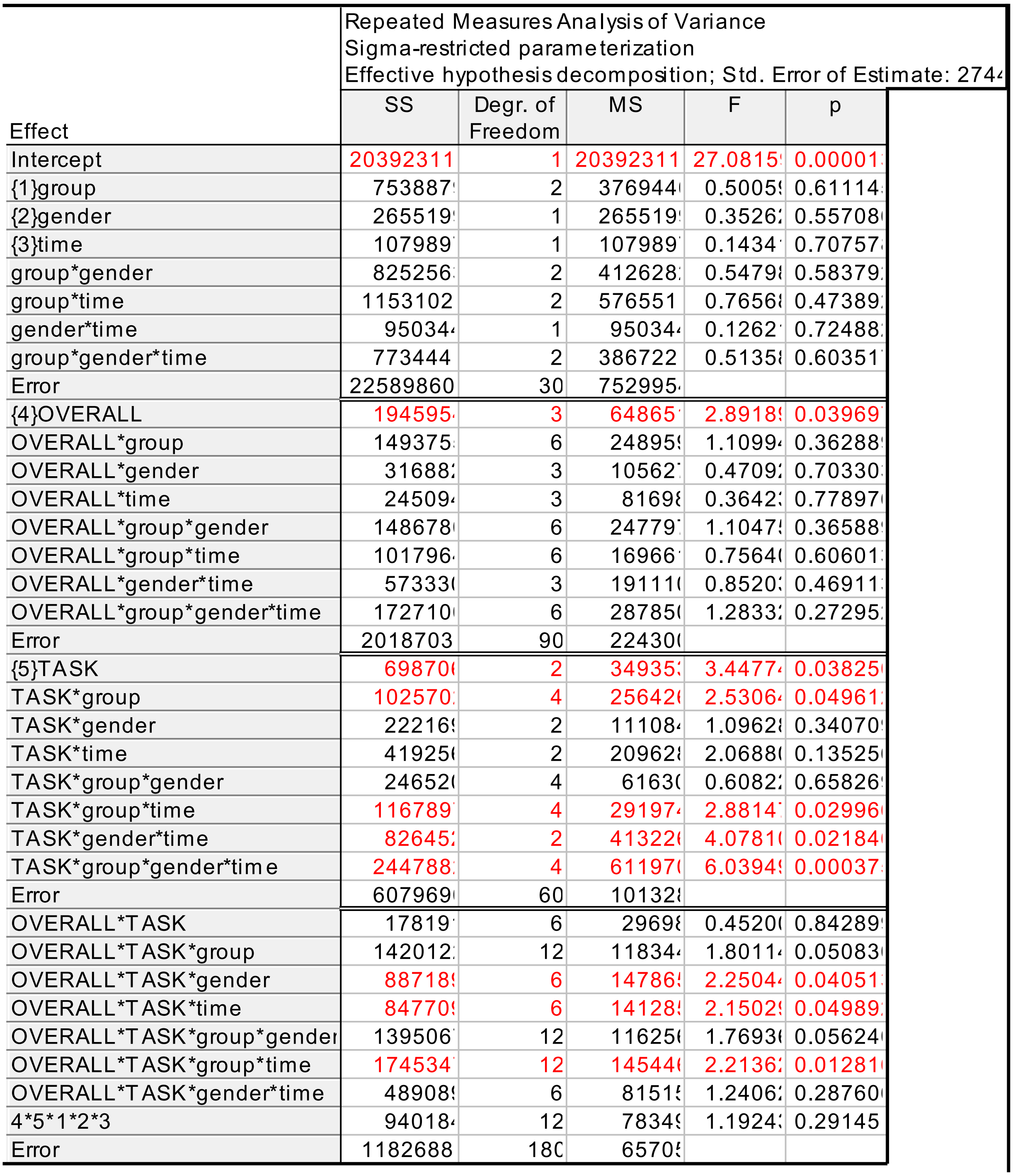
e. Low frequency centre frequency



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .022

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	3.12107	1	3.12107	6162.04	0.00000
{1}group	0.00107	2	0.00053	1.065	0.35740
{2}gender	0.00024	1	0.00024	0.483	0.49241
{3}time	0.00161	1	0.00161	3.184	0.08447
group*gender	0.00079	2	0.00039	0.784	0.46577
group*time	0.00176	2	0.00088	1.743	0.19216
gender*time	0.00317	1	0.00317	6.270	0.01795
group*gender*time	0.00070	2	0.00035	0.695	0.50681
Error	0.01519	30	0.00050		
{4}OVERALL	0.00051	3	0.00017	3.644	0.01563
OVERALL*group	0.00032	6	0.00005	1.139	0.34617
OVERALL*gender	0.00011	3	0.00003	0.816	0.48851
OVERALL*time	0.00022	3	0.00007	1.572	0.20157
OVERALL*group*gender	0.00027	6	0.00004	0.959	0.45773
OVERALL*group*time	0.00087	6	0.00014	3.072	0.00881
OVERALL*gender*time	0.00000	3	0.00000	0.063	0.97914
OVERALL*group*gender*time	0.00027	6	0.00004	0.975	0.44704
Error	0.00425	90	0.00004		
{5}TASK	0.00009	2	0.00004	1.253	0.29305
TASK*group	0.00039	4	0.00010	2.587	0.04577
TASK*gender	0.00000	2	0.00000	0.053	0.94853
TASK*time	0.00001	2	0.00000	0.179	0.83694
TASK*group*gender	0.00008	4	0.00002	0.553	0.69731
TASK*group*time	0.00002	4	0.00000	0.142	0.96571
TASK*gender*time	0.00002	2	0.00001	0.381	0.68500
TASK*group*gender*time	0.00017	4	0.00004	1.130	0.35115
Error	0.00230	60	0.00003		
OVERALL*TASK	0.00024	6	0.00004	1.469	0.19123
OVERALL*TASK*group	0.00043	12	0.00003	1.332	0.20373
OVERALL*TASK*gender	0.00036	6	0.00006	2.200	0.04497
OVERALL*TASK*time	0.00021	6	0.00003	1.328	0.24688
OVERALL*TASK*group*gender	0.00030	12	0.00002	0.928	0.51999
OVERALL*TASK*group*time	0.00031	12	0.00002	0.945	0.50313
OVERALL*TASK*gender*time	0.00016	6	0.00002	0.998	0.42805
4*5*1*2*3	0.00041	12	0.00003	1.265	0.24314
Error	0.00493	180	0.00002		

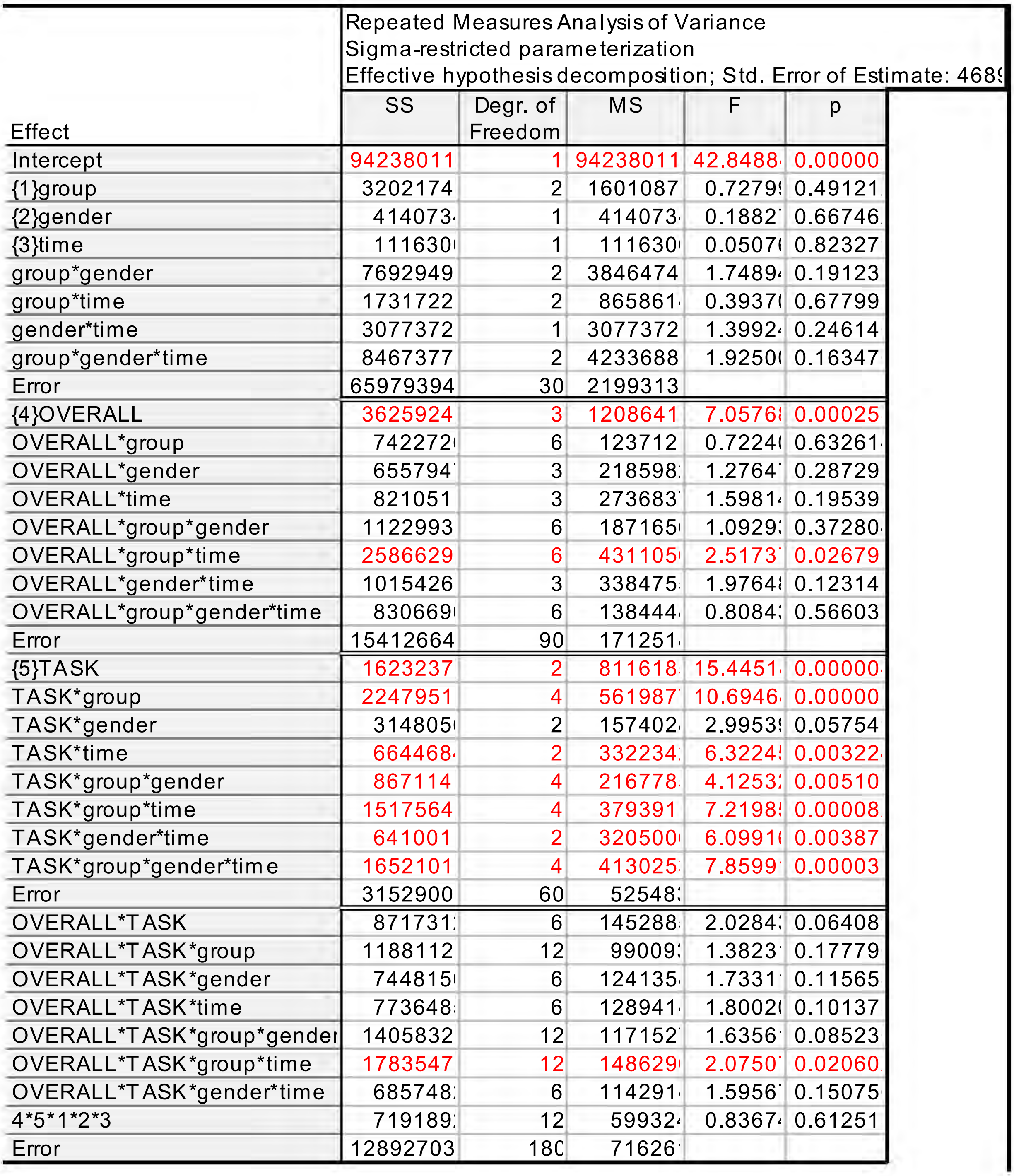
f. High frequency power



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 274

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	20392311	1	20392311	27.0815	0.00001
{1}group	753887	2	376944	0.5005	0.61114
{2}gender	265519	1	265519	0.3526	0.55708
{3}time	107989	1	107989	0.1434	0.70757
group*gender	825256	2	412628	0.5479	0.58379
group*time	1153102	2	576551	0.7656	0.47389
gender*time	95034	1	95034	0.1262	0.72488
group*gender*time	773444	2	386722	0.5135	0.60351
Error	22589860	30	752995		
{4}OVERALL	194595	3	64865	2.8918	0.03969
OVERALL*group	149375	6	24895	1.1099	0.36288
OVERALL*gender	31688	3	10562	0.4709	0.70330
OVERALL*time	24509	3	8169	0.3642	0.77897
OVERALL*group*gender	148678	6	24779	1.1047	0.36588
OVERALL*group*time	101796	6	16966	0.7564	0.60601
OVERALL*gender*time	57333	3	19111	0.8520	0.46911
OVERALL*group*gender*time	172710	6	28785	1.2833	0.27295
Error	2018703	90	22430		
{5}TASK	69870	2	34935	3.4477	0.03825
TASK*group	102570	4	25642	2.5306	0.04961
TASK*gender	22216	2	11108	1.0962	0.34070
TASK*time	41925	2	20962	2.0688	0.13525
TASK*group*gender	24652	4	6163	0.6082	0.65826
TASK*group*time	116789	4	29197	2.8814	0.02996
TASK*gender*time	82645	2	41322	4.0781	0.02184
TASK*group*gender*time	244788	4	61197	6.0394	0.00037
Error	607969	60	10132		
OVERALL*TASK	17819	6	2969	0.4520	0.84289
OVERALL*TASK*group	142012	12	11834	1.8011	0.05083
OVERALL*TASK*gender	88718	6	14786	2.2504	0.04051
OVERALL*TASK*time	84770	6	14128	2.1502	0.04989
OVERALL*TASK*group*gender	139506	12	11625	1.7693	0.05624
OVERALL*TASK*gender*time	48908	6	8151	1.2406	0.28760
4*5*1*2*3	94018	12	7834	1.1924	0.29145
Error	1182688	180	6570		

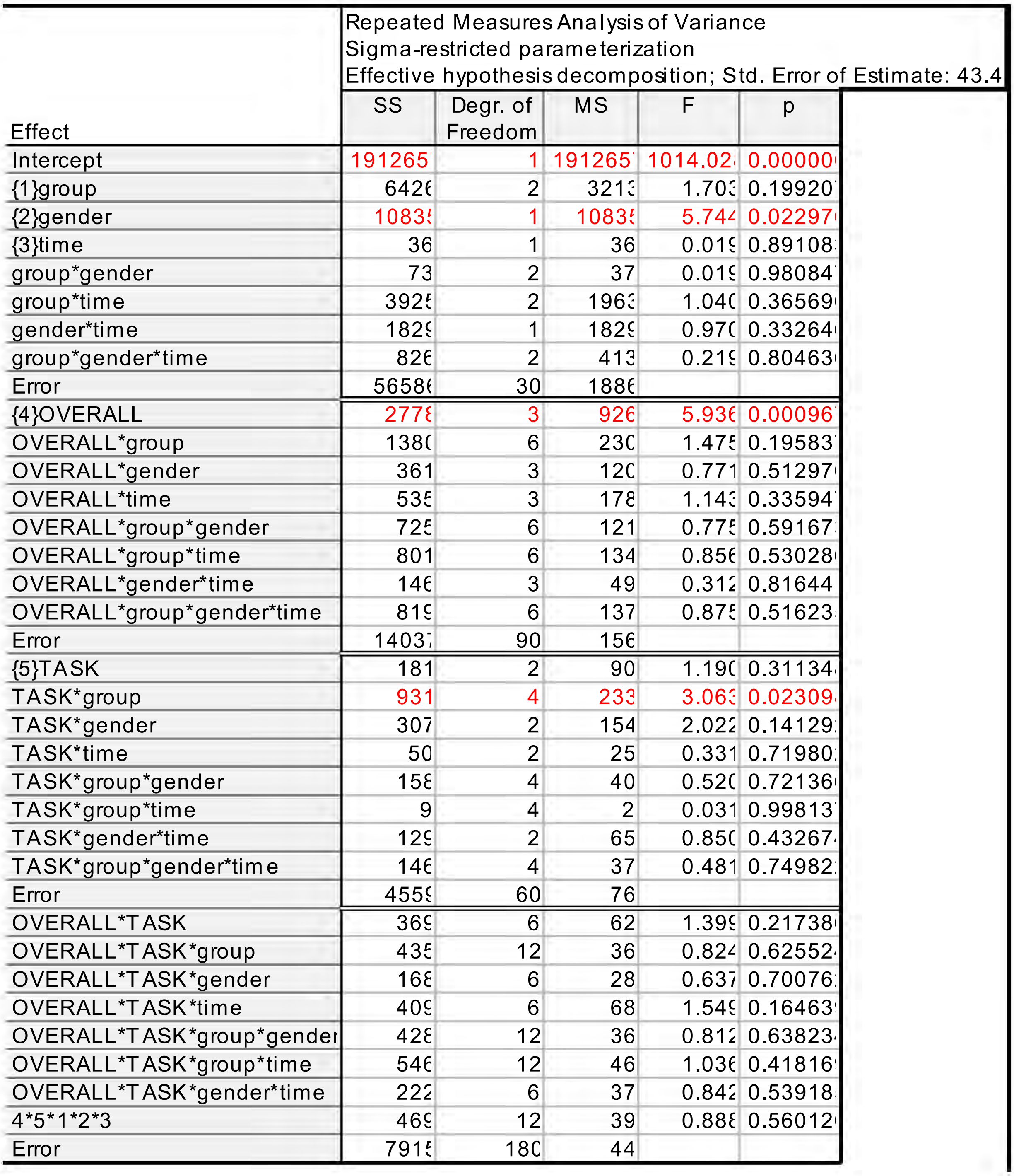
g. Low frequency power



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 468

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	94238011	1	94238011	42.8488	0.00000
{1}group	3202174	2	1601087	0.7279	0.49121
{2}gender	414073	1	414073	0.1882	0.66746
{3}time	111630	1	111630	0.0507	0.82327
group*gender	7692949	2	3846474	1.7489	0.19123
group*time	1731722	2	865861	0.3937	0.67799
gender*time	3077372	1	3077372	1.3992	0.24614
group*gender*time	8467377	2	4233688	1.9250	0.16347
Error	65979394	30	2199313		
{4}OVERALL	3625924	3	1208641	7.0576	0.00025
OVERALL*group	742272	6	123712	0.7224	0.63261
OVERALL*gender	655794	3	218598	1.2764	0.28729
OVERALL*time	821051	3	273683	1.5981	0.19539
OVERALL*group*gender	1122993	6	187165	1.0929	0.37280
OVERALL*group*time	2586629	6	431105	2.5173	0.02679
OVERALL*gender*time	1015426	3	338475	1.9764	0.12314
OVERALL*group*gender*time	830669	6	138444	0.8084	0.56603
Error	15412664	90	171251		
{5}TASK	1623237	2	811618	15.4451	0.00000
TASK*group	2247951	4	561987	10.6946	0.00000
TASK*gender	314805	2	157402	2.9953	0.05754
TASK*time	664468	2	332234	6.3224	0.00322
TASK*group*gender	867114	4	216778	4.1253	0.00510
TASK*group*time	1517564	4	379391	7.2198	0.00008
TASK*gender*time	641001	2	320500	6.0991	0.00387
TASK*group*gender*time	1652101	4	413025	7.8599	0.00003
Error	3152900	60	52548		
OVERALL*TASK	871731	6	145288	2.0284	0.06408
OVERALL*TASK*group	1188112	12	99009	1.3823	0.17779
OVERALL*TASK*gender	744815	6	124135	1.7331	0.11565
OVERALL*TASK*time	773648	6	128941	1.8002	0.10137
OVERALL*TASK*group*gender	1405832	12	117152	1.6356	0.08523
OVERALL*TASK*group*time	1783547	12	148629	2.0750	0.02060
OVERALL*TASK*gender*time	685748	6	114291	1.5956	0.15075
4*5*1*2*3	719189	12	59932	0.8367	0.61251
Error	12892703	180	71626		

