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Investigating Tools and Methods for Data Capture of Forestry Workers

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Abstract

The forestry industry in New Zealand has been in the spotlight for many years due to its poor health and safety record. Workplace locations are often remote requiring extended travel times and worksites rarely offer any shelter from the elements. The nature of the work is physically demanding, requiring lots of 'boots on the ground' time, as such employees can be susceptible to impaired performance due to workplace fatigue. In order to assess the impact of activity on performance we initially investigated the relationship between activity measured as steps and simple reaction time. Using Fitbit Charge HR activity trackers we collected physiological data and tested reaction time at various times throughout the day. We identified that an inverse curve relationship existed between activity and reaction time; slower times being recorded at the start and end of the day with faster times through the middle of the day.

We then expanded the scope of our study to incorporate individuals working in the forestry industry. PF Olsen a forest management company, sourced sub-contractor crews currently undertaking tree felling and harvesting operations within the Bay of Plenty. Participating crews used separate operational techniques; mechanised by way of plant, manual using a more hands on approach, and hauling, a combination of the two aforementioned techniques.

Using the same activity monitors as in our preliminary study we collected physiological data off crew members as they performed their daily duties. In order to assess the possible impact of fatigue we measured both simple and choice reaction time at three periods during the working day; start of shift, after four hours work and at the end of the shift. As workplace locations are open to the elements we also

collected ambient temperature readings to further assess their impact as a contributory factor to performance impairment. We identified that in cold temperatures < 0^{o}C individuals have slower reaction times, as temperature increases reaction time decreases. Furthermore we identified that reaction time varies across the daily monitoring periods; generally following the slow-fast-slow relationship as found in our preliminary study. We also noted large variations in reaction time for individuals working in close proximity to mechanised plant, suggesting that the extra vigilance needed to complete tasks in operational areas that are shared with mechanised plant can negatively impact the speed at which an individual can react. The use of automated activity collection facilitated by the use of activity monitors has also provided an insight into the physiological demands of typical roles performed within the harvesting operations. We also suggest captured data from activity trackers can be used in conjunction with current risk assessment processes to add an extra dimension to the risk assessment process, facilitating a more informed view of individual role demands.

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CHAPTER 1 – INTRODUCTION

The forestry industry in New Zealand has a poor Health and Safety record with some 12,921 active Accident Compensation Corporation (ACC) claims between 2008 and 2013; more importantly the number of reported fatalities for the same period is 32. Such high levels of fatalities are concerning to the industry with reforms being planned to address safety of employees. Suggestions based on experimental data are limited, and difficult to source. Currently, the only practicable solution is seen as increasing the level of mechanisation; remove the employee from the worksite and remove the risk.

Commercial forestry operations in New Zealand are large in scale with 1.7 million hectares currently in use as commercial forests, split between state and private ownership (Statistics New Zealand, 1999). The industry is covered by four primary associations, The New Zealand Institute of Forestry is the professional body under which fall three separate associations; Forest Owners Association (FOA) covering forest owners, Forest Industry Contractors Association (FICA) covering contractors and the New Zealand Farm Forest Association (NZFFA) covering smaller farm owned forestry blocks.

Companies such as PF Olsen and Hancock Forest Management act as a ‘middle man’ providing management and consultancy services; they source and manage contactors for operations such as harvesting, planting and forest maintenance. As well as providing a management service these middle man companies police contractors, ensuring on site operations comply with both operational standards and relevant legislation such as the Health and Safety at Work Act.

Work is distributed by way of tender for which smaller companies compete for contracts covering the operational aspects of harvesting, transport and silviculture. These smaller companies are generally small in size having a workforce of < 20 employees with roles split between manual and mechanical operators.

According to Statistics New Zealand the workforce is biased to both younger and Maori employees, 21.5 percent are aged 15 – 24 (5.6 percent higher than the total New Zealand workforce) with 38.5 percent identifying as Maori (27.2 percent higher than the total New Zealand workforce). Low levels of educational achievement are prevalent within the industry with over 60 percent having no formal post-school qualifications, however current competency requirements are seeing more and more individuals completing industry specific training.

The work is hard both physically and mentally with operations being performed irrespective of the weather, as such there is a high level of employee turnover; 45 percent of individuals change jobs within the first 12 months leading to a start rate of around 3000 individuals annually (Forest Industry Contractors Association, 2014). This combined with a poor pay rate ($17.50 per hour median, Payscale Inc., 2015) has contributed to a high rate of worker attrition. The Forest Industry Contractors Association (FICA), 2015 identifies the need to attract and retain employees, and as such have proposed a strategy to promote forestry as a career be developed.

Recently (2014) the large numbers of incidents reported prompted the Independent Forestry Safety Review, a report sponsored by the Forestry Industry Contractors Association, the Forest Owners Association and the New Zealand Farm Forestry Association. The focus of the review was to identify and analyse the factors that

impact on health and safety within the forestry industry and to produce guidelines designed to minimize the amount of incidents. Data was gathered primarily by way of questionnaires to which there were over 330 respondents; this seems a large number although Statistics New Zealand, 2013 state 6,910 employees are employed within the forestry and logging industries.

It was identified that the forestry industry is one of the most dangerous occupations in New Zealand; employees being 15 times more likely to suffer a workplace injury compared to other NZ based industries (Forestry Safety Review, 2014). The nature of the work is physically demanding; employees can expend as much energy throughout the course of their day as an athlete would in running a marathon (Kirk, 1996). Such a high level of energy expenditure combined with hazardous working environments can substantially contribute to the levels of risk employees are exposed to.

Worksites are generally remote requiring the working day be lengthened to incorporate travel time. This extension to the working day combined with the physically demanding workload can cause issues with fatigue in workers and adversely impact safe working practices (Spurgeon, Harrington & Cooper, 1997) and be a contributor to the high numbers of incidents within the industry.

Findings of the review identified many issues that could be addressed; and provided recommendations that could be used to improve the poor health and safety record. It identified that impairment through fatigue can be a contributor to safe working practices, recommending that impairment indicators currently being developed by Worksafe NZ should incorporate the effects of fatigue. They further address issues

such as working conditions; workplaces tend to be outside, and of hazardous nature, and as such are subject to weather extremes and difficult terrain.

These aspects can exacerbate the impact of fatigue (Ellis, 1982, Pilcher, Nadler and Busch, 2002); high demand tasks require more energy to complete; as such employees may experience the effects of fatigue earlier. The importance of welfare facilities was also noted; employees need to be able to take breaks in an area sheltered from adverse weather conditions. The provision of such facilities and recovery periods (breaks) can allow levels of fatigue to reduce minimizing the effect of fatigue induced impairment, reducing workplace risk.

Although there are many facets that may cause impairment such as drug and alcohol use, this thesis focuses on the impact of fatigue, and its contributors within a workplace context; that being the forestry industry. It further discusses how real time physiological monitoring may be utilised to identify the onset of fatigue and how this data may be used to supplement the risk assessment process.

There has been no large scale data-collection on fatigue in the forestry industry, information to date has been based on questionnaires and self-reporting of selected groups of workers. This method of data collection has many pitfalls as it is subjective by nature and susceptible to response bias; individuals tend to agree with questions (Samuels, 2002).

1.1 Research Question

This research has two main objectives, the first being to determine if it is possible to use physiological data as a basis for determining an individual's ability to perform a given task; if so can this information be used to better identify risk, and be used as an

early indicator of fatigue? Secondly it examines the use of commercially available fitness monitoring devices as a tool for gathering physiological data and investigates how changes in this data when used in conjunction with simple and choice reaction time testing can be used as a predictor of fatigue. By investigating these two variables we can then consider what types of technology based solutions may be suitable for ongoing monitoring of workers and their conditions as a first step towards a larger safety solution.

Wearable technologies (activity trackers) exist that facilitate automated collection of physiological data; as such they provide quantitative rather than qualitative data. However as they are not designed to collect data in challenging environments, such as those found in the forestry industry, part of this study serves to investigate their durability.

This thesis forms part of a larger scale study designed to investigate the impact of fatigue in the workplace, it investigates the use of quantitative data as a method for determining work task intensity. Furthermore it investigates mechanisms to measure activity and reaction time to assess the impact of high work rates on an individual in the field and to determine if physiological data can be used to provide feedback/warnings to individuals indicating possible impairment through fatigue.

It is hoped that information generated by this research will positively impact upon the poor health and safety record within industries, such as, the New Zealand forestry industry.

1.2 Study Scope

Currently there are a large number of commercially available activity trackers in the marketplace, each offering different levels of accuracy and types of data collected. We examine the suitability of these devices as a tool for gathering quantitative physiological data in a workplace environment and evaluate the most popular devices currently available.