h. Low frequency component of (LF+HF) power

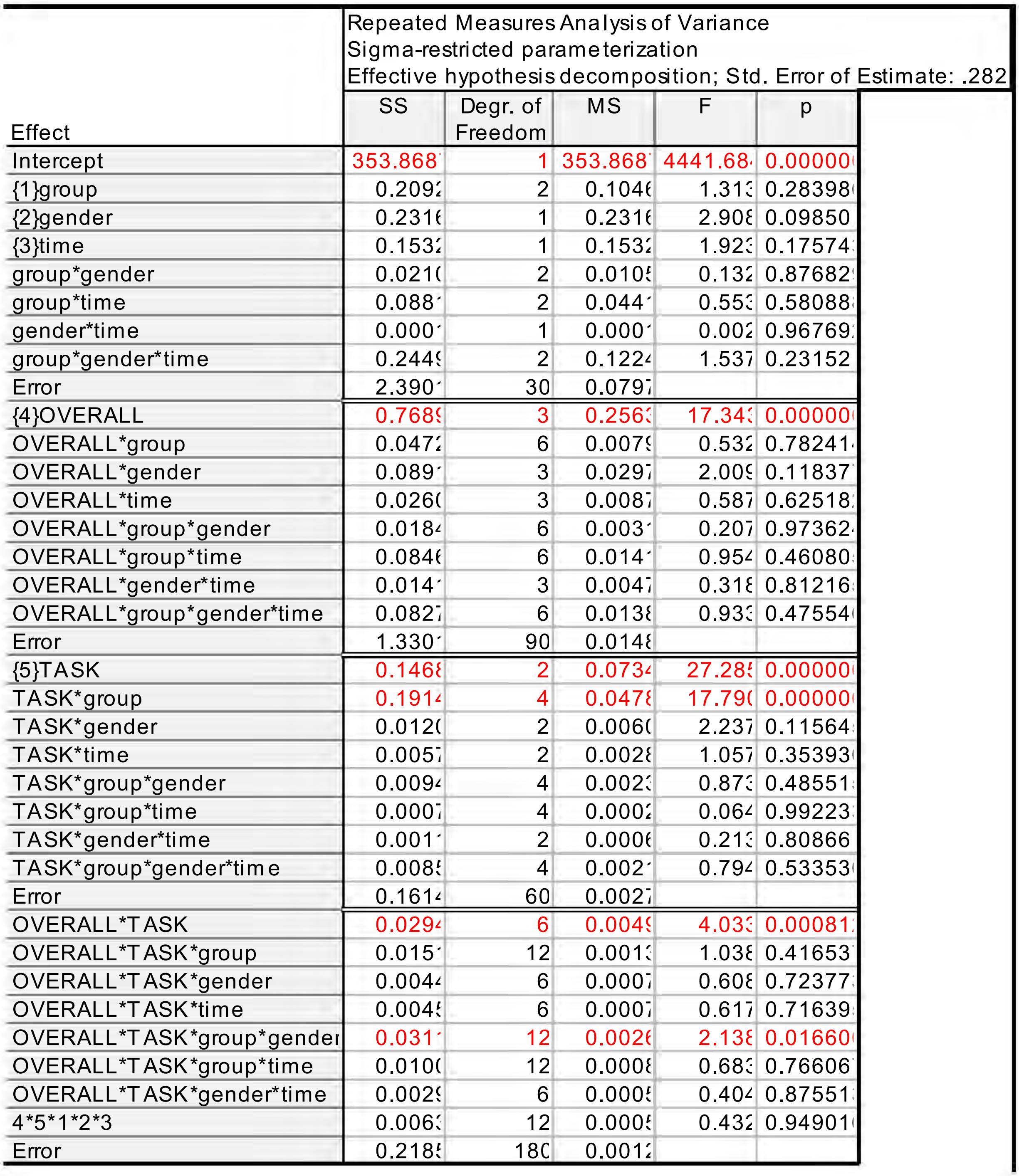


Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 43.4

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	191265	1	191265	1014.02	0.00000
{1}group	6426	2	3213	1.703	0.19920
{2}gender	10835	1	10835	5.744	0.02297
{3}time	36	1	36	0.019	0.89108
group*gender	73	2	37	0.019	0.98084
group*time	3925	2	1963	1.040	0.36569
gender*time	1829	1	1829	0.970	0.33264
group*gender*time	826	2	413	0.219	0.80463
Error	56586	30	1886		
{4}OVERALL	2778	3	926	5.936	0.00096
OVERALL*group	1380	6	230	1.475	0.19583
OVERALL*gender	361	3	120	0.771	0.51297
OVERALL*time	535	3	178	1.143	0.33594
OVERALL*group*gender	725	6	121	0.775	0.59167
OVERALL*group*time	801	6	134	0.856	0.53028
OVERALL*gender*time	146	3	49	0.312	0.81644
OVERALL*group*gender*time	819	6	137	0.875	0.51623
Error	14037	90	156		
{5}TASK	181	2	90	1.190	0.31134
TASK*group	931	4	233	3.063	0.02309
TASK*gender	307	2	154	2.022	0.14129
TASK*time	50	2	25	0.331	0.71980
TASK*group*gender	158	4	40	0.520	0.72136
TASK*group*time	9	4	2	0.031	0.99813
TASK*gender*time	129	2	65	0.850	0.43267
TASK*group*gender*time	146	4	37	0.481	0.74982
Error	4559	60	76		
OVERALL*TASK	369	6	62	1.399	0.21738
OVERALL*TASK*group	435	12	36	0.824	0.62552
OVERALL*TASK*gender	168	6	28	0.637	0.70076
OVERALL*TASK*time	409	6	68	1.549	0.16463
OVERALL*TASK*group*gender	428	12	36	0.812	0.63823
OVERALL*TASK*group*time	546	12	46	1.036	0.41816
OVERALL*TASK*gender*time	222	6	37	0.842	0.53918
4*5*1*2*3	469	12	39	0.888	0.56012
Error	7915	180	44		

3. Oculomotor parameters

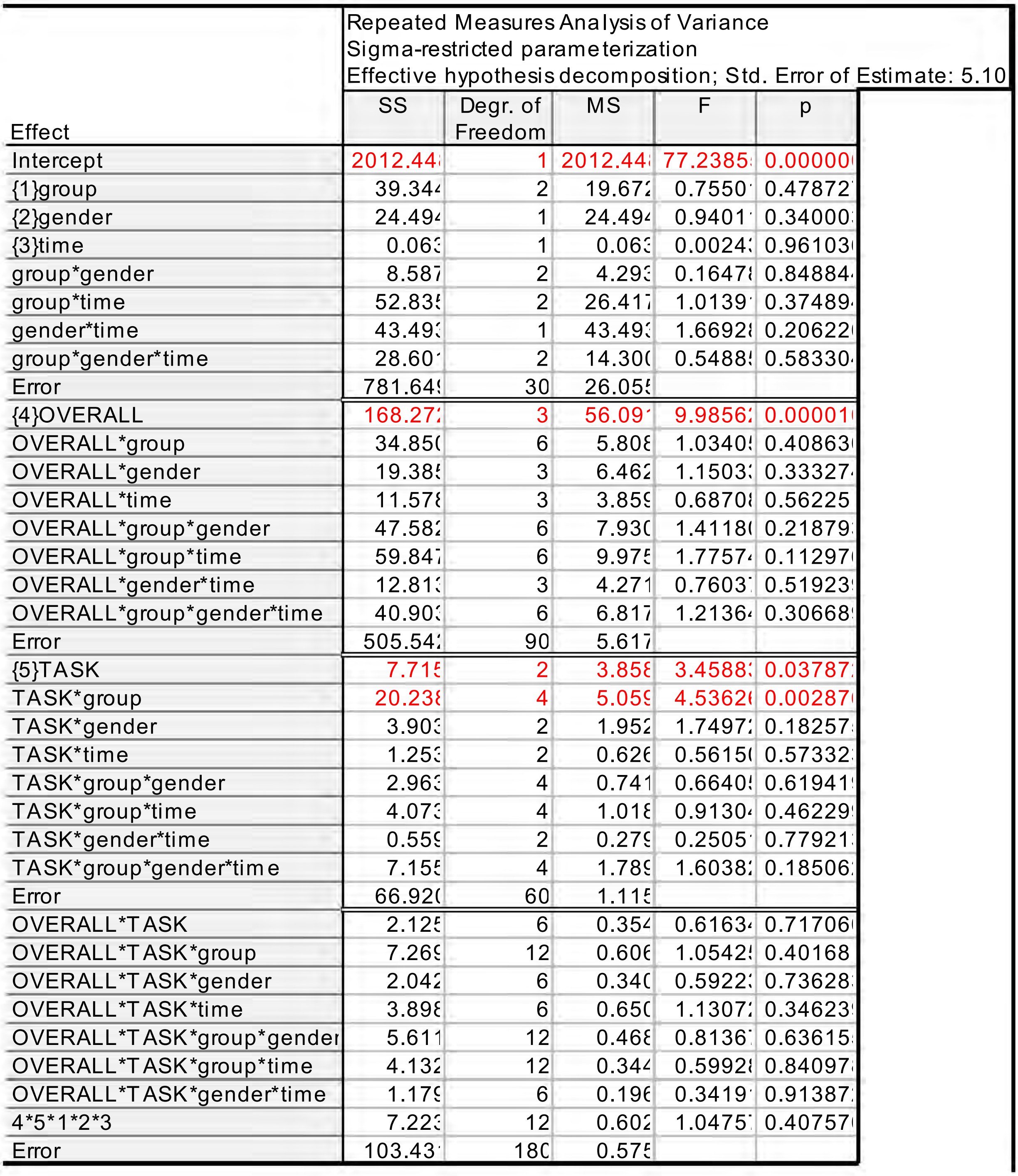
a. Pupil diameter



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .282

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	353.8687	1	353.8687	4441.684	0.000000
{1}group	0.2092	2	0.1046	1.313	0.283980
{2}gender	0.2316	1	0.2316	2.908	0.09850
{3}time	0.1532	1	0.1532	1.923	0.17574
group*gender	0.0210	2	0.0105	0.132	0.87682
group*time	0.0881	2	0.0441	0.553	0.58088
gender*time	0.0001	1	0.0001	0.002	0.96769
group*gender*time	0.2449	2	0.1224	1.537	0.23152
Error	2.3901	30	0.0797		
{4}OVERALL	0.7689	3	0.2563	17.343	0.000000
OVERALL*group	0.0472	6	0.0079	0.532	0.782414
OVERALL*gender	0.0891	3	0.0297	2.009	0.118377
OVERALL*time	0.0260	3	0.0087	0.587	0.62518
OVERALL*group*gender	0.0184	6	0.0031	0.207	0.973624
OVERALL*group*time	0.0846	6	0.0141	0.954	0.46080
OVERALL*gender*time	0.0141	3	0.0047	0.318	0.81216
OVERALL*group*gender*time	0.0827	6	0.0138	0.933	0.475540
Error	1.3301	90	0.0148		
{5}TASK	0.1468	2	0.0734	27.285	0.000000
TASK*group	0.1914	4	0.0478	17.790	0.000000
TASK*gender	0.0120	2	0.0060	2.237	0.11564
TASK*time	0.0057	2	0.0028	1.057	0.353930
TASK*group*gender	0.0094	4	0.0023	0.873	0.48551
TASK*group*time	0.0007	4	0.0002	0.064	0.99223
TASK*gender*time	0.0011	2	0.0006	0.213	0.80866
TASK*group*gender*time	0.0085	4	0.0021	0.794	0.533530
Error	0.1614	60	0.0027		
OVERALL*TASK	0.0294	6	0.0049	4.033	0.00081
OVERALL*TASK*group	0.0151	12	0.0013	1.038	0.416537
OVERALL*TASK*gender	0.0044	6	0.0007	0.608	0.72377
OVERALL*TASK*time	0.0045	6	0.0007	0.617	0.71639
OVERALL*TASK*group*gender	0.0311	12	0.0026	2.138	0.016600
OVERALL*TASK*group*time	0.0100	12	0.0008	0.683	0.766067
OVERALL*TASK*gender*time	0.0029	6	0.0005	0.404	0.87551
4*5*1*2*3	0.0063	12	0.0005	0.432	0.949010
Error	0.2185	180	0.0012		

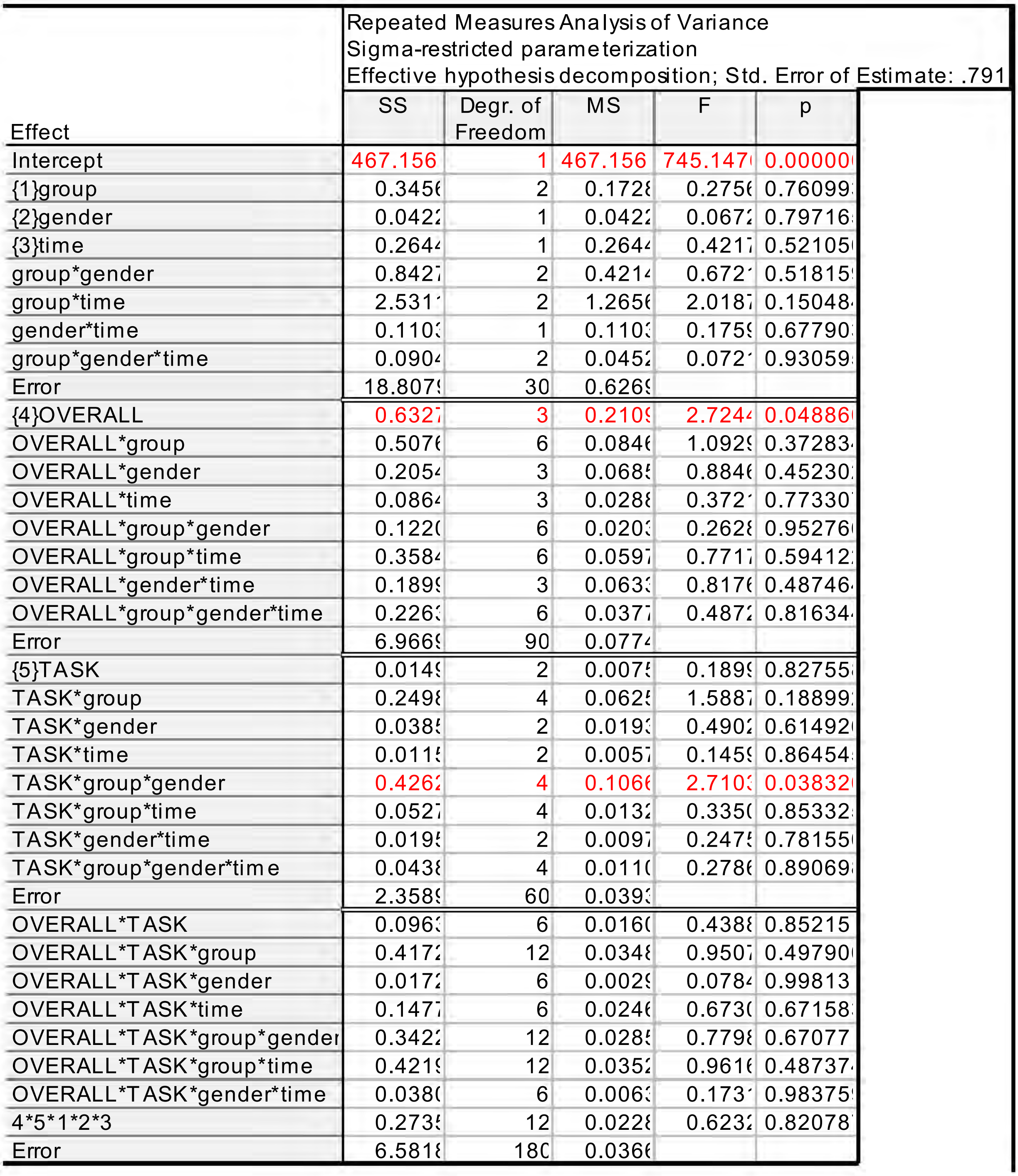
b. Blink frequency



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 5.10

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2012.44	1	2012.44	77.2385	0.00000
{1}group	39.34	2	19.67	0.7550	0.47872
{2}gender	24.49	1	24.49	0.9401	0.34000
{3}time	0.06	1	0.06	0.0024	0.96103
group*gender	8.587	2	4.29	0.1647	0.84884
group*time	52.83	2	26.41	1.0139	0.37489
gender*time	43.49	1	43.49	1.6692	0.20622
group*gender*time	28.60	2	14.30	0.5488	0.58330
Error	781.64	30	26.05		
{4}OVERALL	168.27	3	56.09	9.9856	0.00001
OVERALL*group	34.85	6	5.80	1.0340	0.40863
OVERALL*gender	19.38	3	6.46	1.1503	0.33327
OVERALL*time	11.57	3	3.85	0.6870	0.56225
OVERALL*group*gender	47.58	6	7.93	1.4118	0.21879
OVERALL*group*time	59.84	6	9.97	1.7757	0.11297
OVERALL*gender*time	12.81	3	4.271	0.7603	0.51923
OVERALL*group*gender*time	40.90	6	6.817	1.2136	0.30668
Error	505.54	90	5.617		
{5}TASK	7.71	2	3.85	3.4588	0.03787
TASK*group	20.23	4	5.05	4.5362	0.00287
TASK*gender	3.90	2	1.95	1.7497	0.18257
TASK*time	1.25	2	0.62	0.5615	0.57332
TASK*group*gender	2.96	4	0.741	0.6640	0.61941
TASK*group*time	4.07	4	1.01	0.9130	0.46229
TASK*gender*time	0.55	2	0.27	0.2505	0.77921
TASK*group*gender*time	7.15	4	1.78	1.6038	0.18506
Error	66.92	60	1.11		
OVERALL*TASK	2.12	6	0.35	0.6163	0.71706
OVERALL*TASK*group	7.26	12	0.60	1.0542	0.40168
OVERALL*TASK*gender	2.04	6	0.34	0.5922	0.73628
OVERALL*TASK*time	3.89	6	0.65	1.1307	0.34623
OVERALL*TASK*group*gender	5.611	12	0.46	0.8136	0.63615
OVERALL*TASK*group*time	4.13	12	0.34	0.5992	0.84097
OVERALL*TASK*gender*time	1.17	6	0.19	0.3419	0.91387
4*5*1*2*3	7.22	12	0.60	1.0475	0.40757
Error	103.43	18	0.57		

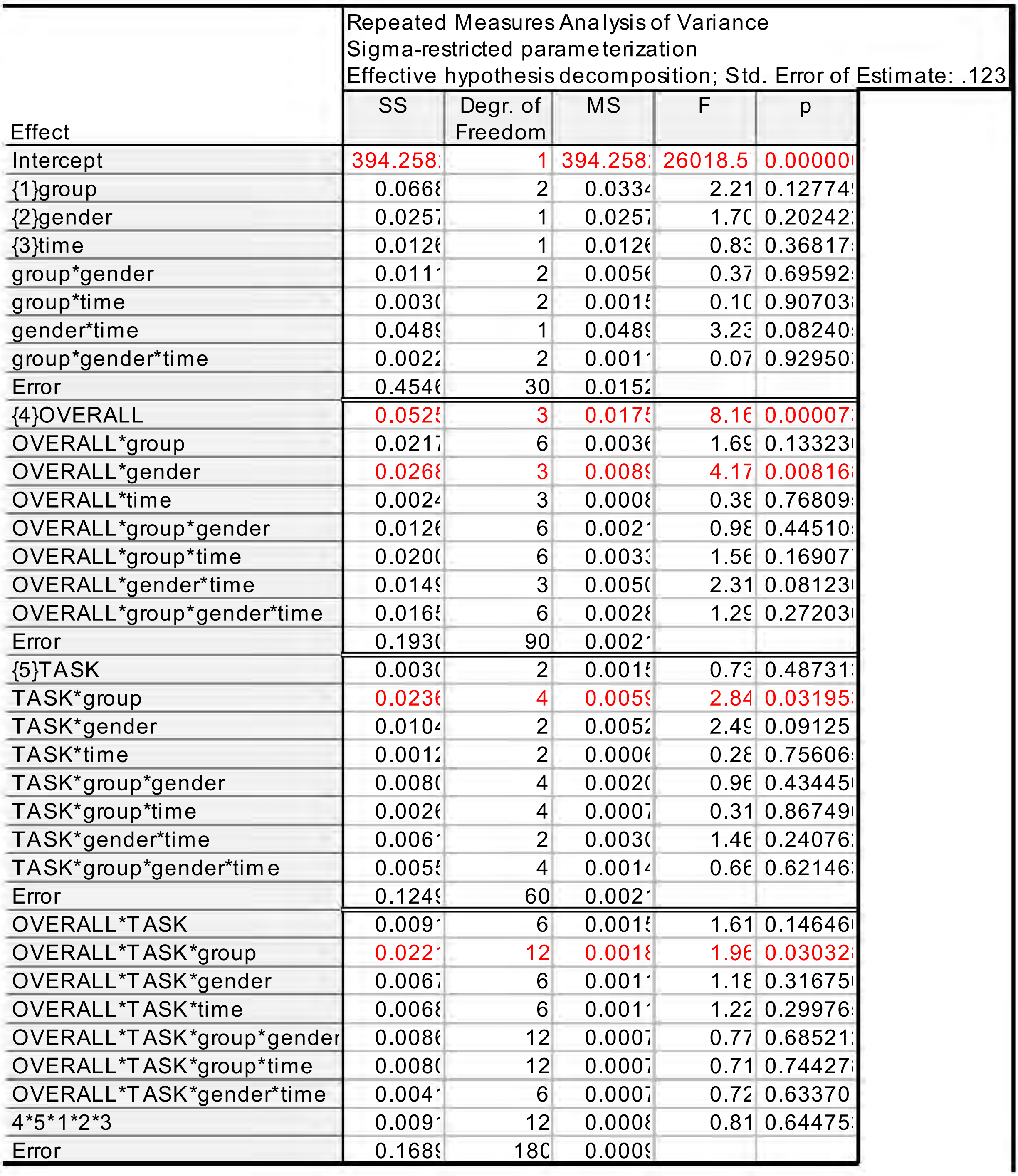
c. Blink duration



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .791

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	467.156	1	467.156	745.147	0.00000
{1}group	0.3456	2	0.1728	0.2756	0.76099
{2}gender	0.0422	1	0.0422	0.0672	0.79716
{3}time	0.2644	1	0.2644	0.4217	0.52105
group*gender	0.8427	2	0.4214	0.6721	0.51815
group*time	2.5311	2	1.2656	2.0187	0.15048
gender*time	0.1103	1	0.1103	0.1759	0.67790
group*gender*time	0.0904	2	0.0452	0.0721	0.93059
Error	18.8079	30	0.6269		
{4}OVERALL	0.6327	3	0.2109	2.7244	0.04886
OVERALL*group	0.5076	6	0.0846	1.0929	0.37283
OVERALL*gender	0.2054	3	0.0685	0.8846	0.45230
OVERALL*time	0.0864	3	0.0288	0.3721	0.77330
OVERALL*group*gender	0.1220	6	0.0203	0.2628	0.95276
OVERALL*group*time	0.3584	6	0.0597	0.7717	0.59412
OVERALL*gender*time	0.1899	3	0.0633	0.8176	0.48746
OVERALL*group*gender*time	0.2263	6	0.0377	0.4872	0.81634
Error	6.9669	90	0.0774		
{5}TASK	0.0149	2	0.0075	0.1899	0.82755
TASK*group	0.2498	4	0.0625	1.5887	0.18899
TASK*gender	0.0385	2	0.0193	0.4902	0.61492
TASK*time	0.0115	2	0.0057	0.1459	0.86454
TASK*group*gender	0.4262	4	0.1066	2.7103	0.03832
TASK*group*time	0.0527	4	0.0132	0.3350	0.85332
TASK*gender*time	0.0195	2	0.0097	0.2475	0.78155
TASK*group*gender*time	0.0438	4	0.0110	0.2786	0.89069
Error	2.3589	60	0.0393		
OVERALL*TASK	0.0963	6	0.0160	0.4388	0.85215
OVERALL*TASK*group	0.4172	12	0.0348	0.9507	0.49790
OVERALL*TASK*gender	0.0172	6	0.0029	0.0784	0.99813
OVERALL*TASK*time	0.1477	6	0.0246	0.6730	0.67158
OVERALL*TASK*group*gender	0.3422	12	0.0285	0.7798	0.67077
OVERALL*TASK*group*time	0.4219	12	0.0352	0.9616	0.48737
OVERALL*TASK*gender*time	0.0380	6	0.0063	0.1731	0.98375
4*5*1*2*3	0.2735	12	0.0228	0.6232	0.82078
Error	6.5818	180	0.0366		

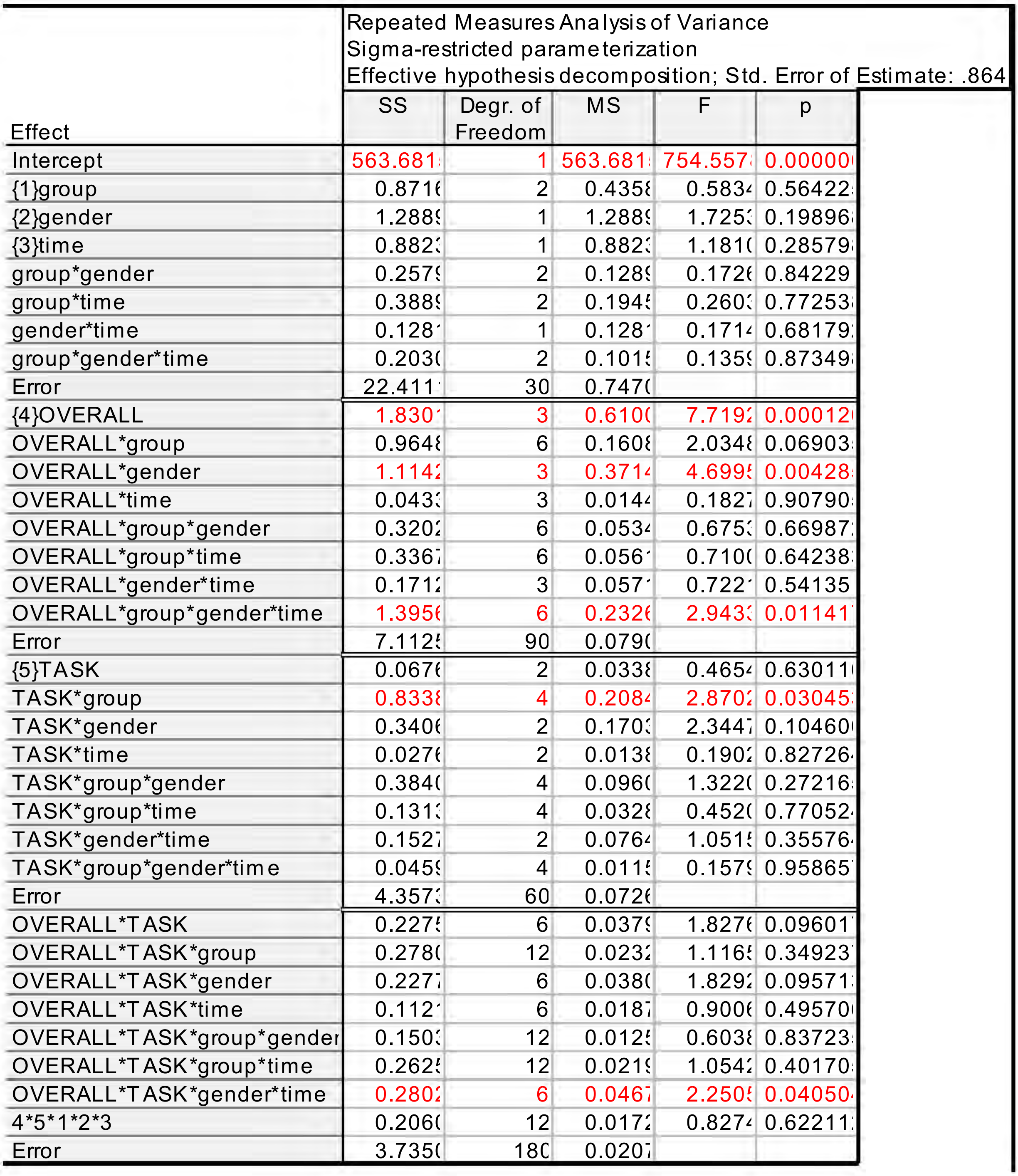
d. Short fixation duration



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .123

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	394.258	1	394.258	26018.57	0.000000
{1}group	0.0668	2	0.0334	2.21	0.12774
{2}gender	0.0257	1	0.0257	1.70	0.20242
{3}time	0.0126	1	0.0126	0.83	0.36817
group*gender	0.0111	2	0.0056	0.37	0.69592
group*time	0.0030	2	0.0015	0.10	0.90703
gender*time	0.0489	1	0.0489	3.23	0.08240
group*gender*time	0.0022	2	0.0011	0.07	0.92950
Error	0.4546	30	0.0152		
{4}OVERALL	0.0525	3	0.0175	8.16	0.00007
OVERALL*group	0.0217	6	0.0036	1.69	0.133230
OVERALL*gender	0.0268	3	0.0089	4.17	0.00816
OVERALL*time	0.0024	3	0.0008	0.38	0.76809
OVERALL*group*gender	0.0126	6	0.0021	0.98	0.44510
OVERALL*group*time	0.0200	6	0.0033	1.56	0.169077
OVERALL*gender*time	0.0149	3	0.0050	2.31	0.081230
OVERALL*group*gender*time	0.0165	6	0.0028	1.29	0.272030
Error	0.1930	90	0.0021		
{5}TASK	0.0030	2	0.0015	0.73	0.48731
TASK*group	0.0236	4	0.0059	2.84	0.03195
TASK*gender	0.0104	2	0.0052	2.49	0.09125
TASK*time	0.0012	2	0.0006	0.28	0.75606
TASK*group*gender	0.0080	4	0.0020	0.96	0.434450
TASK*group*time	0.0026	4	0.0007	0.31	0.867490
TASK*gender*time	0.0061	2	0.0030	1.46	0.24076
TASK*group*gender*time	0.0055	4	0.0014	0.66	0.62146
Error	0.1249	60	0.0021		
OVERALL*TASK	0.0091	6	0.0015	1.61	0.146460
OVERALL*TASK*group	0.0221	12	0.0018	1.96	0.03032
OVERALL*TASK*gender	0.0067	6	0.0011	1.18	0.316750
OVERALL*TASK*time	0.0068	6	0.0011	1.22	0.29976
OVERALL*TASK*group*gender	0.0086	12	0.0007	0.77	0.68521
OVERALL*TASK*group*time	0.0080	12	0.0007	0.71	0.74427
OVERALL*TASK*gender*time	0.0041	6	0.0007	0.72	0.63370
4*5*1*2*3	0.0091	12	0.0008	0.81	0.64475
Error	0.1689	180	0.0009		