There are numerous indicators of activity, such as oxygen consumption, heart rate, calorific burn etc. investigation was also undertaken into which indicators of activity best suited evaluation of workload and could be used as determinants of task intensity.

Reaction time has been a common method for the identification of fatigue (Brisswalter *et al*, 1997, Åkerstedt *et al*, 2002, Chang *et al*, 2009). The forestry industry is productivity based, as such investigations into reaction time measurement methodology was also undertaken to identify a method causing least disruption to workplace activities.

1.3 Thesis structure

Chapter 2 discusses the nature of fatigue and identifies easily collectable physiological and environmental variables that can contribute to fatigue within individuals. It discusses how an individual's fatigue level can be negatively impacted by these variables and further discusses previous works related to each of the measurable indicators, it also investigates the impact of monitoring on employer – employee relationships and discusses the need for monitoring external to the workplace. Poor sleep quality can also impact an individual's ability to perform, as

such we further discuss limited sleep as a contributor to fatigue. Chapter 3 introduces the use of activity monitors as a method of data collection, and evaluates their suitability for use in our study, additionally we discuss the use of reaction time as a dependent variable and identify the method of testing used in our study. In chapter 4 we present the methodology undertaken in our study, workplace activities are identified and general observations of environmental conditions are discussed. Chapter 5 presents the results of the individual monitoring sessions conducted across the course of the study it summarises both activity by role and reaction time by work period. In chapter 6 we discuss the results obtained and how they both compare and contrast to existing works; we also discuss the differing workloads between role types. Chapter 7 provides conclusions and recommendations for future works into the effect of task intensity on fatigue.

CHAPTER 2 - BACKGROUND

This chapter defines fatigue as both a physiological and mental state experienced by individuals. We examine previous works on physical and mental fatigue, and how they impact on an individual's ability to perform sustained tasks. Furthermore we identify a set of easily measureable variables both physiological and environmental that can be seen as contributors to fatigue, and examine previous works undertaken on each. Sleep quality is seen as a major contributor to fatigue, although not measured outside of phase one of our studies, the importance of sleep is discussed separately within Section 2.3.

2.1 Fatigue

Fatigue can be classified into two general types; mental fatigue that affects an individual's cognitive processes and physical fatigue that affects an individual's ability to maintain physical actions. Both types of fatigue are cumulative by nature in that the more a task is performed the level of fatigue generated by performing the task increases; although both types of fatigue lessen after a period of rest.

Although quantifiable by such indicators as reduction of muscle strength for physical fatigue, and slower response times for mental fatigue, it is a subjective physiological state experienced by individuals as a result of either physical or mental exertion. The levels of fatigue experienced are determined by the individual's perception of these physiological changes. The nature of this physiological state can be best explained by Desmond, Matthews and Hancock, 2012 as:

> "The taking possession of the mind by a sense of lassitude. It is a reduction in the capacity and desire to react. It is characterized by tiredness and an aversion to the continuation of goal-directed work. It is accompanied by a strong desire for rest through the cessation of ongoing activity."

This desire for rest is an evolutionary physiological process designed to protect an individual from harm. Fatigue provides a barrier designed to leave enough energy available to an individual should unexpected threats occur and rapid reaction be required. This barrier is able to be overcome by an individual's determination or desire to complete a goal. This can be thought of as a 'return on investment', with energy expenditure being the invested variable; for example, does the reward from the goal completion justify the energy expenditure.

The amount of energy required for either physical tasks or tasks requiring high levels of cognitive processing are personal to the individual concerned. The level of energy expenditure required for task completion being dependent upon many factors such as age, physical fitness and mental ability.

Individuals have a level of available energy that is unique to them available for task completion; as this level diminishes the physiological feelings of fatigue increase until the individual either completes the task or gives up. There is some contention as to whether fatigue should or even could be separated into separate areas; many researchers believe fatigue is a general state that is driven

by physiological responses to energy expenditure (Hockey, R., & Ebrary, I. 2013).

2.1.2 Physical fatigue

Physical fatigue is the feeling of exhaustion or tiredness that accompanies repeated physical exertions. This often results in a feeling that much more effort is required to move the muscle. A good example of this would be after one has done too much activity in a given time period; such as taking an extra-long bicycle ride or going for an extra-long run.

Repeated use of individual muscle groups reduce the amount of oxygen being supplied to the muscle groups resulting in an increase of lactic acid as glycogen is anaerobically broken down, leading to intracellular acidosis. Inorganic phosphate (Pi) accumulates as phospoceratine (PCr) is broken down to ceratine (Cr) and Pi. This results in a reduction of muscle efficiency and reduction in the force exerted by the muscles. Allen and Westerbald, (2001) state:

> "There is a decline in the performance of muscles when they are used at near their maximum capacity. The changes in performance include reduced force production, decreased velocity of shortening, and slowed relaxation; the combination of these factors can lead to profound reductions in performance particularly for rapidly repeated movements."

Investigating the concentration of inorganic phosphate within myoplasm they identify a substantial increase during fatigue, affecting the muscle activation process.

In a study undertaken by Eberstien and Sandow, (1963) muscles were deliberately fatigued using tetanic contraction, and the force exerted by the muscle measured. They found a reduction in measured force as the duration of the muscle contraction exercise increased. In an interesting conclusion they shared that the use of caffeine could reverse a large proportion of the decline in force of a fatigued muscle.

This was somewhat reinforced in a study by Graham, Hibbert and Sathasivan (1998). They studies nine subjects who exercised to voluntary exhaustion by way of running on a treadmill. Exhaustion was recorded as the point at which the subject could no longer run at the required speed or slope. This exhaustion process was repeated after treating subjects with a dose of 4.45mg/kg of caffeine based on the subject's weight, delivered by caffeine capsules, decaffeinated coffee plus caffeine capsules or regular coffee. Although they reported no significant difference when caffeine was administered by regular coffee they did measure a 31% increase in endurance levels when caffeine was administered by capsule.

In a similar study of physical fatigue Kumar, Tyler, Narayan and Prasad, 2002 found a steady reduction in force over the duration of a physical task. Using nine students from the University of Alberta they induced physical fatigue by asking the subjects to undertake a physically demanding exercise and measured oxygen uptake, ventilation, heart rate, blood oxygenation, blood volume and Electromyographic readings. They state that as the duration of muscle contractions increased the level of fatigue also increased.

2.1.3 Mental fatigue

The frontal lobes of the human brain are an area that controls the executive process of the brain involving higher level organization and the execution of complex thoughts and behaviour (Alvarez and Emory, 2006). Mental fatigue induced by long periods of cognitive processing can impact these executive processes and reduce their efficiency. Norman and Shallice, 2000 proposed five situations which could be impacted if an individual is suffering from mental fatigue:

1. Those that involve planning or decision making
2. Those that involve error correction or troubleshooting
3. Situations where responses are not well-rehearsed or contain novel sequences of actions
4. Dangerous or technically difficult situations
5. Situations that require the overcoming of a strong habitual response or resisting temptation

In a workplace context, especially where employees are working in remote locations such as those found within the forestry industry, detrimental effects from mental fatigue especially on points 1, 3 and 4 can invariably lead to situations where individuals can come to harm.

Increasing levels of mental fatigue have been shown to effect task motivation and moods with both being adversely affected when an individual is mentally fatigued. A study by Linden, Frese and Meijamin, (2002) using the Wisconsin Card Sorting Test, and the Tower of London Test designed to induce mental fatigue found:

> "Willingness to exert effort on the experimental tasks and to do ones best on these tasks, as measured directly after the manipulation, was significantly lower for the fatigued participants than for the non-fatigued participants."

As such, a higher the level of mental fatigue experienced by an individual can result in lower productivity levels. This conclusion was reinforced by Murata, Uetake, Takasawa (2004), where they found "fatigue is usually related to a loss of efficiency and disinclination to work."

Disturbed sleep can be defined as anything that interrupts an individual's natural sleeping patterns; and can have many causes ranging from medical such as sleep apnoea, fibromyalgia and nocturia through to insomnia triggered by such issues as stress and anxiety. The lack of total sleep obtained by an individual has been shown to increase the levels of mental fatigue experienced by an individual whilst performing cognitive tasks.

Akerstedt, Knutsson, Westerholm, Theorell, Alfredaon and Kecklund (2003), found that disturbed sleep is an important predictor of fatigue. They also state that fatigue is closely related to high work demands, immersion in work and disturbed sleep.

Their experiment conducted in Stockholm, Sweden consisted of 3250 males and 2470 females (N= 5710) who provided data on sleep by use of the Karolinska Sleep Questionnaire, developed by Kerstedt , Fredlund, Gillberg, Jansson, 2005 where individuals rate their quality of sleep.