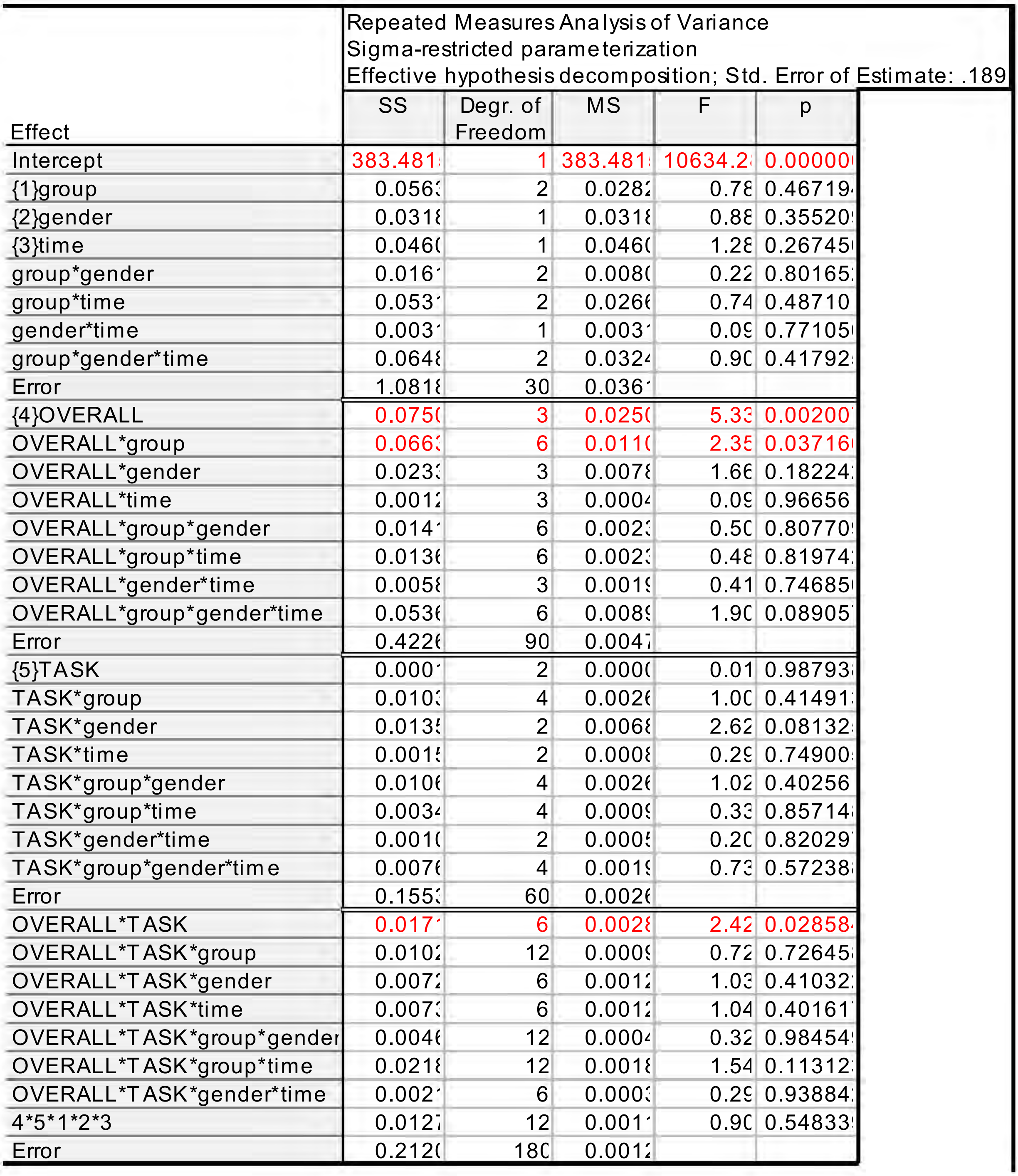
e. Percentage of short fixations



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .864

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	563.681	1	563.681	754.557	0.00000
{1}group	0.871	2	0.435	0.583	0.56422
{2}gender	1.288	1	1.288	1.725	0.19896
{3}time	0.882	1	0.882	1.181	0.28579
group*gender	0.257	2	0.128	0.172	0.84229
group*time	0.388	2	0.194	0.260	0.77253
gender*time	0.128	1	0.128	0.171	0.68179
group*gender*time	0.203	2	0.101	0.135	0.87349
Error	22.411	30	0.747		
{4}OVERALL	1.830	3	0.610	7.719	0.00012
OVERALL*group	0.964	6	0.160	2.034	0.06903
OVERALL*gender	1.114	3	0.371	4.699	0.00428
OVERALL*time	0.043	3	0.014	0.182	0.90790
OVERALL*group*gender	0.320	6	0.053	0.675	0.66987
OVERALL*group*time	0.336	6	0.056	0.710	0.64238
OVERALL*gender*time	0.171	3	0.057	0.722	0.54135
OVERALL*group*gender*time	1.395	6	0.232	2.943	0.01141
Error	7.112	90	0.079		
{5}TASK	0.067	2	0.033	0.465	0.63011
TASK*group	0.833	4	0.208	2.870	0.03045
TASK*gender	0.340	2	0.170	2.344	0.10460
TASK*time	0.027	2	0.013	0.190	0.82726
TASK*group*gender	0.384	4	0.096	1.322	0.27216
TASK*group*time	0.131	4	0.032	0.452	0.77052
TASK*gender*time	0.152	2	0.076	1.051	0.35576
TASK*group*gender*time	0.045	4	0.011	0.157	0.95865
Error	4.357	60	0.072		
OVERALL*TASK	0.227	6	0.037	1.827	0.09601
OVERALL*TASK*group	0.278	12	0.023	1.116	0.34923
OVERALL*TASK*gender	0.227	6	0.038	1.829	0.09571
OVERALL*TASK*time	0.112	6	0.018	0.900	0.49570
OVERALL*TASK*group*gender	0.150	12	0.012	0.603	0.83723
OVERALL*TASK*group*time	0.262	12	0.021	1.054	0.40170
OVERALL*TASK*gender*time	0.280	6	0.046	2.250	0.04050
4*5*1*2*3	0.206	12	0.017	0.827	0.62211
Error	3.735	180	0.020		

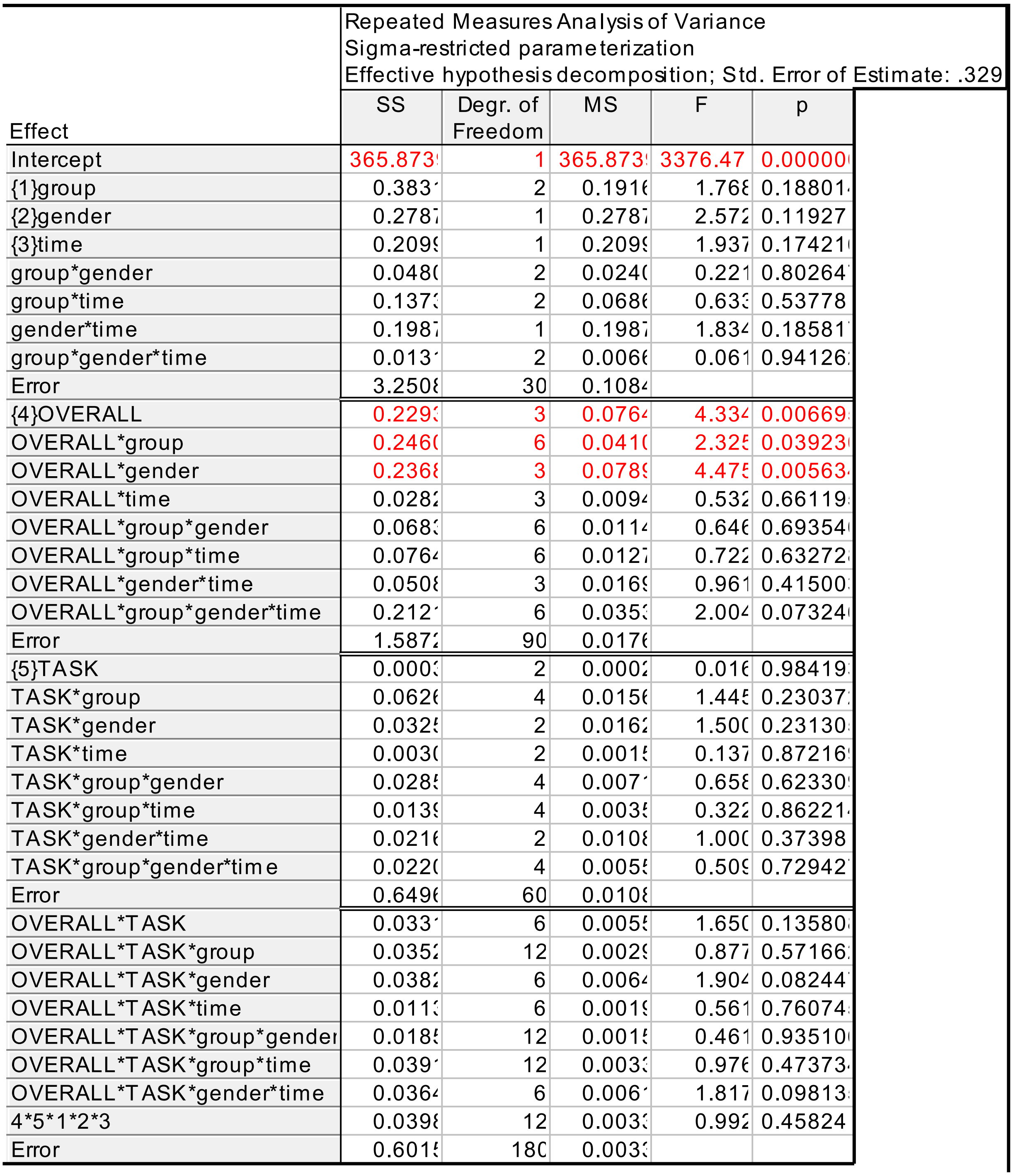
f. Medium fixation duration



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .189

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	383.481	1	383.481	10634.2	0.00000
{1}group	0.056	2	0.028	0.7	0.46719
{2}gender	0.031	1	0.031	0.8	0.35520
{3}time	0.046	1	0.046	1.2	0.26745
group*gender	0.016	2	0.008	0.22	0.80165
group*time	0.053	2	0.026	0.74	0.48710
gender*time	0.003	1	0.003	0.0	0.77105
group*gender*time	0.064	2	0.032	0.9	0.41792
Error	1.081	30	0.036		
{4}OVERALL	0.075	3	0.025	5.3	0.00200
OVERALL*group	0.066	6	0.011	2.3	0.03716
OVERALL*gender	0.023	3	0.007	1.6	0.18224
OVERALL*time	0.001	3	0.000	0.0	0.96656
OVERALL*group*gender	0.014	6	0.002	0.5	0.80770
OVERALL*group*time	0.013	6	0.002	0.4	0.81974
OVERALL*gender*time	0.005	3	0.001	0.41	0.74685
OVERALL*group*gender*time	0.053	6	0.008	1.9	0.08905
Error	0.422	90	0.0047		
{5}TASK	0.000	2	0.000	0.01	0.98793
TASK*group	0.010	4	0.002	1.0	0.41491
TASK*gender	0.013	2	0.006	2.62	0.08132
TASK*time	0.001	2	0.000	0.2	0.74900
TASK*group*gender	0.010	4	0.002	1.02	0.40256
TASK*group*time	0.003	4	0.000	0.3	0.85714
TASK*gender*time	0.001	2	0.000	0.2	0.82029
TASK*group*gender*time	0.007	4	0.001	0.7	0.57238
Error	0.155	60	0.002		
OVERALL*TASK	0.017	6	0.002	2.42	0.02858
OVERALL*TASK*group	0.010	12	0.000	0.72	0.72645
OVERALL*TASK*gender	0.007	6	0.001	1.0	0.41032
OVERALL*TASK*time	0.007	6	0.001	1.04	0.40161
OVERALL*TASK*group*gender	0.004	12	0.000	0.32	0.98454
OVERALL*TASK*group*time	0.021	12	0.001	1.54	0.11312
OVERALL*TASK*gender*time	0.002	6	0.000	0.2	0.93884
4*5*1*2*3	0.012	12	0.001	0.9	0.54833
Error	0.212	180	0.001		

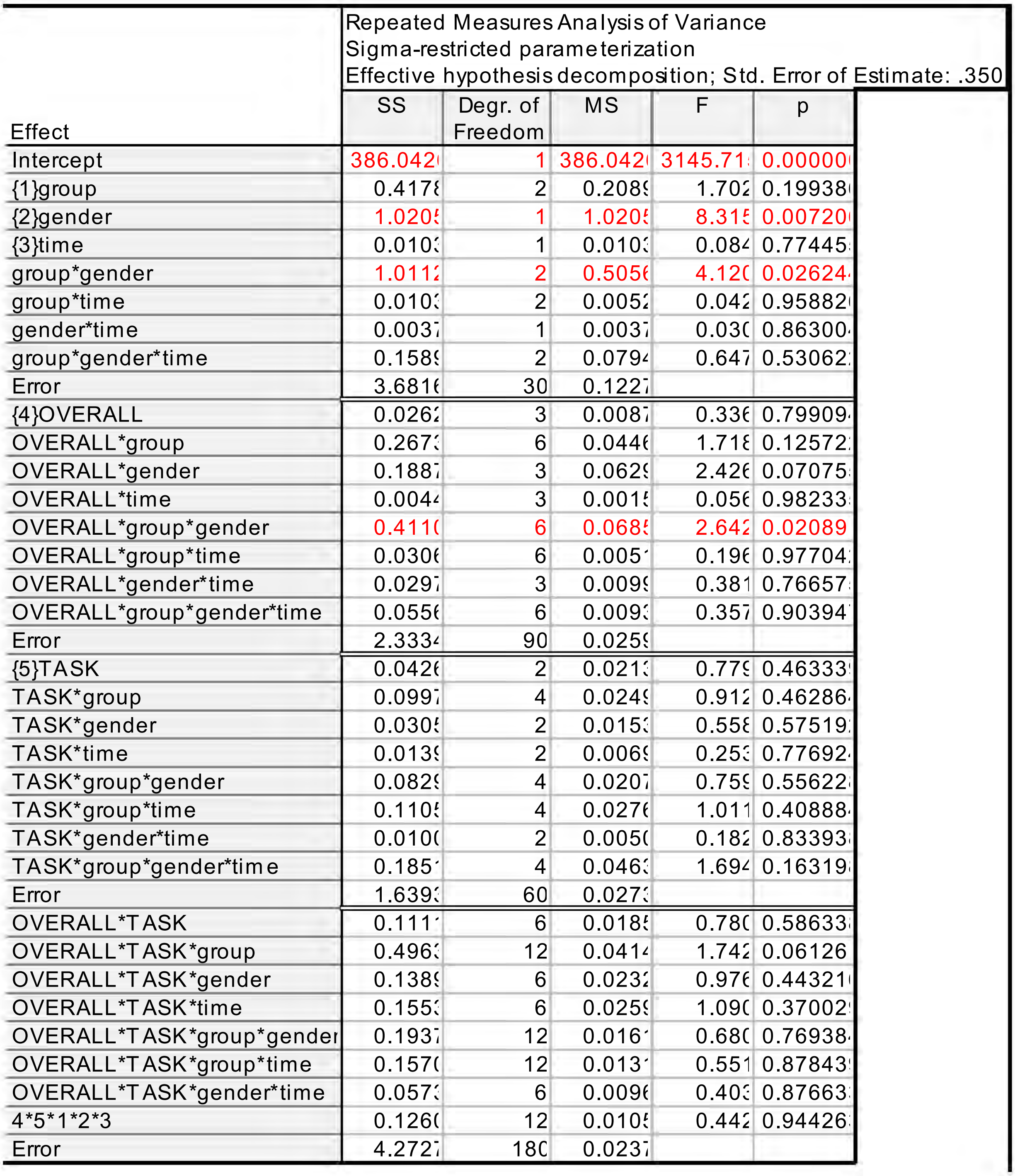
g. Percentage of medium fixations



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .329

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	365.8739	1	365.8739	3376.47	0.000000
{1}group	0.3831	2	0.1916	1.768	0.188014
{2}gender	0.2787	1	0.2787	2.572	0.11927
{3}time	0.2099	1	0.2099	1.937	0.174210
group*gender	0.0480	2	0.0240	0.221	0.802647
group*time	0.1373	2	0.0686	0.633	0.53778
gender*time	0.1987	1	0.1987	1.834	0.185817
group*gender*time	0.0131	2	0.0066	0.061	0.941262
Error	3.2508	30	0.1084		
{4}OVERALL	0.2293	3	0.0764	4.334	0.006693
OVERALL*group	0.2460	6	0.0410	2.325	0.039230
OVERALL*gender	0.2368	3	0.0789	4.475	0.005634
OVERALL*time	0.0282	3	0.0094	0.532	0.661193
OVERALL*group*gender	0.0683	6	0.0114	0.646	0.693540
OVERALL*group*time	0.0764	6	0.0127	0.722	0.632728
OVERALL*gender*time	0.0508	3	0.0169	0.961	0.415003
OVERALL*group*gender*time	0.2121	6	0.0353	2.004	0.073240
Error	1.5872	90	0.0176		
{5}TASK	0.0003	2	0.0002	0.016	0.984193
TASK*group	0.0626	4	0.0156	1.445	0.230372
TASK*gender	0.0325	2	0.0162	1.500	0.231303
TASK*time	0.0030	2	0.0015	0.137	0.872169
TASK*group*gender	0.0285	4	0.0071	0.658	0.623309
TASK*group*time	0.0139	4	0.0035	0.322	0.862214
TASK*gender*time	0.0216	2	0.0108	1.000	0.37398
TASK*group*gender*time	0.0220	4	0.0055	0.509	0.729427
Error	0.6496	60	0.0108		
OVERALL*TASK	0.0331	6	0.0055	1.650	0.135808
OVERALL*TASK*group	0.0352	12	0.0029	0.877	0.571662
OVERALL*TASK*gender	0.0382	6	0.0064	1.904	0.082447
OVERALL*TASK*time	0.0113	6	0.0019	0.561	0.760743
OVERALL*TASK*group*gender	0.0185	12	0.0015	0.461	0.935100
OVERALL*TASK*group*time	0.0391	12	0.0033	0.976	0.473734
OVERALL*TASK*gender*time	0.0364	6	0.0061	1.817	0.098133
4*5*1*2*3	0.0398	12	0.0033	0.992	0.45824
Error	0.6015	180	0.0033		