The level of cognitive load encountered during the day was measured using the Karasek/Theorell demand control model detailing the relationship between job demands and decision making (cognitive processing requirements) Figure 1.

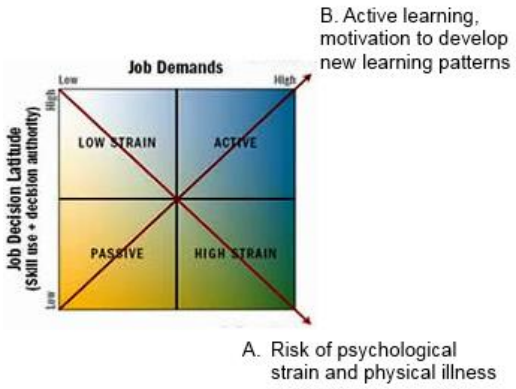


Figure 1. Job demand control model. From *Healthy work: stress, productivity and the reconstruction of working life* by R. Karasek, and T. Theorell, 1990. New York: Basic Books. Reprinted with permission.

Defining low control as:

> "de-skilled labour and reduced decision making autonomy. Employees in this position are not given the leeway to make decisions regarding their work or work environment. They also do not have the opportunity to learn new skills on the job or problem solve."

and high control as:

> "Inadequate time to meet job demands and excessive workload. When asked about their workload, employees in high demand situations often say, 'I work very fast and/or hard,' and, 'There is not enough time to get the job done'."

The combination of these two factors can induce mental fatigue that can be responsible for loss in production or work efficiency or more importantly a reduction in levels of alertness.

2.2 Measurable indicators of fatigue

The symptoms of fatigue are unique to the individual experiencing the physiological state; desire for goal completion reduces proportionately to the perceived levels of fatigue. This physiological state designed as a safety mechanism to prevent harm, presents some measurable variables that can be used to determine when an individual is experiencing reduced performance. Increases in physiological systems such as heart rate and core temperature can be used to provide indicators of physical activity. Measured increases in physiological readings when combined with duration, can be used to indicate how active an individual has been. Higher levels of activity when compared to baseline levels can indicate fatigue, and if used within an industrial context can identify increased risk.

2.2.1 Simple Reaction Time (SRT)

Developed by Galton in 1889, the simple reaction time test is a measure of the length of time it takes an individual to respond to either a visual or auditory stimulus. Response is usually the press of a button on presentation of the stimulus. The test itself is usually comprised of a predetermined number of sub trials with the result being presented as an average of these sub trials. It is used in the testing of general alertness and motor speed of an individual with uncertainty being introduced by a variable time period between individual trials.

In the context of this thesis reaction time is used as a measure of fatigue within an individual over the course of a work period; slower reaction times indicating the effects of fatigue.

In a study by Brisswalter, Arcelin, Audiffren and Deligniers, (1997) examining the influence of physical exercise on simple reaction time participants exercised at 20%, 40%, 60%and 80% of their maximal aerobic power. During the exercise period Brisswalter *et al* identified a decrease in cognitive performance, although on completion of the exercise period no significant difference in simple reaction time was apparent. This led them to conclude that 'during an imposed physical task, a negative effect on the performance of a simple decisional task can be observed' and that 'among workloads, this deterioration depends on the physical fitness of subjects'

2.2.2 Choice Reaction Time (CRT)

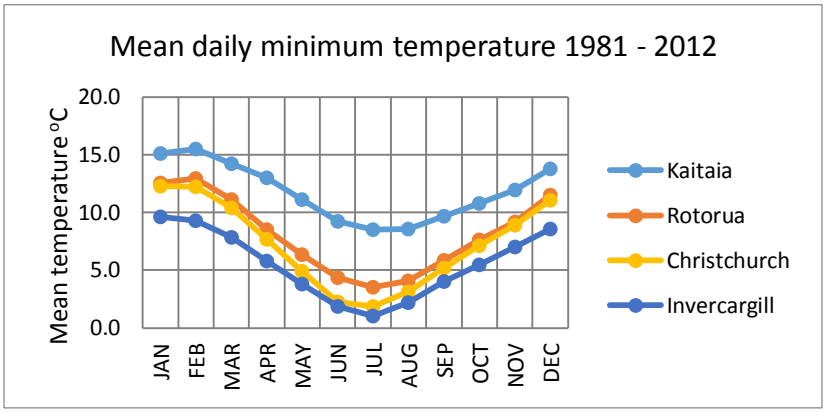
Being somewhat similar to simple reaction time choice reaction times measures the response time of an individual when presented with a visual stimulus, although this test requires the subject to make a choice. These choices are usually presented visually and require a certain response to a stimulus. A prime example being that a user is presented with a visual representation of an arrow pointing either left or right and they must select the corresponding button on a keypad. The act of having to choose the correct response requires more cognitive processing than simple reaction time and can indicate delays that may be caused by impairment such as fatigue. Tests are usually comprised of a predetermined number of sub trials which require selection of the correct response to a stimulus. Uncertainty is added by the requirement to choose, and

a variable time between presentations of the stimulus. On completion of testing choice reaction time is presented as an average of the sub trials.

A study conducted by Sabzi, (2012) investigated the effect of exercise induced fatigue on choice reaction time. Using a mix of exercise types, aerobic, anaerobic, mixed, prolonged intermittent and super maximal intermittent, Sabzi measured the choice reaction time of 15 participants both before and after exercise periods. Increase in reaction time was identified across all exercise types with anaerobic, mixed and super maximal intermittent producing the largest differences, respectively. This leaded Sabzi to conclude that 'exercise induced fatigue could reduce choice reaction time'.

2.2.3 Ambient temperature

New Zealand, due to its geographical location has a wide temperature differential across its area; NIWA Science, 2014 provides mean daily temperature data indicating a range of $0^{o}C$ (Southland) measured in winter to $24^{o}C$ (Northland) measured in summer (Figure 2). Climate conditions can dictate ambient temperatures that individuals work at, especially if duties are outdoor based, such as construction, farming and forestry. Employees working in high or low temperatures can be at risk of hypothermic or hyperthermic conditions which can impact their physiological state.



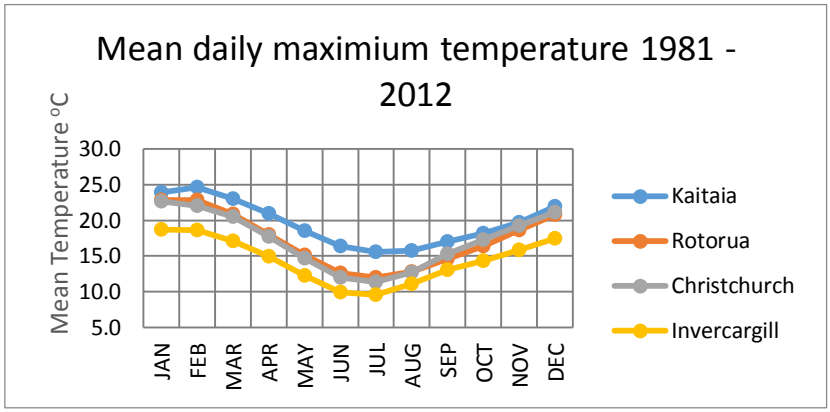


Figure 2. Minimum and maximum daily temperature 1981 – 2012. From National Institute of Water & Atmospheric Research. (2014). *Past climate variations over New Zealand.*

Note: Temperatures represent the daily mean values, not maximum and minimum temperatures.

Pilcher, Nadler and Busch, 2002 undertook a meta-analysis on the effects of temperature, both hot and cold, on performance. Using the American Psychological Association's PsychInfo database, Ergonomics and Human Factors journals they identified prior studies undertaken to examine the effect of environmental temperature on performance. This identified 22 studies

yielding 515 effect sizes on which meta-analysis was performed using an SAS Institute computer program developed by Huffcutt, Arthur and Bennett, 1992.

For the basis of their analysis Pilcher *et al.* defined separate categories for both hot and cold environmental conditions, three representing high temperature, Hot1, Hot2 and Hot3; two representing low temperature, Cold1 and Cold2. Hot1 represented experimental temperatures ranging between 21.11 and 26.61^{o}C, Hot2 between 26.67 and 32.17^{o}C and Hot3 greater than 32.22^{o}C. Cold1 represented experimental temperatures ranging between 10 and 18.28^{o}C and Cold2 less than 10^{o}C.

Pre-task exposure time was defined by length with short exposure being less than 59 minutes and long exposure greater than 60 minutes. Tasks undertaken after exposure were defined as either reaction, attention, mathematical or reasoning; duration of task was defined as either short 1-59 minutes or long >60 minutes.

Meta-analysis results identified both cold and hot temperatures had negative effects with deterioration in performance increasing as ambient temperature moved further away from neutral temperature (Figure 3). Overall they noted a 7.61% reduction in performance in comparison to the neutral temperature condition. It was also identified that exposure to cold temperatures produced poorer results with a 10.06% mean decrement against a 5.96% mean decrement for high temperature exposure.

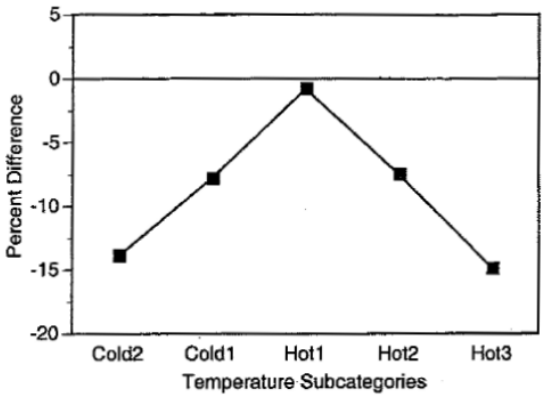


Figure 3. Mean percentage difference in performance between temperature groups. From "Effects of hot and cold temperature exposure on performance: a meta-analyitic review" by J.J. Pilcher, E. Nadler and C. Busch, 2002, *Ergonomics,45*(10), p.692. Copyright Taylor and Francis Group, LLC 2002. Reprinted with permission.

Note: Cold2: < 10°C; Cold1 10 – 18.28°C; Hot1 21.11 – 26.62°C; Hot2 26.67 – 32.17°C; Hot3 ≥ 32.22°C.

Results from the meta-analysis indicate that performance is negatively affected by either hot or cold temperatures and length of exposure produces worse performance. Pilcher *et al*. conclude that 'industries requiring workers to perform under either hot or cold temperature conditions should be aware of the potential negative effects of temperature exposure on performance.'

2.2.4 Core body temperature

The human body has a built in regulatory process (thermoregulation) that is designed to maintain a core temperature between 36.1°C and 37.5°C, core body temperatures outside of this range result in discomfort. Physical symptoms begin to be experienced once core temperatures fall outside of this temperature

range. Increasing core temperatures initially result in feelings of discomfort, irritability and sweating (38^{o}C), through to fainting, weakness, and dizziness (40^{o}C) and ultimately death (44^{o}C). Decreasing core temperatures result in feelings of cold and shivering (36^{o}C), through to blue colouration and confusion (34^{o}C) and ultimately death (24^{o}C).

Although experiencing such extremes of temperature is rare especially in the working environment it is possible for individuals to experience rise or fall in core temperature due to environmental conditions and work performed. This variation of core temperature can impact both physical and mental performance leading to fatigue and increased risk.

Hypothermia, defined as a decrease in core temperature below the optimal value of 37^{o}C and has been found to impair performance and increase reaction times (Rammsayer, Bahner and Netter, 1995). Using a climatic chamber body core temperature was lowered to a mean of 36.18^{o}C (n=15) by means of lowering ambient temperature to 5^{o}C for a 20 minute period. On completion of the cooling period reaction and movement time readings were taken using response to a visual stimulus, based on the Stimulus Evaluation-Response Selection (SERS) test developed by Halliday and Callaway at the University of California. Response tasks were designated as easy stimulus/easy response, easy stimulus/hard response, hard stimulus/easy response and hard stimulus/hard response.

On completion of testing results were compared with a control group (n=15) who were held at an ambient temperature of 28^{o}C. Correlation analysis between

reaction time and movement time along with body core temperature and mean skin temperature indicated significant positive correlation between body core temperature and reaction time (Figure 4).

	Control group		Cold Group	
	BCT	MST	BCT	MST
Reaction Time				
EE	-.11	.20	.38(*)	.06
EH	-.16	.14	.51*	.09
HE	-.20	.24	.61**	.12
HH	.05	.23	.73**	.19
Movement Time				
EE	.01	.11	-.32	-.05
EH	-.10	.01	-.34(*)	-.10
HE	-.12	.08	-.54*	-.03
HH	-.07	.03	-.38(*)	-.11

(*): $p < .10$; *: $p < .05$; **: $p < .01$

(BCT: body core temperature; MST:mean skin temperature;
EE: easy stimulus/easy response; EH: easy stimulus/hard response;
HE: hard stimulus/easy response; HH: hard stimlus/hard response).

Figure 4. Results of correlation analysis. From "Effects of cold on human information processing: application of a reaction time paradigm" by T.E. Rammasayer, 1995, *Integrative Physiological & Behavioral Science: the official journal of the Pavlovian Society 30*(1), p43. Copyright 1995 Springer. Reprinted with permission.

In concluding Ramnsayer *et al.* suggest that 'lowering of core body temperature may differentially affect various stages of human information processing.' They further postulate that 'a decrease in body core temperature of approximately 0.5ºC directly affects response-related stages of information processing and that their preliminary findings may be relevant for performance in cold working environments.'

Similar findings on impaired performance due to low core body temperatures were identified by Ellis, 1982. Using a combination of serial choice reaction time (SCRT) where both errors and response lag are measured, simple reaction time to a visual stimulus and Stroop Word Colour Test participants (n=6) were exposed to cold ambient temperatures (-12^{o}C) for a period of 120 minutes. Measurements for each variable were taken prior to exposure, twice throughout the duration of expose and after exposure. Core body temperature was determined by the use of a rectal thermistor probe.

Results of the study indicate a mean increase in simple reaction time of 6.7msec (1.6%). Stroop testing yielded an increase in time to name 100 colours of 22.4sec (24.6%), although this difference was not statistically significant (2.2, $p > 0.05$). SCRT provided the best indicator of impaired performance with low core body temperatures with an increase in error scores between 200 and 300% (Figure 5).

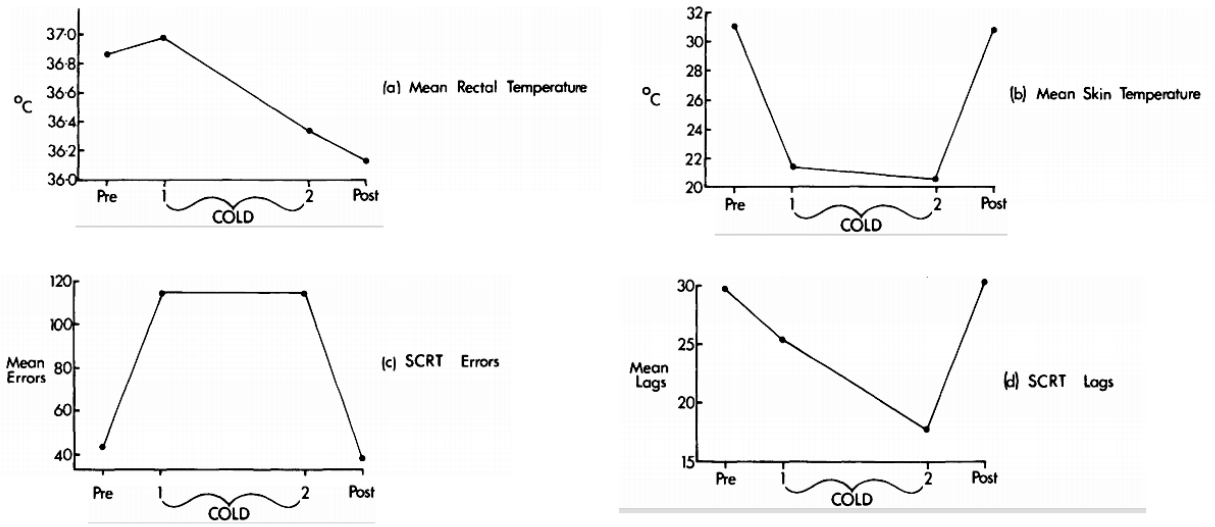


Figure 5. Mean rectal and skin temperatures for eight subjects in experiment 2. From The Effects of Cold on the Performance of Serial Choice Reaction Time and Various Discrete Tasks, by H. Ellis, 1982, *Human Factors*, 24(5) p.595. Copyright 1982 Elsevier B.V. Reprinted with permission.

Both experiments reviewed above indicate a reduction in performance when core body temperature drops. Impaired performance is not only limited to physical aspects of cold such as those brought about by shivering, trembling hands etc. cognitive processes can also be adversely effected. In essence the lower the core body temperature falls, the higher the amount of impairment.

Hyperthermia, defined as an increase in core temperature outside of the range of 37°C for resting and 38°C for moderate exercise, impairs performance during prolonged exercise (Journal of Thermal Biology, 2003). It is a state that affects both the central nervous system (CNS) and the cardiovascular system, negatively impacting an individual's ability to sustain effort required for goal completion. In a review of hyperthermia and fatigue Nybo, (2008) stated that

> "During high-intensity exercise, reduced performance is highly associated with failure of the cardiovascular system to maintain arterial oxygen delivery to the exercising muscles, whereas hyperthermia-induced fatigue during prolonged exercise originates mainly from perturbations of the brain's ability to sustain sufficient activation of the skeletal muscles."