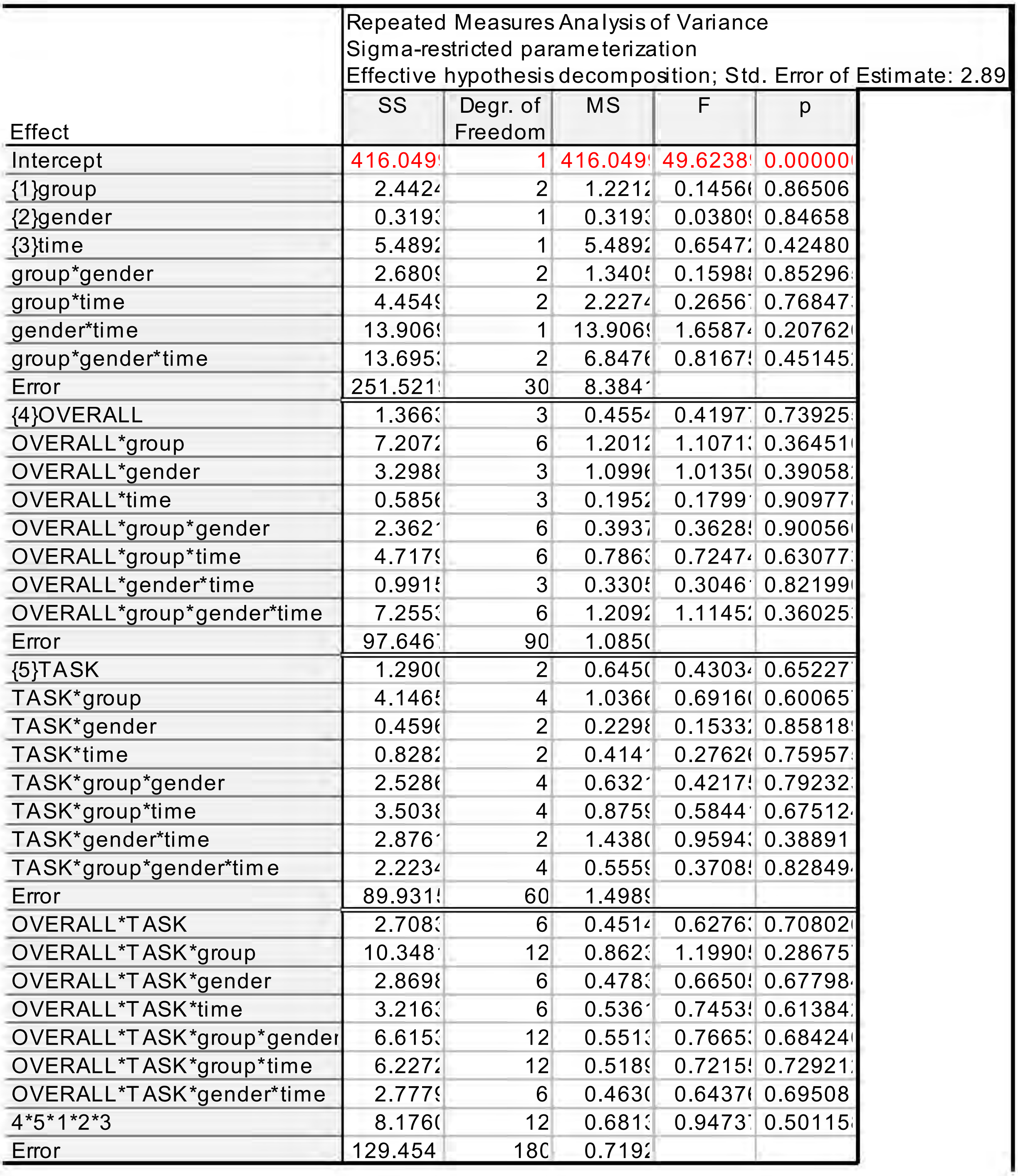
h. Long fixation duration



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .350

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	386.042	1	386.042	3145.71	0.00000
{1}group	0.417	2	0.208	1.70	0.19938
{2}gender	1.020	1	1.020	8.31	0.00720
{3}time	0.010	1	0.010	0.08	0.77445
group*gender	1.011	2	0.505	4.12	0.02624
group*time	0.010	2	0.005	0.04	0.95882
gender*time	0.003	1	0.003	0.03	0.86300
group*gender*time	0.158	2	0.079	0.647	0.53062
Error	3.681	30	0.122		
{4}OVERALL	0.026	3	0.008	0.33	0.79909
OVERALL*group	0.267	6	0.044	1.71	0.12572
OVERALL*gender	0.188	3	0.062	2.42	0.07075
OVERALL*time	0.004	3	0.001	0.05	0.98233
OVERALL*group*gender	0.411	6	0.068	2.64	0.02089
OVERALL*group*time	0.030	6	0.005	0.19	0.97704
OVERALL*gender*time	0.029	3	0.009	0.381	0.76657
OVERALL*group*gender*time	0.055	6	0.009	0.357	0.90394
Error	2.333	90	0.025		
{5}TASK	0.042	2	0.021	0.77	0.46333
TASK*group	0.099	4	0.024	0.91	0.46286
TASK*gender	0.030	2	0.015	0.55	0.57519
TASK*time	0.013	2	0.006	0.25	0.77692
TASK*group*gender	0.082	4	0.020	0.75	0.55622
TASK*group*time	0.110	4	0.027	1.011	0.40888
TASK*gender*time	0.010	2	0.005	0.18	0.83393
TASK*group*gender*time	0.185	4	0.046	1.69	0.16319
Error	1.639	60	0.027		
OVERALL*TASK	0.111	6	0.018	0.78	0.58633
OVERALL*TASK*group	0.496	12	0.041	1.74	0.06126
OVERALL*TASK*gender	0.138	6	0.023	0.97	0.44321
OVERALL*TASK*time	0.155	6	0.025	1.09	0.37002
OVERALL*TASK*group*gender	0.193	12	0.016	0.68	0.76938
OVERALL*TASK*group*time	0.157	12	0.013	0.551	0.87843
OVERALL*TASK*gender*time	0.057	6	0.009	0.40	0.87663
4*5*1*2*3	0.126	12	0.010	0.44	0.94426
Error	4.272	18	0.023		

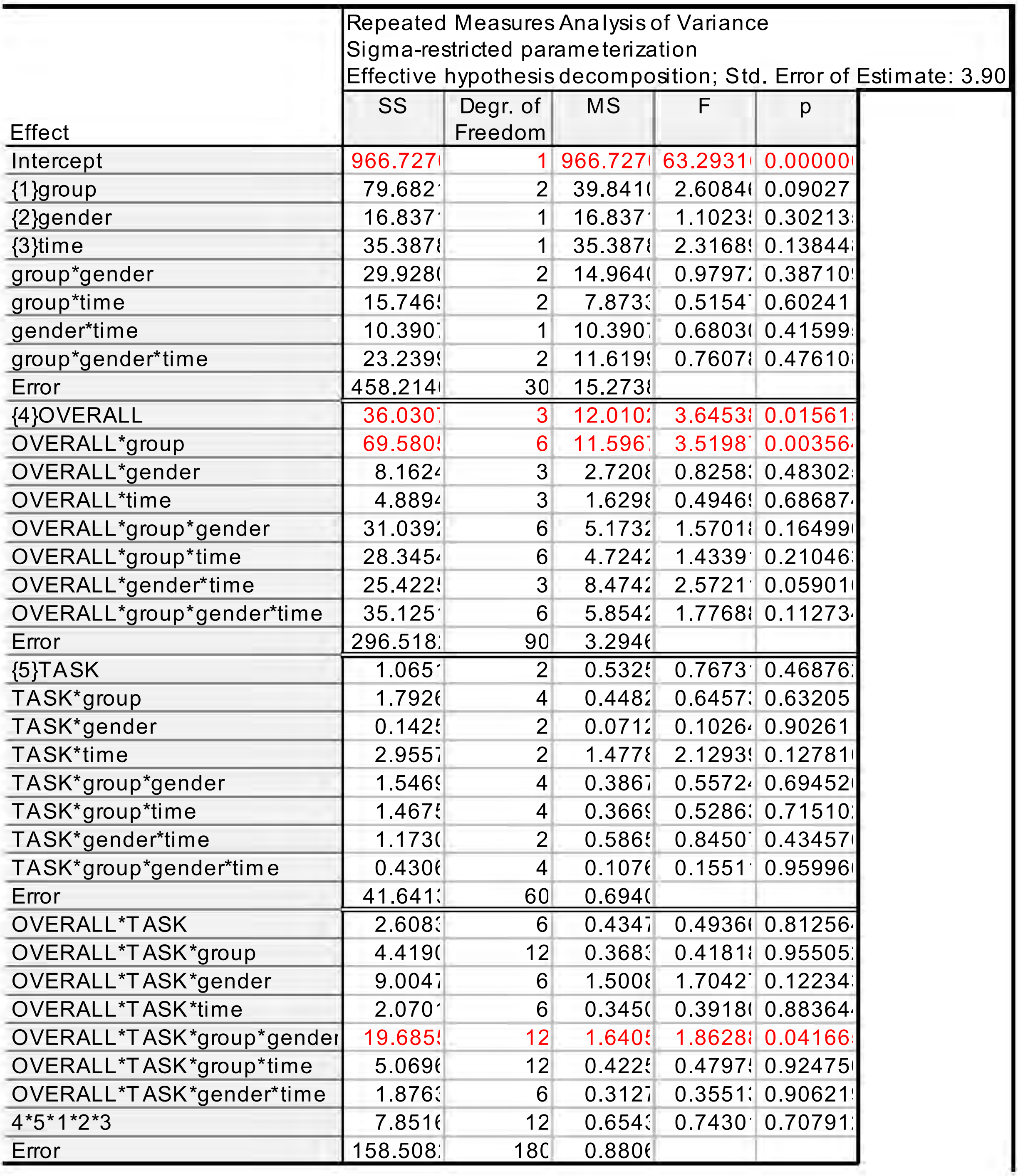
i. Percentage of long fixations



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.89

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	416.049	1	416.049	49.6238	0.00000
{1}group	2.442	2	1.221	0.1456	0.86506
{2}gender	0.319	1	0.319	0.0380	0.84658
{3}time	5.489	1	5.489	0.6547	0.42480
group*gender	2.680	2	1.340	0.1598	0.85296
group*time	4.454	2	2.227	0.2656	0.76847
gender*time	13.906	1	13.906	1.6587	0.20762
group*gender*time	13.695	2	6.847	0.8167	0.45145
Error	251.521	30	8.384		
{4}OVERALL	1.366	3	0.455	0.4197	0.73925
OVERALL*group	7.207	6	1.201	1.1071	0.36451
OVERALL*gender	3.298	3	1.099	1.0135	0.39058
OVERALL*time	0.585	3	0.195	0.1799	0.90977
OVERALL*group*gender	2.362	6	0.393	0.3628	0.90056
OVERALL*group*time	4.717	6	0.786	0.7247	0.63077
OVERALL*gender*time	0.991	3	0.330	0.3046	0.82199
OVERALL*group*gender*time	7.255	6	1.209	1.1145	0.36025
Error	97.646	90	1.085		
{5}TASK	1.290	2	0.645	0.4303	0.65227
TASK*group	4.146	4	1.036	0.6916	0.60065
TASK*gender	0.459	2	0.229	0.1533	0.85818
TASK*time	0.828	2	0.414	0.2762	0.75957
TASK*group*gender	2.528	4	0.632	0.4217	0.79232
TASK*group*time	3.503	4	0.875	0.5844	0.67512
TASK*gender*time	2.876	2	1.438	0.9594	0.38891
TASK*group*gender*time	2.223	4	0.555	0.3708	0.82849
Error	89.931	60	1.498		
OVERALL*TASK	2.708	6	0.451	0.6276	0.70802
OVERALL*TASK*group	10.348	12	0.862	1.1990	0.28675
OVERALL*TASK*gender	2.869	6	0.478	0.6650	0.67798
OVERALL*TASK*time	3.216	6	0.536	0.7453	0.61384
OVERALL*TASK*group*gender	6.615	12	0.551	0.7665	0.68424
OVERALL*TASK*group*time	6.227	12	0.518	0.7215	0.72921
OVERALL*TASK*gender*time	2.777	6	0.463	0.6437	0.69508
4*5*1*2*3	8.176	12	0.681	0.9473	0.50115
Error	129.454	180	0.719		

j. Saccade amplitude



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 3.90

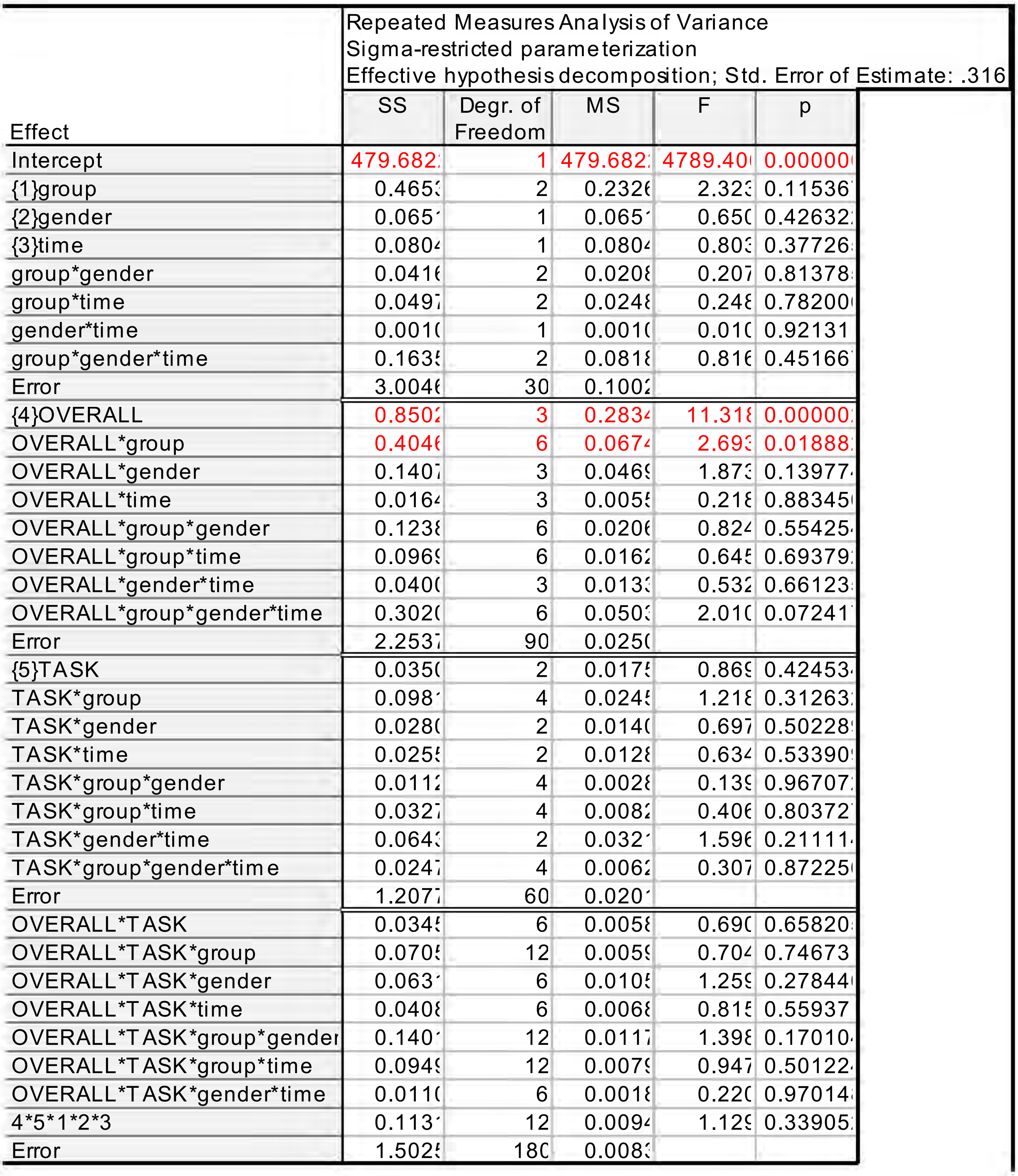
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	966.727	1	966.727	63.2931	0.00000
{1}group	79.682	2	39.841	2.6084	0.09027
{2}gender	16.837	1	16.837	1.1023	0.30213
{3}time	35.387	1	35.387	2.3168	0.13844
group*gender	29.928	2	14.964	0.9797	0.38710
group*time	15.746	2	7.873	0.5154	0.60241
gender*time	10.390	1	10.390	0.6803	0.41599
group*gender*time	23.239	2	11.619	0.7607	0.47610
Error	458.214	30	15.273		
{4}OVERALL	36.030	3	12.010	3.6453	0.01561
OVERALL*group	69.580	6	11.596	3.5198	0.00356
OVERALL*gender	8.162	3	2.720	0.8258	0.48302
OVERALL*time	4.889	3	1.629	0.4946	0.68687
OVERALL*group*gender	31.039	6	5.173	1.5701	0.16499
OVERALL*group*time	28.345	6	4.724	1.4339	0.21046
OVERALL*gender*time	25.422	3	8.474	2.5721	0.05901
OVERALL*group*gender*time	35.125	6	5.854	1.7768	0.11273
Error	296.518	90	3.294		
{5}TASK	1.065	2	0.532	0.7673	0.46876
TASK*group	1.792	4	0.448	0.6457	0.63205
TASK*gender	0.142	2	0.071	0.1026	0.90261
TASK*time	2.955	2	1.477	2.1293	0.12781
TASK*group*gender	1.546	4	0.386	0.5572	0.69452
TASK*group*time	1.467	4	0.366	0.5286	0.71510
TASK*gender*time	1.173	2	0.586	0.8450	0.43457
TASK*group*gender*time	0.430	4	0.107	0.1551	0.95996
Error	41.641	60	0.694		
OVERALL*TASK	2.608	6	0.434	0.4936	0.81256
OVERALL*TASK*group	4.419	12	0.368	0.4181	0.95505
OVERALL*TASK*gender	9.004	6	1.500	1.7042	0.12234
OVERALL*TASK*time	2.070	6	0.345	0.3918	0.88364
OVERALL*TASK*group*gender	19.685	12	1.640	1.8628	0.04166
OVERALL*TASK*group*time	5.069	12	0.422	0.4797	0.92475
OVERALL*TASK*gender*time	1.876	6	0.312	0.3551	0.90621
4*5*1*2*3	7.851	12	0.654	0.7430	0.70791
Error	158.508	180	0.880		