In a study of prolonged exercise and fatigue Nybo and Nielsen, (2001) using maximal voluntary contraction of both exercised (leg) and non-exercised (hand) muscle groups, identified a reduction in force that could be applied. Fatigue was induced by way of a 1 hour cycling trial with individuals experiencing ambient temperatures of 18^{o}C (control group) and 40^{o}C (experimental group). On completion of the fatiguing session applied force by means of knee extension was used to determine reduction of force in exercised muscle groups. Similar force measurements were taken on un-fatigued muscle groups by means of grip strength measurements.

Figure 6 demonstrates the reduction in force of exercised muscle groups applied by the control group and those participants suffering exercise induced hyperthermia.

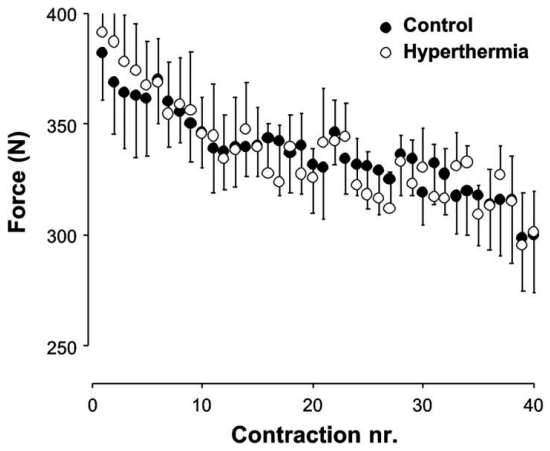


Figure 6. Maximal force development during 40 consecutive MVCs with knee extensors**.** From "Hyperthermia and central fatigue during prolonged exercise in humans" by L. Nybo and B. Nielsen, 2001, *Journal of Applied Physiology, 91*(3), p. 1057. Copyright 2001 The American Physiological Society. Reprinted with permission.

This trend of reduction in applied force was also seen in the non-exercised muscle groups (hand) with lower applied force being measured in hyperthermia induced participants (Figure 7).

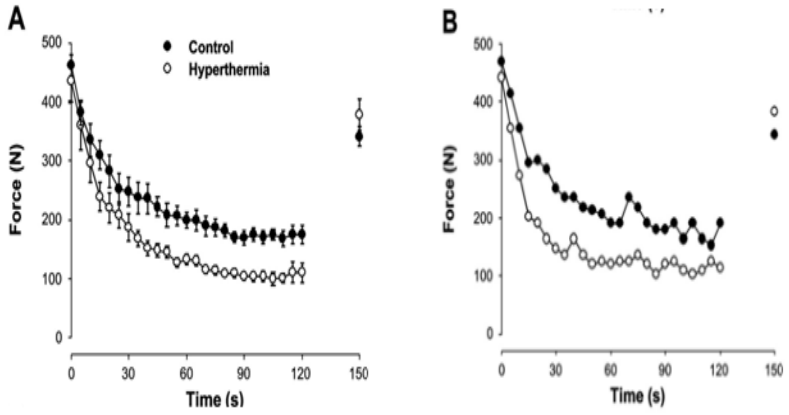


Figure 7. Change in applied force over time. Adapted from "Hyperthermia and central fatigue during prolonged exercise in humans" by L. Nybo and B. Nielsen, 2001, *Journal of Applied Physiology, 91*(3), p. 1059. Copyright 2001 The American Physiological Society. Reprinted with permission.

Note: *A*: changes in force during 2 min of sustained maximal handgrip contraction with or without exercise-induced hyperthermia. Data are means ± SE for 8 subjects. *B*: changes in force during 2 min of sustained maximal handgrip contraction with or without passively induced hyperthermia (mean of 2 subjects).

2.2.5 Heart rate

The measured heart rate of an individual can be used as an estimator of physical activity; higher levels of activity result in higher heart rates. Monitoring an individual's heart rate throughout the course of a work period can be an indicator of how active they have been and how likely they are to be suffering from fatigue. Although heart rate is largely dependent upon such criteria as age and fitness levels, maximal heart rate can be calculated from the general formula equation Maximal Heart Rate = 220 – Age (Karvonen, Kentala and Mustala, 1957). The resultant figure can then be used in conjunction with resting heart rate ($REST_{hr}$) to determine periods of high and low activity. The maximal heart rate (MAX_{hr}) for an individual of 48 years is given by:

$$\text{Maximal heart rate } (MAX_{hr}) = 220 - 48 = 172\text{bpm}$$

This figure can then be used to determine periods of high or low activity where activity is measured as a percentage of maximal heart rate; for example a heart rate of 119bpm can be calculated where intensity of activity (ACT) is given at 50% by:

$$\text{Heart rate} = ((MAX_{hr} - REST_{hr}) \times ACT) + REST_{hr}$$

It is proposed that heart rate v activity duration can be used as an indicator of fatigue; longer times within high heart rate activity zones equate to higher levels of fatigue.

Figure 8 provides an example of the experimenter's heart rate collected over two separate days, during phase one of this study. Days were chosen to represent high activity, 18,068 steps, and low activity 3,347 steps. It indicates higher levels of heart rate proportional to activity; measured as steps by means of a Fitbit Charge HR wrist worn fitness device.

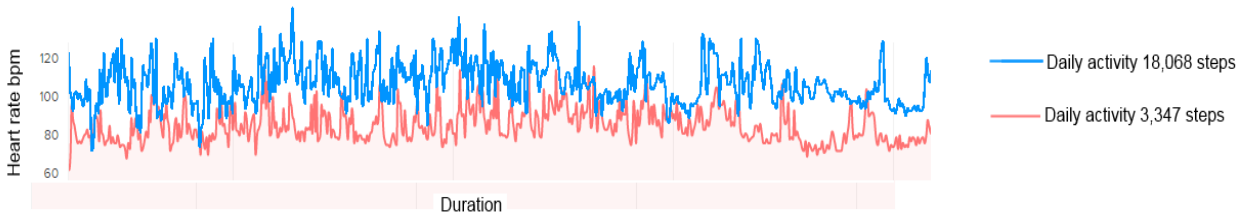


Figure 8. Heart rate traces showing daily activity measured by Fitbit Charge HR.

Similar monitoring of heart rate over working period duration was undertaken by Bates and Schneider (2006) as part of a study into physiological responses of construction workers in thermally stressful environments. The study was designed to determine if workers were becoming fatigued throughout the course of their work period, assess trends in hydration and to perform a heat-stress risk assessment. Although Bates & Schneider measured additional variables such as temperature and hydration levels only heart rate monitoring is discussed here.

Heart rates of construction workers (carpenters, steel fixers and general labourers), was continually monitored every 30 seconds for a period of three days by use of a Polar S720i heart rate monitor. Results from the monitoring were used to determine fatigue by means of comparison; average heart rate measured daily both in the morning and afternoon.

They did not identify significant changes in mean heart rate between morning and afternoon work periods (Figure 9). This led to Bates & Schneider hypothesizing 'either workers are not becoming fatigued, or they are self-pacing, that is, slowing down to avoid over-exertion.' They did however identify a positive (correlation coefficient 0.719) relationship between heart rate and fluid intake suggesting that

> "those workers who worked harder (higher heart rates) drank more fluid. An alternate explanation may be that those that drink more fluid can work harder. The latter explanation, if correct, would be of significant interest to employers and may promote better supply and availability of suitable fluid on work sites."

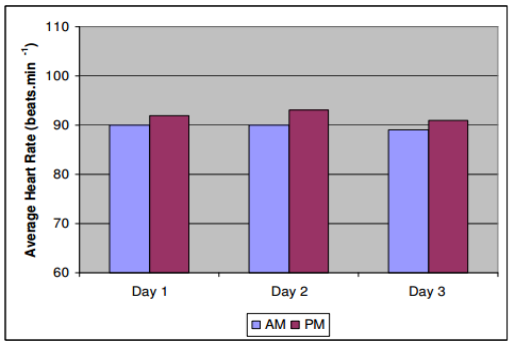


Figure 9. Average heart rates. From Hydration status and physiological workload of UAE construction workers: A prospective longitudinal observational study, by G. Bates and J. Schneider, 2006, *Journal of Occupational Medicine and Toxicology*, p.7. Copyright 2008 Elsevier B.V. Reprinted with permission.

Bates & Schneider also provided an example of an individuals continual monitoring throughout the course of their work period, indicating both high and low levels of heart rate (Figure 10). It is interesting to note the rest period (lunch break) can be identified by the marked reduction in heart rate.