k. Saccade speed

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.16

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	613.363	1	613.363	131.091	0.00000
{1}group	23.165	2	11.582	2.475	0.10113
{2}gender	6.175	1	6.175	1.319	0.25970
{3}time	14.029	1	14.029	2.998	0.09361
group*gender	11.996	2	5.998	1.282	0.29224
group*time	4.595	2	2.297	0.491	0.61677
gender*time	5.234	1	5.234	1.118	0.29861
group*gender*time	6.460	2	3.230	0.690	0.50916
Error	140.366	30	4.678		
{4}OVERALL	8.578	3	2.859	3.002	0.03462
OVERALL*group	21.440	6	3.573	3.751	0.00223
OVERALL*gender	3.881	3	1.293	1.358	0.26070
OVERALL*time	2.007	3	0.669	0.702	0.55300
OVERALL*group*gender	10.821	6	1.803	1.893	0.09045
OVERALL*group*time	9.035	6	1.505	1.581	0.16177
OVERALL*gender*time	9.320	3	3.106	3.261	0.02509
OVERALL*group*gender*time	10.812	6	1.802	1.892	0.09074
Error	85.723	90	0.952		
{5}TASK	0.239	2	0.119	0.697	0.50167
TASK*group	0.527	4	0.131	0.768	0.55025
TASK*gender	0.046	2	0.023	0.134	0.87421
TASK*time	0.523	2	0.261	1.525	0.22587
TASK*group*gender	0.795	4	0.198	1.157	0.33854
TASK*group*time	0.727	4	0.181	1.059	0.38467
TASK*gender*time	0.487	2	0.243	1.418	0.25010
TASK*group*gender*time	0.253	4	0.063	0.368	0.83020
Error	10.302	60	0.171		
OVERALL*TASK	0.475	6	0.079	0.393	0.88256
OVERALL*TASK*group	1.399	12	0.116	0.578	0.85759
OVERALL*TASK*gender	1.994	6	0.332	1.649	0.13602
OVERALL*TASK*time	0.696	6	0.116	0.575	0.74933
OVERALL*TASK*group*gender	4.429	12	0.369	1.831	0.04607
OVERALL*TASK*group*time	1.207	12	0.100	0.499	0.91330
OVERALL*TASK*gender*time	0.466	6	0.077	0.385	0.88751
4*5*1*2*3	1.667	12	0.139	0.689	0.76023
Error	36.272	180	0.201		

I. Saccade duration



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .316

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	479.682	1	479.682	4789.40	0.00000
{1}group	0.465	2	0.232	2.32	0.11536
{2}gender	0.065	1	0.065	0.65	0.42632
{3}time	0.080	1	0.080	0.80	0.37726
group*gender	0.041	2	0.020	0.20	0.81378
group*time	0.049	2	0.024	0.24	0.78200
gender*time	0.001	1	0.001	0.01	0.92131
group*gender*time	0.163	2	0.081	0.81	0.45166
Error	3.004	30	0.100		
{4}OVERALL	0.850	3	0.283	11.31	0.00000
OVERALL*group	0.404	6	0.067	2.69	0.01888
OVERALL*gender	0.140	3	0.046	1.87	0.13977
OVERALL*time	0.016	3	0.005	0.21	0.88345
OVERALL*group*gender	0.123	6	0.020	0.82	0.55425
OVERALL*group*time	0.096	6	0.016	0.64	0.69379
OVERALL*gender*time	0.040	3	0.013	0.53	0.66123
OVERALL*group*gender*time	0.302	6	0.050	2.01	0.07241
Error	2.253	90	0.025		
{5}TASK	0.035	2	0.017	0.86	0.42453
TASK*group	0.098	4	0.024	1.21	0.31263
TASK*gender	0.028	2	0.014	0.69	0.50228
TASK*time	0.025	2	0.012	0.63	0.53390
TASK*group*gender	0.011	4	0.002	0.13	0.96707
TASK*group*time	0.032	4	0.008	0.40	0.80372
TASK*gender*time	0.064	2	0.032	1.59	0.21111
TASK*group*gender*time	0.024	4	0.006	0.30	0.87225
Error	1.207	60	0.020		
OVERALL*TASK	0.034	6	0.005	0.69	0.65820
OVERALL*TASK*group	0.070	12	0.005	0.70	0.74673
OVERALL*TASK*gender	0.063	6	0.010	1.25	0.27844
OVERALL*TASK*time	0.040	6	0.006	0.81	0.55937
OVERALL*TASK*group*gender	0.140	12	0.011	1.39	0.17010
OVERALL*TASK*group*time	0.094	12	0.007	0.94	0.50122
OVERALL*TASK*gender*time	0.011	6	0.001	0.22	0.97014
4*5*1*2*3	0.113	12	0.009	1.12	0.33905
Error	1.502	180	0.008		

APPENDIX C3

Effect of Music

The effect of music was analysed with a repeated-measures ANOVA considering the intervals before, during and after the music stimulus. The covariates analysed include “group” (the experimental group), “gender” (the gender of the subject) and “time” (the time of day that testing took place. Significant effects are highlighted in red.

1. Performance parameters
    a. Mean deviation

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .008 SS	Degr. of Freedom	MS	F	p
Intercept	0.01423	1	0.01423	192.979	0.000000
group	0.00003	2	0.00001	0.258	0.77368
gender	0.00002	1	0.00002	0.325	0.57258
time	0.00011	1	0.00011	1.525	0.22632
group*gender	0.00011	2	0.00005	0.751	0.48015
group*time	0.00020	2	0.00010	1.371	0.26916
gender*time	0.00000	1	0.00000	0.033	0.85510
group*gender*time	0.00007	2	0.00004	0.536	0.59038
Error	0.00221	30	0.00007		
MUSIC	0.00030	2	0.00015	15.021	0.00000
MUSIC*group	0.00000	4	0.00000	0.220	0.92572
MUSIC*gender	0.00000	2	0.00000	0.126	0.88107
MUSIC*time	0.00000	2	0.00000	0.386	0.68108
MUSIC*group*gender	0.00002	4	0.00000	0.521	0.72045
MUSIC*group*time	0.00001	4	0.00000	0.347	0.84461
MUSIC*gender*time	0.00002	2	0.00001	1.346	0.26791
MUSIC*group*gender*time	0.00001	4	0.00000	0.259	0.90262
Error	0.00061	60	0.00001		

b. Effective reaction time

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .0334

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.201549	1	0.201549	179.8439	0.000000
group	0.000608	2	0.000304	0.2711	0.764380
gender	0.000733	1	0.000733	0.6543	0.424950
time	0.001367	1	0.001367	1.2196	0.278212
group*gender	0.001160	2	0.000580	0.5174	0.601288
group*time	0.002654	2	0.001327	1.1841	0.319922
gender*time	0.00001	1	0.00001	0.0094	0.923287
group*gender*time	0.000938	2	0.000469	0.4185	0.661810
Error	0.03362	30	0.00112		
MUSIC	0.004083	2	0.002041	10.3648	0.000130
MUSIC*group	0.000400	4	0.000100	0.5080	0.730010
MUSIC*gender	0.000273	2	0.000136	0.6922	0.504444
MUSIC*time	0.000129	2	0.000065	0.3281	0.721564
MUSIC*group*gender	0.000269	4	0.000067	0.3413	0.849018
MUSIC*group*time	0.00060	4	0.000150	0.7623	0.553960
MUSIC*gender*time	0.000303	2	0.00015	0.7684	0.468253
MUSIC*group*gender*time	0.000147	4	0.000037	0.1871	0.944218
Error	0.011818	60	0.000197		

c. Information processing capacity

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 1.01

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2540.877	1	2540.877	2485.127	0.000000
group	1.191	2	0.596	0.583	0.56460
gender	0.892	1	0.892	0.872	0.35786
time	0.593	1	0.593	0.580	0.452220
group*gender	0.862	2	0.431	0.421	0.659917
group*time	1.762	2	0.881	0.862	0.432653
gender*time	0.144	1	0.144	0.141	0.709707
group*gender*time	0.641	2	0.321	0.313	0.73327
Error	30.673	30	1.022		
MUSIC	2.964	2	1.482	19.096	0.000000
MUSIC*group	0.119	4	0.030	0.384	0.819470
MUSIC*gender	0.226	2	0.113	1.453	0.24195
MUSIC*time	0.005	2	0.003	0.034	0.966609
MUSIC*group*gender	0.125	4	0.031	0.403	0.805660
MUSIC*group*time	0.259	4	0.065	0.833	0.509459
MUSIC*gender*time	0.162	2	0.081	1.045	0.357983
MUSIC*group*gender*time	0.260	4	0.065	0.838	0.506193
Error	4.656	60	0.078		

d. Steering alteration frequency

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .092

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	7.30361	1	7.30361	862.001	0.00000
group	0.01326	2	0.00663	0.782	0.46622
gender	0.00234	1	0.00234	0.277	0.60248
time	0.00582	1	0.00582	0.687	0.41349
group*gender	0.01672	2	0.00836	0.986	0.38454
group*time	0.01668	2	0.00834	0.984	0.38530
gender*time	0.00212	1	0.00212	0.250	0.62046
group*gender*time	0.00584	2	0.00292	0.344	0.71117
Error	0.25418	30	0.00847		
MUSIC	0.00970	2	0.00485	3.630	0.03248
MUSIC*group	0.00341	4	0.00085	0.638	0.63701
MUSIC*gender	0.00273	2	0.00136	1.023	0.36536
MUSIC*time	0.00048	2	0.00024	0.181	0.83450
MUSIC*group*gender	0.00099	4	0.00025	0.186	0.94433
MUSIC*group*time	0.00796	4	0.00199	1.489	0.21673
MUSIC*gender*time	0.00037	2	0.00018	0.140	0.86938
MUSIC*group*gender*time	0.00666	4	0.00166	1.245	0.30134
Error	0.08019	60	0.00133		

2. Cardiovascular parameters

a. Heart rate

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 17.3

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	549511.	1	549511.	1829.12	0.00000
group	737.	2	368.	1.22	0.30731
gender	448.	1	448.	1.49	0.23107
time	76.4	1	76.4	0.25	0.61774
group*gender	124.	2	62.4	0.20	0.81367
group*time	236.	2	118.	0.39	0.67826
gender*time	565.	1	565.	1.88	0.18019
group*gender*time	813.1	2	406.	1.35	0.27369
Error	9012.	30	300.		
MUSIC	59.	2	29.	11.74	0.00005
MUSIC*group	1.6	4	0.4	0.15	0.95894
MUSIC*gender	0.6	2	0.3	0.12	0.88008
MUSIC*time	1.1	2	0.6	0.22	0.79744
MUSIC*group*gender	1.8	4	0.5	0.18	0.94667
MUSIC*group*time	13.4	4	3.3	1.33	0.26799
MUSIC*gender*time	9.6	2	4.8	1.91	0.15616
MUSIC*group*gender*time	16.	4	4.2	1.681	0.16621
Error	150.	60	2.5		

b. RMSSD

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 49.70

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	475630.9	1	475630.9	192.0200	0.000000
group	482.4	2	241.2	0.0974	0.907499
gender	1285.7	1	1285.7	0.5190	0.476820
time	121.7	1	121.7	0.0491	0.826099
group*gender	5383.0	2	2691.5	1.0866	0.35027
group*time	61.4	2	30.7	0.0124	0.987692
gender*time	5765.7	1	5765.7	2.3277	0.137564
group*gender*time	6621.1	2	3310.5	1.3365	0.277950
Error	74309.4	30	2477.0		
MUSIC	185.3	2	92.7	0.7457	0.478743
MUSIC*group	91.4	4	22.9	0.1840	0.945870
MUSIC*gender	248.8	2	124.4	1.0012	0.373509
MUSIC*time	926.8	2	463.4	3.7292	0.029747
MUSIC*group*gender	1363.4	4	340.8	2.7429	0.036569
MUSIC*group*time	712.3	4	178.1	1.4331	0.234113
MUSIC*gender*time	492.2	2	246.1	1.9804	0.146927
MUSIC*group*gender*time	133.1	4	33.3	0.2677	0.897593
Error	7455.9	60	124.3		

c. PNN30

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 34.29

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	165056.2	1	165056.2	140.3442	0.000000
group	5024.1	2	2512.0	2.1359	0.135752
gender	751.0	1	751.0	0.6385	0.430525
time	310.2	1	310.2	0.2638	0.611292
group*gender	2092.4	2	1046.2	0.8896	0.421388
group*time	1353.7	2	676.9	0.5755	0.568494
gender*time	190.4	1	190.4	0.1619	0.690287
group*gender*time	677.9	2	338.9	0.2882	0.751673
Error	35282.5	30	1176.1		
MUSIC	459.4	2	229.7	6.4842	0.002822
MUSIC*group	206.0	4	51.5	1.4539	0.227552
MUSIC*gender	62.4	2	31.2	0.8811	0.419605
MUSIC*time	132.1	2	66.1	1.8650	0.163768
MUSIC*group*gender	56.5	4	14.1	0.3985	0.808929
MUSIC*group*time	274.0	4	68.5	1.9338	0.116440
MUSIC*gender*time	16.8	2	8.4	0.2375	0.789340
MUSIC*group*gender*time	75.3	4	18.8	0.5316	0.712932
Error	2125.3	60	35.4		

d. High frequency centre frequency

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .038

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	5.72559	1	5.72559	3835.78	0.00000
group	0.00164	2	0.00082	0.551	0.58213
gender	0.00080	1	0.00080	0.53	0.46882
time	0.00332	1	0.00332	2.22	0.14621
group*gender	0.00233	2	0.00116	0.78	0.46654
group*time	0.00535	2	0.00267	1.79	0.18368
gender*time	0.00000	1	0.00000	0.00	0.94507
group*gender*time	0.00021	2	0.00010	0.07	0.92958
Error	0.04478	30	0.00149		
MUSIC	0.00393	2	0.00196	11.59	0.00005
MUSIC*group	0.00087	4	0.00021	1.28	0.28573
MUSIC*gender	0.00034	2	0.00017	1.01	0.36826
MUSIC*time	0.00045	2	0.00022	1.32	0.27329
MUSIC*group*gender	0.00002	4	0.00000	0.03	0.99723
MUSIC*group*time	0.00016	4	0.00004	0.247	0.91022
MUSIC*gender*time	0.00008	2	0.00004	0.237	0.78976
MUSIC*group*gender*time	0.00021	4	0.00005	0.31	0.86612
Error	0.01018	60	0.00017		