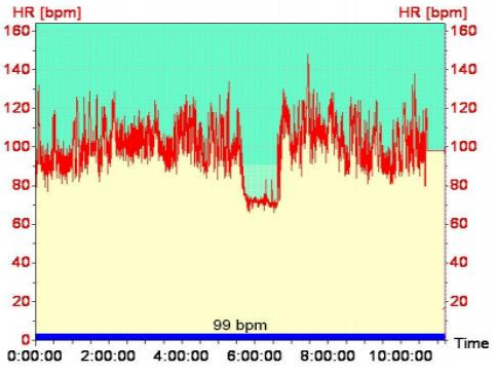


Figure 10. Typical heart rate recording. From Hydration status and physiological workload of UAE construction workers: A prospective longitudinal observational study, by G. Bates and J. Schneider, 2006, Journal of Occupational Medicine and Toxicology, p.8. Copyright 2008 Elsevier B.V. Reprinted with permission.

Similar studies using construction workers have been undertaken by Chang, Sun, Chaungt and Hsu, 2007. They continually monitored heart rates of employees working on a high-elevation construction project in Taiwan. Using a large sample size of n=302 participants were grouped by tasks performed, scaffolders, steel fixers, electrician-plumbers, formworkers and concreters. Chang *et al.* collected subjective fatigue symptoms, physiological measurements such as calf circumference and mean heart rates for each group.

Heart rate monitoring indicated different mean heart rates across all groups with Scaffolders having the highest heart rate (Figure 11). Chang *et al.* conclude that 'this could be due to emotion stress and physiological strain that could be attributable to instinctive responses arising from standing on a scaffold.'

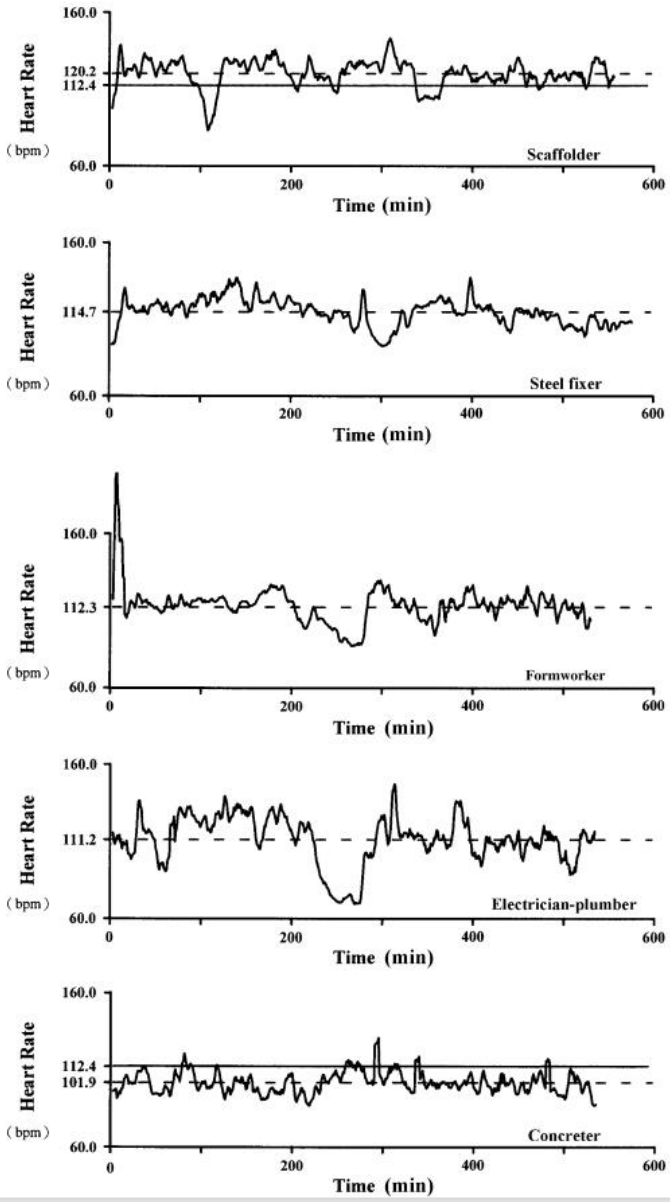


Figure 11. Heart rate change plotted as a function of elapsed time for workers of different occupations on the 8th floor. From Work fatigue and physiological symptoms in different occupations of high-elevation construction workers, by F. Chang, Y. Sun, K. Chuang and D. Shu, *Applied Ergonomics,* p.595. Copyright 2009 Elsevier. Reprinted with permission.

Note: (—— average heart rates of all workers monitored on the 8th floor, - - - - average heart rates of the five workers monitored on the 8th floor).

Chang *et al.* further analysed the difference between resting heart rate taken at the start of an employee's shift and mean heart rate throughout the course of their shift. They identified mean differences of 42.9bpm for scaffolders over the course of a 9 hour shift; representing a work intensity level of 39 percent. The concreter group had a mean difference of 25.2bpm over the course of a 9 hour shift representing an intensity level of 25.5 percent.

It should be remembered however that a work period contains many exertions, as such physical fatigue can be considered to be cumulative throughout the course of a work period. Levels of fatigue being equitable to the total amount of physical work exerted during the course of a work period. Not only are fatigue levels cumulative over the course of a work period it has been found that fatigue levels are also cumulative across many work periods.

In a study into cumulated fatigue Pichot, V., Bourin, E., Roche, F., Garet, M., Gaspoz, J. M., Duverney, D., ... & Barthélémy, J. C., 2002 used measurement of the autonomic nervous system index using ECG readings taken nocturnally from six male French rubbish collectors. These readings were compared against a control group of eight sedentary male subjects, for a period of four weeks. It was found that heart rate of the rubbish workers increased from 54.4±5.7 beats per minute to 59.4±5.6 beats per minute measured over the course of a three week working period.

The fourth week of the study was set as a rest period during which heart rate reduced to 54.6±5.5 beats per minute. This led them to conclude that 'nocturnal autonomic nervous system activity reflects cumulated physical fatigue mainly through a progressive parasympathetic withdrawal, while the following recovery period is

characterized by a parasympathetic rebound' and propose the method as a means for the determination of cumulative physical fatigue.

It is interesting to note that each of the different tasks produced different mean heart rates. If this method of monitoring was repeated across different industries, profiles of task v heart rate could be constructed. This information could be used by employers to identify more physically demanding tasks that result in higher heart rates. Management of these tasks can minimize the amount of time an individual spends performing the tasks; as such reducing its impact on fatigue levels.

2.2.6 Activity as steps

Workplace activity is the amount of physical or cognitive exertion required for task completion and its impact is linked to an individual's age or fitness levels (Casperensen, Powell and Chrisenson, 1985). It is cumulative in that as the working day passes the amount of tasks or sub-tasks undertaken by an employee also increases. Large amounts of activity can lead to high fatigue levels in individuals and impaired performance at the physiological level; increased reaction times, motor skills and strength. This impairment can be a contributor to workplace safety with fatigued individuals being more susceptible to accidents.

Traditionally activity levels have been determined by the use of questionnaires where individuals produce a self-evaluated level of activity they have undertaken throughout a monitoring period. This method of data collection can be flawed in its nature with limitations in recall ability and judgment of activity intensity affecting the accuracy of data gathered.

A more accurate method of gathering activity information may be facilitated by the use of pedometers to measure ambulatory activity. Designed to capture accelerations of the hip during gait cycles they count the number of steps taken by an individual. Pedometers are only designed to measure this type of activity and as such physical activities undertaken in a semi stationary position such as production line work cannot be captured. Combined with data from questionnaires a more complete picture of an individual's daily activity levels can be created.

This disparity between activity levels is aptly demonstrated in Figure 12; it demonstrates the activity levels (measured as steps) of the experimenter during phase one of this study. It can be seen that on three days of the week the experimenter is extremely active with step totals in the region of 20,000, conversely the remaining four days show markedly lower activity levels with step totals in the region of 7,000. Higher step levels are due to the experimenter having a part time position within a retail environment which requires large amounts of ambulatory activity in response to customer demand.

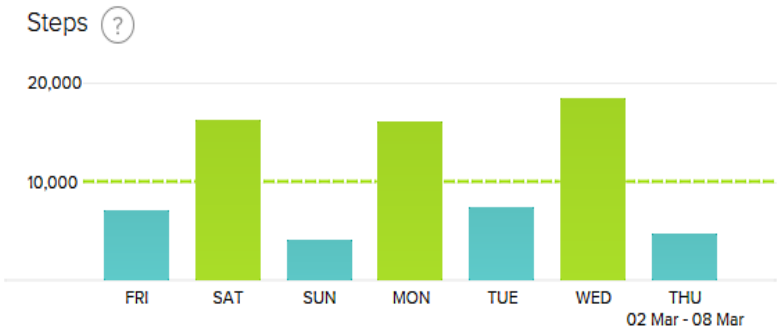


Figure 12. Step totals measured by Fitbit Charge HR activity monitor over the course of a week.