e. Low frequency centre frequency

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .012

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.78209	1	0.78209	4735.90	0.00000
group	0.00011	2	0.00006	0.361	0.69970
gender	0.00025	1	0.00025	1.531	0.22554
time	0.00027	1	0.00027	1.64	0.20957
group*gender	0.00017	2	0.00008	0.52	0.59825
group*time	0.00008	2	0.00004	0.247	0.78306
gender*time	0.00065	1	0.00065	3.97	0.05542
group*gender*time	0.00035	2	0.00017	1.08	0.35160
Error	0.00495	30	0.00016		
MUSIC	0.00018	2	0.00009	2.80	0.06856
MUSIC*group	0.00051	4	0.00012	3.98	0.00620
MUSIC*gender	0.00007	2	0.00003	1.16	0.31980
MUSIC*time	0.00008	2	0.00004	1.25	0.29290
MUSIC*group*gender	0.00041	4	0.00010	3.22	0.01831
MUSIC*group*time	0.00020	4	0.00005	1.61	0.18298
MUSIC*gender*time	0.00009	2	0.00004	1.46	0.23962
MUSIC*group*gender*time	0.00027	4	0.00006	2.14	0.08684
Error	0.00193	60	0.00003		

f. High frequency power

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 1407

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	6504754	1	6504754	32.8421	0.00000
group	67900	2	33950	0.1714	0.84329
gender	139268	1	139268	0.7031	0.40835
time	50885	1	50885	0.2569	0.61595
group*gender	413228	2	206614	1.0431	0.36476
group*time	500501	2	250250	1.2635	0.29727
gender*time	401	1	401	0.0020	0.96441
group*gender*time	26990	2	13495	0.0681	0.93427
Error	5941842	30	198061		
MUSIC	34162	2	17081	1.1072	0.33711
MUSIC*group	16844	4	4211	0.2729	0.89427
MUSIC*gender	35031	2	17515	1.1354	0.32808
MUSIC*time	8809	2	4404	0.2855	0.75264
MUSIC*group*gender	32759	4	8189	0.5308	0.71346
MUSIC*group*time	5484	4	1371	0.0888	0.98559
MUSIC*gender*time	12161	2	6080	0.3941	0.67596
MUSIC*group*gender*time	24225	4	6056	0.3926	0.81314
Error	925582	60	15426		

g. Low frequency power

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2673

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	28912893	1	28912893	40.4514	0.00000
group	160702	2	80351	0.1124	0.89404
gender	80042	1	80042	0.1119	0.74022
time	238949	1	238949	0.3343	0.56744
group*gender	2372698	2	1186349	1.6598	0.20716
group*time	246177	2	123088	0.1722	0.84262
gender*time	419295	1	419295	0.5866	0.44971
group*gender*time	667439	2	333719	0.4669	0.63142
Error	21442678	30	714755		
MUSIC	304478	2	152239	1.2665	0.28923
MUSIC*group	64967	4	16241	0.1351	0.96877
MUSIC*gender	104652	2	52326	0.4353	0.64908
MUSIC*time	424647	2	212323	1.7664	0.17971
MUSIC*group*gender	894355	4	223588	1.8601	0.12923
MUSIC*group*time	908072	4	227018	1.8886	0.12412
MUSIC*gender*time	250878	2	125439	1.0435	0.35849
MUSIC*group*gender*time	55386	4	13846	0.1152	0.97667
Error	7212047	60	120200		

h. Low frequency component of (LF+HF) power

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 23.8

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	468154.	1	468154.	820.412	0.00000
group	1779.	2	889.	1.558	0.22694
gender	2292.	1	2292.	4.017	0.05412
time	0.1	1	0.1	0.000	0.98870
group*gender	341.	2	170.	0.299	0.74357
group*time	825.	2	412.	0.723	0.49334
gender*time	694.	1	694.	1.217	0.27865
group*gender*time	126.	2	63.	0.110	0.89545
Error	17119.	30	570.		
MUSIC	837.	2	418.	6.036	0.00408
MUSIC*group	61.	4	15.	0.223	0.92452
MUSIC*gender	320.	2	160.	2.305	0.10845
MUSIC*time	773.	2	386.	5.575	0.00601
MUSIC*group*gender	473.	4	118.	1.705	0.16060
MUSIC*group*time	741.	4	185.	2.670	0.04058
MUSIC*gender*time	111.	2	55.	0.803	0.45245
MUSIC*group*gender*time	357.	4	89.4	1.288	0.28463
Error	4163.	60	69.4		

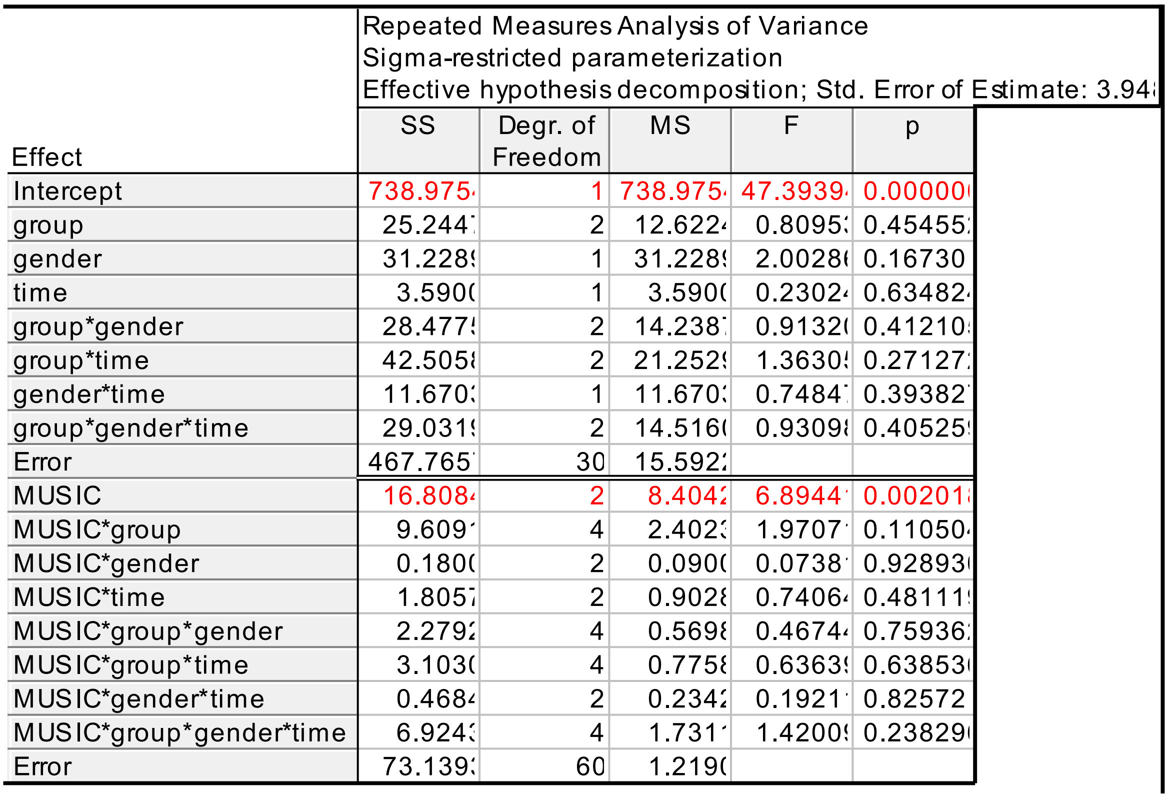
3. Oculomotor parameters

a. Pupil diameter

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .258

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	80.0934	1	80.0934	1202.23	0.00000
group	0.0356	2	0.0178	0.267	0.76710
gender	0.3132	1	0.3132	4.702	0.03818
time	0.0536	1	0.0536	0.806	0.37653
group*gender	0.0487	2	0.0243	0.366	0.69652
group*time	0.0426	2	0.0213	0.320	0.72831
gender*time	0.0240	1	0.0240	0.362	0.55209
group*gender*time	0.2372	2	0.1186	1.781	0.18586
Error	1.9986	30	0.0666		
MUSIC	0.0414	2	0.0207	20.93	0.00000
MUSIC*group	0.0098	4	0.0024	2.486	0.05289
MUSIC*gender	0.0014	2	0.0007	0.749	0.47702
MUSIC*time	0.0003	2	0.0001	0.191	0.82674
MUSIC*group*gender	0.0047	4	0.0011	1.194	0.32289
MUSIC*group*time	0.0015	4	0.0004	0.400	0.80767
MUSIC*gender*time	0.0001	2	0.0000	0.059	0.94257
MUSIC*group*gender*time	0.0122	4	0.0030	3.107	0.02167
Error	0.0593	60	0.0009		

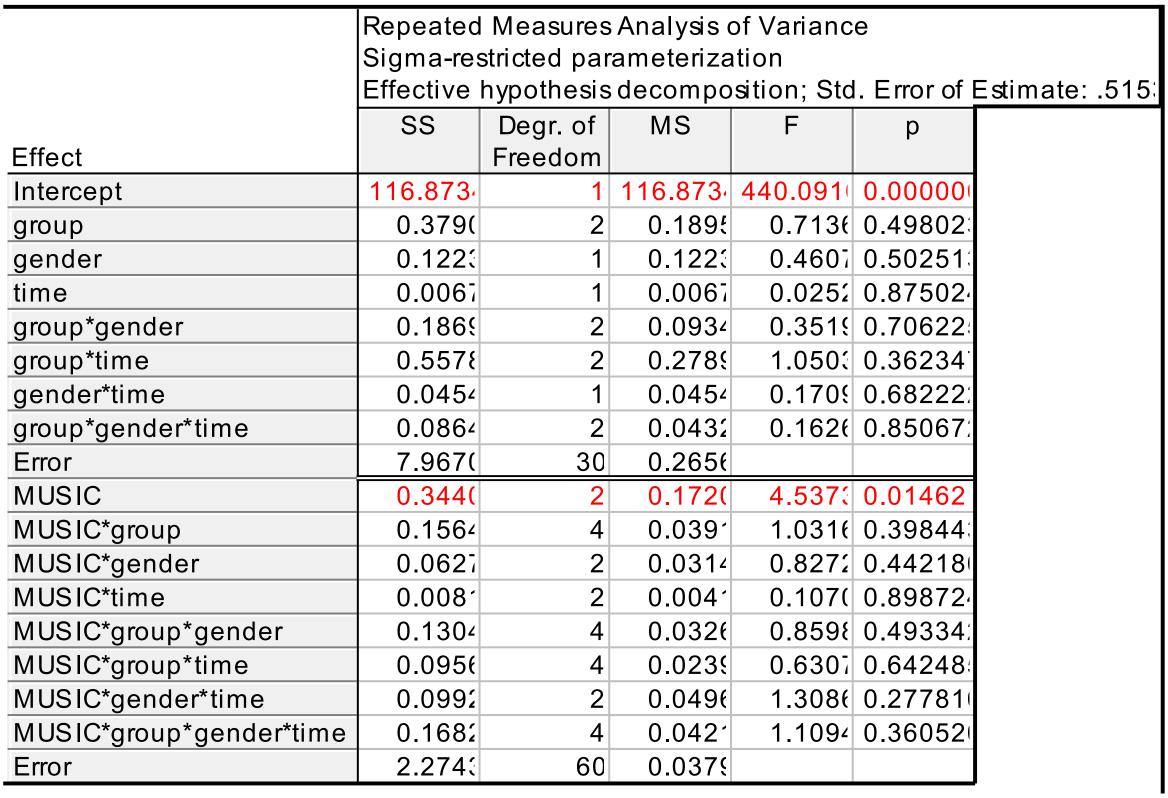
b. Blink frequency



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 3.94

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	738.975	1	738.975	47.3939	0.00000
group	25.244	2	12.622	0.8095	0.45455
gender	31.228	1	31.228	2.0028	0.16730
time	3.590	1	3.590	0.2302	0.63482
group*gender	28.477	2	14.238	0.9132	0.41210
group*time	42.505	2	21.252	1.3630	0.27127
gender*time	11.670	1	11.670	0.7484	0.39382
group*gender*time	29.031	2	14.516	0.9309	0.40525
Error	467.765	30	15.592		
MUSIC	16.808	2	8.404	6.8944	0.00201
MUSIC*group	9.609	4	2.402	1.9707	0.11050
MUSIC*gender	0.180	2	0.090	0.0738	0.92893
MUSIC*time	1.805	2	0.902	0.7406	0.48111
MUSIC*group*gender	2.279	4	0.569	0.4674	0.75936
MUSIC*group*time	3.103	4	0.775	0.6363	0.63853
MUSIC*gender*time	0.468	2	0.234	0.1921	0.82572
MUSIC*group*gender*time	6.924	4	1.731	1.4200	0.23829
Error	73.139	60	1.219		

c. Blink duration



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .515

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	116.873	1	116.873	440.091	0.00000
group	0.379	2	0.189	0.713	0.49802
gender	0.122	1	0.122	0.460	0.50251
time	0.006	1	0.006	0.025	0.87502
group*gender	0.186	2	0.093	0.351	0.70622
group*time	0.557	2	0.278	1.050	0.36234
gender*time	0.045	1	0.045	0.170	0.68222
group*gender*time	0.086	2	0.043	0.162	0.85067
Error	7.967	30	0.265		
MUSIC	0.344	2	0.172	4.537	0.01462
MUSIC*group	0.156	4	0.039	1.031	0.39844
MUSIC*gender	0.062	2	0.031	0.827	0.44218
MUSIC*time	0.008	2	0.004	0.107	0.89872
MUSIC*group*gender	0.130	4	0.032	0.859	0.49334
MUSIC*group*time	0.095	4	0.023	0.630	0.64248
MUSIC*gender*time	0.099	2	0.049	1.308	0.27781
MUSIC*group*gender*time	0.168	4	0.042	1.109	0.36052
Error	2.274	60	0.037		

d. Short fixation duration

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .099

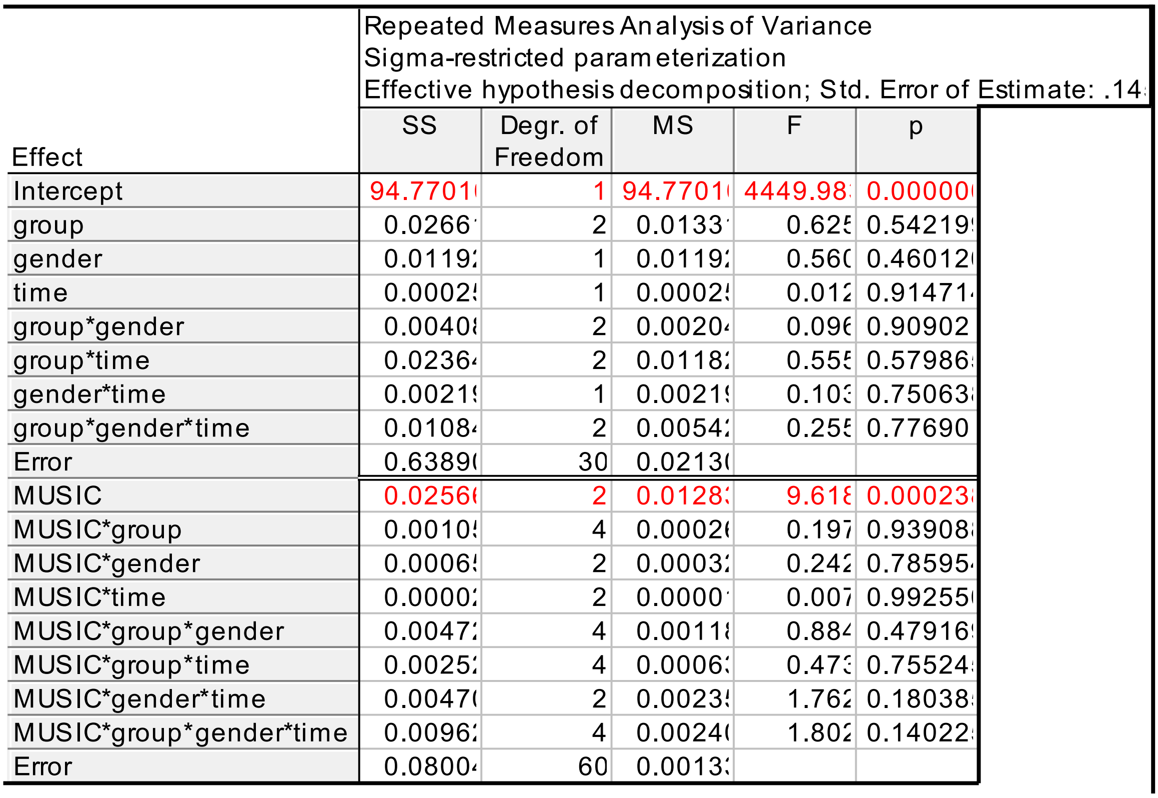
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	99.6220	1	99.6220	9982.95	0.00000
group	0.0725	2	0.0363	3.637	0.03851
gender	0.0395	1	0.0395	3.96	0.055657
time	0.01237	1	0.01237	1.24	0.27434
group*gender	0.0196	2	0.0098	0.98	0.38486
group*time	0.0019	2	0.0009	0.09	0.90841
gender*time	0.0234	1	0.0234	2.351	0.13570
group*gender*time	0.0033	2	0.0016	0.16	0.84503
Error	0.2993	30	0.0099		
MUSIC	0.0078	2	0.0039	1.68	0.19402
MUSIC*group	0.0095	4	0.0023	1.02	0.40417
MUSIC*gender	0.0008	2	0.0004	0.181	0.83519
MUSIC*time	0.0033	2	0.0016	0.71	0.49492
MUSIC*group*gender	0.0070	4	0.0017	0.75	0.56210
MUSIC*group*time	0.0016	4	0.0004	0.17	0.95077
MUSIC*gender*time	0.0013	2	0.0006	0.28	0.75457
MUSIC*group*gender*time	0.0102	4	0.0025	1.09	0.36863
Error	0.1402	60	0.0023		