Lower activity levels, in this case, represent the more sedentary processes that tertiary study requires. During days of low ambulatory activity the experimenter is mainly conducting research and as such spends most of the time stationary at a computer screen. This illustrates the need for additional information in order to supplement pedometer readings; although activity levels are low, high levels of cognitive load were being undertaken.

Similar scenarios exist within the workplace, and in the context of this thesis, within the forestry industry. Although the majority of tasks are of a 'feet on the ground' nature it must be remembered that plant and machinery require stationary operators where the majority of activity undertaken is of a cognitive nature. Temperature, heart rate and activity measurements would not reflect working conditions as the majority of plant operation is undertaken from within a protected environment provided by the cab. As such temperature is usually controlled by air conditioning and activity is performed by hand in a seated position.

2.2.7 Calorific burn rate

Similar to the determination of activity by heart rate, the more active an individual is the higher the calorific burn rate. Also defined as energy expenditure it is a combination of the amount of energy used by the body to fuel the autonomic nervous system and perform motor actions undertaken throughout the course of a day. A deficit in calorie intake results in weight loss where energy is sourced from the body's natural resources such as fat stores; a surplus results in weight gain.

The amount of calories that the body requires to satisfy the requirements of the autonomic nervous system is known as the Basal Metabolic Rate and is unique to every individual. It is calculated using the formulae developed by Harris-Benedict, 1919 and later revised by Roza and Shizgal, 1984. The formula uses an individual's height, weight, age and sex to determine calorie requirements and is given by:

Male: 88.362 + (13.397 x weight in kg) + (4.799 x height in cm) – (5.677 x age in years)

Female: 447.593 + (9.247 x weight in kg) + (3.098 x height in cm) – (4.330 x age in years)

Therefore, for the experimenter, the BMR is given by

$$88.362 + (13.397 \times 117) + (4.799 \times 167.64) – (5.677 \times 49)$$

$$= 88.362 + 1567.449 + 804.5 – 278.13$$

$$= 2182 \text{ kilocalories}$$

Therefore the experimenter requires 2182 calories provided from food to satisfy autonomic nervous system requirements. Energy expenditure used for motor actions are taken from surplus calorie intake over the course of the day. If energy expenditure is greater than calorific intake weight loss is incurred whereas if calorific intake is greater than energy expenditure weight gain ensues.

Although restricted calorie intake has been found not to impact on simple reaction time (Cheatham, Roberts, Das, Gilhooly, Golden, Hyatt, Lieberman, 2009), it can impact on an individual's physical work capacity (Gutierrez, Gonzalez-Gross, Delgado, and Castillo, 2001). Figure 13 provides a comparison between calorie burn across both inactive and active days. It can be seen that during periods of high activity calorific burn rates are markedly higher than periods of low activity.

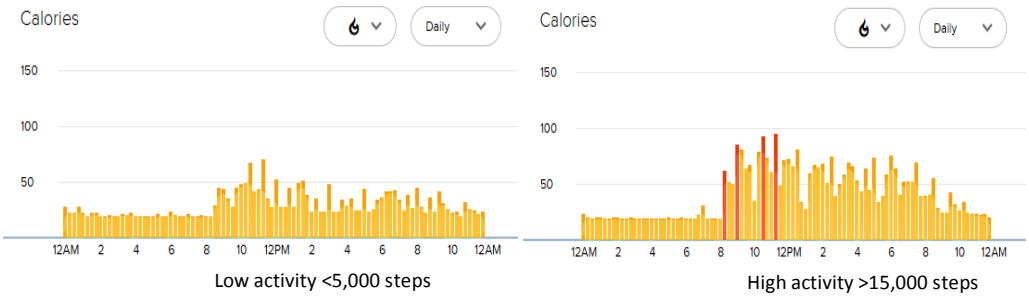


Figure 13. Comparison of calorific burn rate low v high daily activity

As such it is proposed that real time monitoring of calorific burn can be used as an identifier of fatigue if high values over long durations are present.

2.2.8 Blink rate

Blink rate is defined as the number of times an individual blinks over the course of a given time period. There is no standard number of blinks; they are unique to the individual and are linked to various physiological states and/or cognitive processes being experienced. Changes in blink rates have been identified as an indicator of fatigue with increases indicating higher fatigue levels.

Blink rate changes as a function of task duration have been seen to be significantly affected by fatigue, Buettger, (1923) found an increase in blink rate of between 200 and 300 percent for a reading task over a of four hour duration. Similar increases in blink rate of 268 percent for a reading task over the same duration were identified by Hoffman, 1946.

Later studies focusing on driving as time on task have also been found to produce an increase in blink rates. Halder and Rohmert, 1976 reported a blink rate increase of 80 – 100% over a task duration of one hour. Higher blink rates whilst driving were also identified in a study by Stern, Beiderman and Chen, (1976), they reported an increase of 31% in blink rate over the course of a driving task with a duration of 30mins.

2.2.9 Blink duration and microsleep

The duration of a blink or length of time to complete an open close cycle has also been identified as an indicator of fatigue. In a state of wakefulness blink duration has a cycle of between one and four milliseconds (Schleicher, Galley, Briest and Galley, 2015). This is somewhat faster than a blink rate of several milliseconds present during episodes of microsleep; a temporary condition of sleep having a short duration, lasting from a few milliseconds through to 30 seconds. It is a condition in which individuals fail to respond to external stimulus especially found where an individual is experiencing fatigue and trying to remain awake through a monotonous task. Prime examples of microsleep episodes can be found in driving and reading.

Schleicher *et al.* investigated blink duration as one of a set of oculomotoric parameters that could be used to indicate fatigue and the onset of sleepiness in drivers. Using a total of 138 subjects, a driving task lasting two hours was undertaken using a driving simulator. Facial monitoring was undertaken by the use of video cameras with an experimenter inserting any objective indicators of fatigue such as extended blink duration into the video stream. Participants were also asked to rate their subjective alertness on a scale of 1 to 10 with 10 being fully awake and 1 being absolutely tired at 30 minute intervals. Indepth analysis of the raw data was undertaken using a MATLAB based program designed to automatically detect blinks and saccades. They identified that eyelid closing was slower as fatigue increased and that prior to a microsleep event blink duration increases (Figure 14).

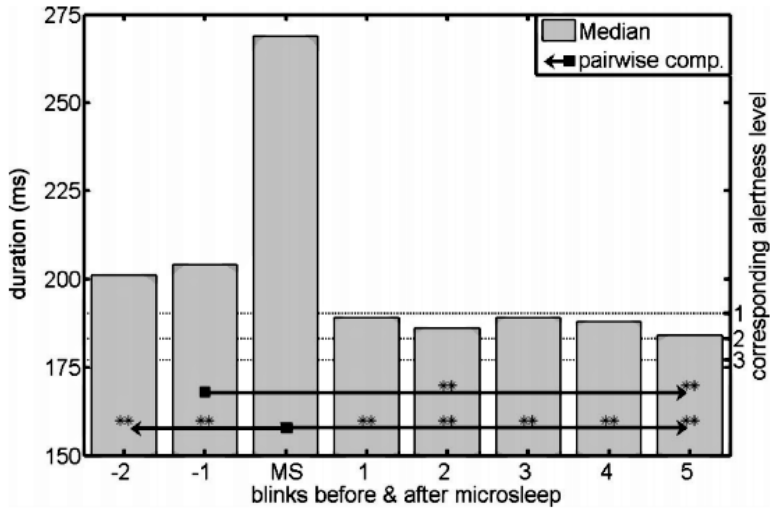


Figure 14. Blink duration before and after an overlong lid closure coded as microsleep. From Blinks and saccades as indicators of fatigue in sleepiness warnings: looking tired?, by R. Schleicher, N. Galley, S. Brest and L. Galley, *Applied Ergonomics, 51*(7) p.997. Copyright 2008 Taylor and Francis Group. Reprinted with permission.

On completion of a microsleep episode it can be seen that blink duration time decreases, Schleicher *et al.* theorize that the decrease in blink duration after a microsleep event may be due to the lowering of the fatigue level as a result of the microsleep event.

The ability to predict when an individual is fatigued has been vigorously investigated in the field of the transport where the results of fatigue can be particularly devastating. Tracking of the eye has been used in the evaluation of fatigue during sustained tasks such as those required by flying and driving; measurement of eyelid closure, rate, and gaze duration have been used to determine fatigue related performance deterioration, examples of which can be seen in the United States trucking and mining industries.