e. Percentage of short fixations

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .617

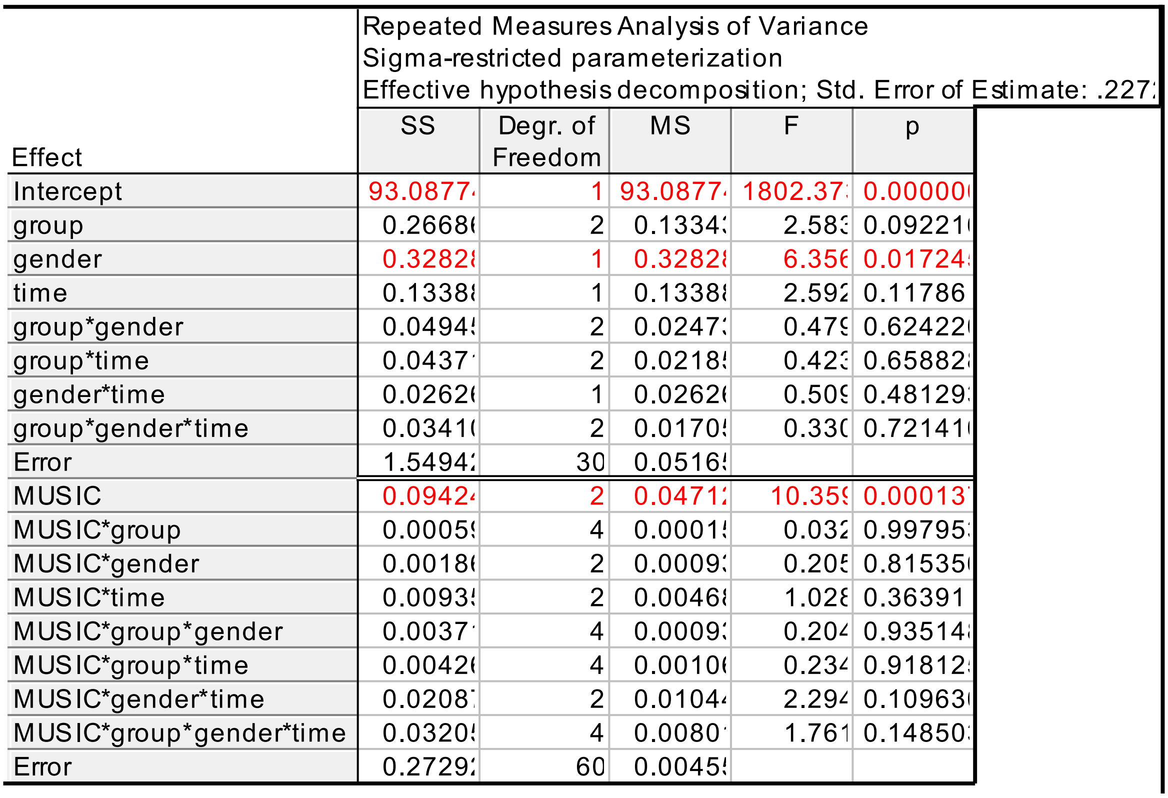
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	142.000	1	142.000	372.987	0.00000
group	0.974	2	0.487	1.280	0.292777
gender	1.962	1	1.962	5.154	0.03053
time	0.464	1	0.464	1.219	0.27823
group*gender	0.0757	2	0.037	0.099	0.90565
group*time	0.069	2	0.034	0.091	0.91269
gender*time	0.028	1	0.028	0.075	0.78578
group*gender*time	0.098	2	0.049	0.129	0.87867
Error	11.421	30	0.3807		
MUSIC	0.766	2	0.383	9.730	0.00021
MUSIC*group	0.072	4	0.018	0.457	0.76668
MUSIC*gender	0.071	2	0.036	0.913	0.40669
MUSIC*time	0.173	2	0.0867	2.203	0.11932
MUSIC*group*gender	0.044	4	0.011	0.283	0.88778
MUSIC*group*time	0.1437	4	0.035	0.912	0.46258
MUSIC*gender*time	0.208	2	0.104	2.645	0.07925
MUSIC*group*gender*time	0.123	4	0.030	0.7837	0.54024
Error	2.361	60	0.039		

f. Medium fixation duration



Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .14 SS	Degr. of Freedom	MS	F	p
Intercept	94.7701	1	94.7701	4449.98	0.00000
group	0.0266	2	0.0133	0.625	0.54219
gender	0.0119	1	0.0119	0.56	0.46012
time	0.0002	1	0.0002	0.01	0.91471
group*gender	0.0040	2	0.0020	0.09	0.90902
group*time	0.0236	2	0.0118	0.555	0.57986
gender*time	0.0021	1	0.0021	0.10	0.75063
group*gender*time	0.0108	2	0.0054	0.255	0.77690
Error	0.6389	30	0.0213		
MUSIC	0.0256	2	0.0128	9.61	0.00023
MUSIC*group	0.0010	4	0.0002	0.197	0.93908
MUSIC*gender	0.0006	2	0.0003	0.24	0.78595
MUSIC*time	0.0000	2	0.0000	0.007	0.99255
MUSIC*group*gender	0.0047	4	0.0011	0.88	0.47916
MUSIC*group*time	0.0025	4	0.0006	0.47	0.75524
MUSIC*gender*time	0.0047	2	0.0023	1.76	0.18038
MUSIC*group*gender*time	0.0096	4	0.0024	1.80	0.14022
Error	0.0800	60	0.0013		

g. Percentage of medium fixations



Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: .227 SS	Degr. of Freedom	MS	F	p
Intercept	93.0877	1	93.0877	1802.37	0.00000
group	0.2668	2	0.1334	2.58	0.09221
gender	0.3282	1	0.3282	6.35	0.01724
time	0.1338	1	0.1338	2.59	0.11786
group*gender	0.0494	2	0.0247	0.47	0.62422
group*time	0.0437	2	0.0218	0.42	0.65882
gender*time	0.0262	1	0.0262	0.50	0.48129
group*gender*time	0.0341	2	0.0170	0.33	0.72141
Error	1.5494	30	0.0516		
MUSIC	0.0942	2	0.0471	10.35	0.00013
MUSIC*group	0.0005	4	0.0001	0.03	0.99795
MUSIC*gender	0.0018	2	0.0009	0.205	0.81535
MUSIC*time	0.0093	2	0.0046	1.02	0.36391
MUSIC*group*gender	0.0037	4	0.0009	0.20	0.93514
MUSIC*group*time	0.0042	4	0.0010	0.23	0.91812
MUSIC*gender*time	0.0208	2	0.0104	2.29	0.10963
MUSIC*group*gender*time	0.0320	4	0.0080	1.761	0.14850
Error	0.2729	60	0.0045		

h. Long fixation duration

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estim

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	92.7566	1	92.7566	1810.46	0.00000
group	0.1830	2	0.0915	1.78	0.18496
gender	0.1079	1	0.1079	2.10	0.15702
time	0.0023	1	0.0023	0.04	0.83328
group*gender	0.2850	2	0.1425	2.781	0.07796
group*time	0.1077	2	0.0538	1.051	0.36209
gender*time	0.0115	1	0.0115	0.22	0.63860
group*gender*time	0.2236	2	0.1118	2.18	0.13029
Error	1.5370	30	0.0512		
MUSIC	0.0306	2	0.0153	0.36	0.69288
MUSIC*group	0.1565	4	0.0391	0.94	0.44466
MUSIC*gender	0.1983	2	0.0991	2.39	0.10006
MUSIC*time	0.0113	2	0.0056	0.13	0.87267
MUSIC*group*gender	0.0474	4	0.0118	0.28	0.88585
MUSIC*group*time	0.1604	4	0.0401	0.96	0.43189
MUSIC*gender*time	0.0746	2	0.0373	0.90	0.41197
MUSIC*group*gender*time	0.1028	4	0.0257	0.621	0.64960
Error	2.4868	60	0.0414		

i. Percentage of long fixations

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 1.88

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	123.876	1	123.876	34.894	0.00000
group	0.776	2	0.388	0.1093	0.89677
gender	1.790	1	1.790	0.5043	0.48310
time	0.336	1	0.336	0.0948	0.76028
group*gender	2.055	2	1.027	0.2895	0.75067
group*time	4.033	2	2.016	0.5681	0.57257
gender*time	1.704	1	1.704	0.4801	0.49367
group*gender*time	5.671	2	2.835	0.7988	0.45919
Error	106.499	30	3.550		
MUSIC	1.097	2	0.548	1.1841	0.31306
MUSIC*group	0.710	4	0.177	0.3831	0.81987
MUSIC*gender	0.078	2	0.039	0.0850	0.91857
MUSIC*time	0.379	2	0.190	0.4098	0.66556
MUSIC*group*gender	0.578	4	0.144	0.3121	0.86874
MUSIC*group*time	0.354	4	0.088	0.1913	0.94200
MUSIC*gender*time	0.259	2	0.129	0.2802	0.75660
MUSIC*group*gender*time	1.265	4	0.316	0.6825	0.60681
Error	27.807	60	0.463		

j. Saccade amplitude

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 4.04

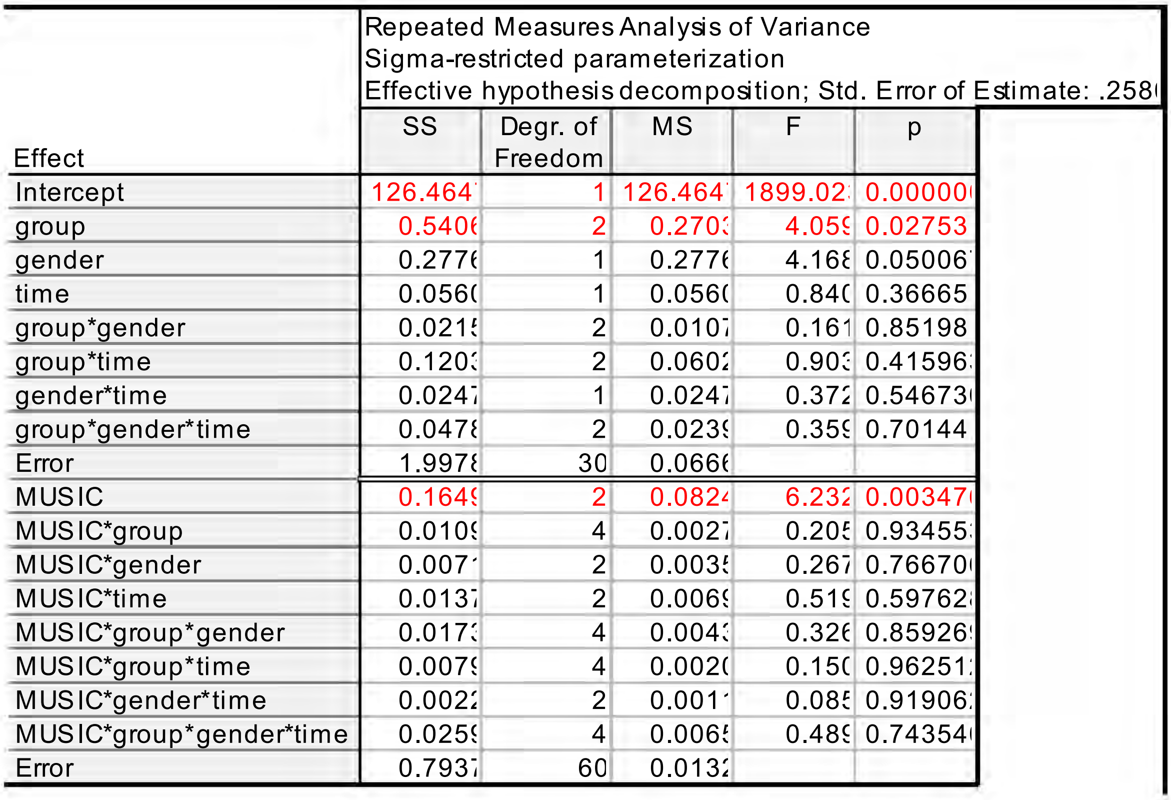
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	304.723	1	304.723	18.6302	0.00015
group	73.439	2	36.719	2.2449	0.12343
gender	9.502	1	9.502	0.5809	0.45188
time	29.044	1	29.044	1.7757	0.19271
group*gender	30.844	2	15.422	0.9428	0.40074
group*time	41.017	2	20.508	1.2538	0.29993
gender*time	20.679	1	20.679	1.2642	0.26975
group*gender*time	32.421	2	16.210	0.9911	0.38299
Error	490.690	30	16.356		
MUSIC	9.322	2	4.661	9.3712	0.00028
MUSIC*group	4.032	4	1.008	2.0268	0.10202
MUSIC*gender	2.408	2	1.204	2.4212	0.09744
MUSIC*time	4.124	2	2.062	4.1463	0.02057
MUSIC*group*gender	1.597	4	0.399	0.8028	0.52818
MUSIC*group*time	1.551	4	0.387	0.7799	0.54263
MUSIC*gender*time	2.561	2	1.280	2.5749	0.08455
MUSIC*group*gender*time	3.331	4	0.832	1.6744	0.16772
Error	29.842	60	0.497		

k. Saccade speed

Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: 2.18

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	176.635	1	176.635	37.0969	0.00000
group	22.244	2	11.122	2.3358	0.11407
gender	4.264	1	4.264	0.8955	0.35152
time	8.658	1	8.658	1.8183	0.18760
group*gender	12.055	2	6.027	1.2659	0.29661
group*time	10.058	2	5.029	1.0562	0.36034
gender*time	7.904	1	7.904	1.6600	0.20744
group*gender*time	10.325	2	5.162	1.0842	0.35103
Error	142.843	30	4.761		
MUSIC	2.705	2	1.352	13.5161	0.00001
MUSIC*group	1.491	4	0.372	3.7256	0.00897
MUSIC*gender	0.880	2	0.440	4.3986	0.01649
MUSIC*time	1.246	2	0.623	6.2281	0.00348
MUSIC*group*gender	0.522	4	0.130	1.3064	0.27789
MUSIC*group*time	0.398	4	0.099	0.9947	0.41750
MUSIC*gender*time	1.218	2	0.609	6.0899	0.00390
MUSIC*group*gender*time	1.124	4	0.281	2.8088	0.03326
Error	6.004	60	0.100		

I. Saccade duration



Repeated Measures Analysis of Variance
Sigma-restricted parameterization
Effective hypothesis decomposition; Std. Error of Estimate: .258

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	126.464	1	126.464	1899.02	0.00000
group	0.540	2	0.270	4.05	0.02753
gender	0.277	1	0.277	4.16	0.05006
time	0.056	1	0.056	0.84	0.36665
group*gender	0.021	2	0.010	0.161	0.85198
group*time	0.120	2	0.060	0.90	0.41596
gender*time	0.024	1	0.024	0.37	0.54673
group*gender*time	0.047	2	0.023	0.35	0.70144
Error	1.997	30	0.066		
MUSIC	0.164	2	0.082	6.23	0.00347
MUSIC*group	0.010	4	0.002	0.20	0.93455
MUSIC*gender	0.007	2	0.003	0.26	0.76670
MUSIC*time	0.013	2	0.006	0.51	0.59762
MUSIC*group*gender	0.017	4	0.004	0.32	0.85926
MUSIC*group*time	0.007	4	0.002	0.15	0.96251
MUSIC*gender*time	0.002	2	0.001	0.08	0.91906
MUSIC*group*gender*time	0.025	4	0.006	0.48	0.74354
Error	0.793	60	0.013		