Monitoring is undertaken by use of cameras that track the position of the eye, with gaze duration being inferred by pupil movement. Eye closure is determined by the use of cameras that record the amount of the eye that is obscured by the eyelid. Fatigue is determined by long periods of a stationary pupil or reduced aperture of the eye. This type of monitoring for fatigue has its roots within the military where degradation in performance can result in poor decision making, high error rates and even mission failure.

Whilst investigating fatigue in pilots Morris and Miller, 1996, identified blink rate, blink amplitude, long-closure rate (blink rates > 200msec) and saccade rate as the best predictors of fatigue levels.

Using US Air Force pilot sorties of 4.5 hour duration were flown within a simulator, each sortie consisted of both flight manoeuver operations such as climbs, banks and descents and straight and level flight where pilots flew on a constant heading at fixed altitude and speed. Using a fixed window of airspeed, heading, altitude and vertical velocity pilot time outside of this window was recorded as errors. Measurement of blink rate, blink duration, long-closure rate, blink amplitude, saccade velocity, saccade rate and peak saccade velocity was taken throughout the course of the sortie.

They identified that performance errors increased over time and although not identifying a single variable that could be used as a identifier of fatigue they conclude that a combination of blink amplitude, long closure rate, blink rate and blink duration could be used a metric for fatigue determination.

Similar results of performance degradation over time were reported by McKinley, McIntire, Schmidt, Repperger and Caldwell, (2011) again using flight as a task for inducing fatigue. Performance tasks were designed to represent real-world Air Force missions and consisted of target acquisition and landing an unmanned aerial vehicle. A third measure of reaction time was made using psychomotor vigilance testing. Data from the eye was captured using the PERCLOS system, developed at the Carnegie Mellon Research Institute.

PERCLOS is a system that operates in real time measuring percentage eye closure, blink rates and pupil position. McKinley *et al* also captured data using the ApEn system developed by Pincus; designed to identify changes in physiological signals or states over time.

They found correlations between PERCLOS results and task performance in both target acquisition and psychomotor vigilance testing, although they state that

> "the high variance in the PERCLOS measure that contributed to the lack of statistically significant declines indicates that it is highly variable among participants in this application and potentially noisy. Although PERCLOS is well suited to the automotive environment."

In the context of this literature review the use of a PERCLOS system is applicable only to plant operators; as tasks are undertaken from within a protected environment provided by the cab.

2.3 Sleep

The importance of sleep in relation to waking performance has long been known (, Williamson *et al*, 2000, Åkerstedt *et al*, 2002, Belenkey *et al*, 2003) ; low duration or poor sleep quality adversely affecting ones mood, physical performance and cognitive processing abilities. By its nature sleep is unique, the amount needed to feel rested and refreshed is determined by the individual. Failure to achieve sleep requirements is cumulative across time with increased sleep deprivation leading to higher fatigue levels experienced by the individual.

Polysomnography is the study of sleep performed using dedicated monitoring devices requiring the subject to visit dedicated sleep laboratories where they are physically connected to these recording devices and their sleep is monitored continually throughout the night. It is mainly used to diagnose sleep disorders such as narcolepsy and sleep apnea. The process typically records 12 channels of data transmitted using 22 wire attachments connected to sensors which are mounted on the test subject. Each of these sensors provide continual data that is recorded throughout the duration of the subject's sleep period and later analysed to provide indicators for sleep related disorders. Initially recorded on paper charts professional sleep disorder specialists would view these charts and using the information diagnose any sleep disorder present. The advent of the computer has replaced the need for paper charting; monitoring data is now both recorded and displayed electronically.

Sleep is usually broken into two distinct phases, REM sleep and NREM sleep. The phases are cyclic with periods of REM sleep occurring on conclusion of a NREM sleep period; this cycle occurs at several times throughout a sleep period. The NREM sleep cycle is measured by use of an electroencephalogram detecting

brain wave activity during sleep and is used to identify the three stages of non-rapid eye movement (NREM) sleep (Schulz, 2008). Electrooculograms are used to determine REM sleep periods by monitoring the movement of the eyes during the sleep cycle. Figure 15 demonstrates the cyclic nature of sleep showing REM occurrences during an eight hour sleep period

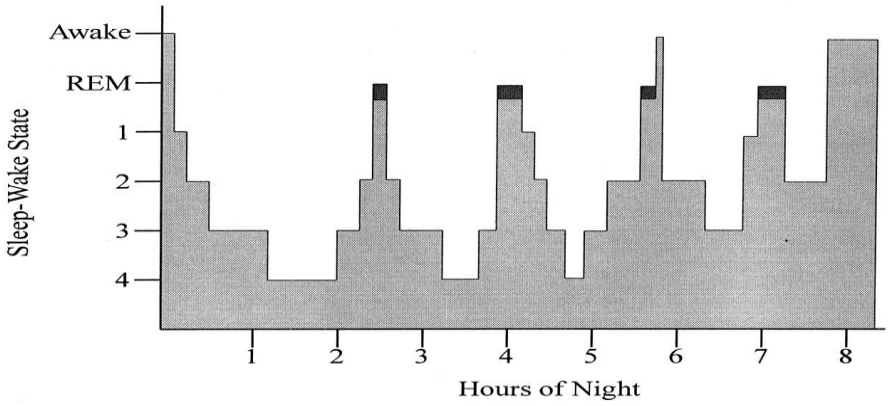


Figure 15. Histogram showing the typical distribution of overnight sleep patterns in a young adult. From Sleep as a teaching tool for integrating respiratory physiology and motor control by R. Thomson, U. Ackermann and R. Horner, *Advances in Physiology Education 25* (2), 29 – 44. Copyright 2001, The American Physiological Society. Reprinted with permission.

2.3.1 NREM sleep stages

Stage 1 NREM sleep occurs predominantly at the start of the sleep cycle, it is at this point that Alpha waves disappear and theta waves occur. According to Green (2001) it is a state of relaxed wakefulness at which point hypnic jerks or the 'feeling of falling' is most likely to occur; individuals woken during this stage believe that they have been fully awake.

Stage 2 of NREM sleep is classified by the lack of eye movements and dream cycles; individuals are awaken easily at this stage. According to Jordan (n.d.). It is highlighted by a burst of fast theta waves lasting less than a second (sleep spindles) and single long delta waves that last for just a second (K- complexes). It is seen as the midpoint of sleep where the heart rate slows and your muscles are completely relaxed as the body prepares for the onset of deep sleep. According to Jordan (n.d.) adults spend approximately half their sleep time within this stage, with each cycle lasting between 10 and 20 minutes.

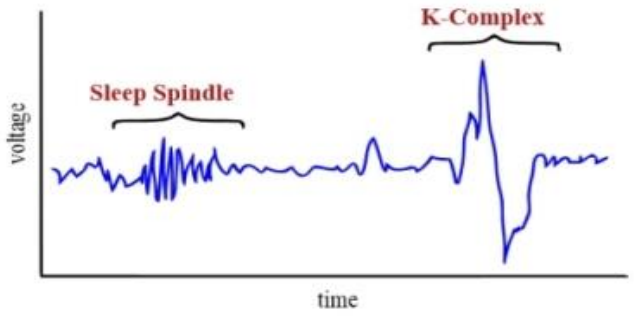


Figure 16. Sleep spindle and K complex waves. Retrieved March 3, 2015 from https://commons.wikimedia.org/wiki/File:Stage2sleep.svg

Jordan (n.d.) further states that stage 3 of NREM sleep occurs when the theta waves are replaced by longer delta waves of 1 to 3Hz. It is during this phase that events such as sleep walking and night terrors can occur. During this sleep stage individuals are difficult to wake and will feel disorientated, groggy and alertness levels will not be high. It is thought that 20% of our sleep cycle is spent in this deep sleep stage which can last for up to an hour. The depth of sleep during this stage is dependent upon age, stimulation of the brain during the day and the length of time between sleep periods. Figure 16 demonstrates differences between sleep spindles (theta waves) and K-complexes (delta waves).

2.3.2 REM sleep stage

The REM sleep stage is somewhat different, brain activity increases to similar levels found during the day; it is in this phase that dreaming occurs. It is classified by the rapid movement of the eyes and paralysis of the muscles, due to the non-production of monoamine neurotransmitters responsible for stimulating the motor neurons (Hall, 1998). The paralysis of the muscles is designed to prevent an individual 'acting out' their dreams.

The amount of time spent within this sleep stage is usually between 20 and 25% of a sleep period (Nordqvist, 2014). Figure 17 shows electrooculograms for the left (LEOG) and right (REOG) eyes during a REM sleep period.

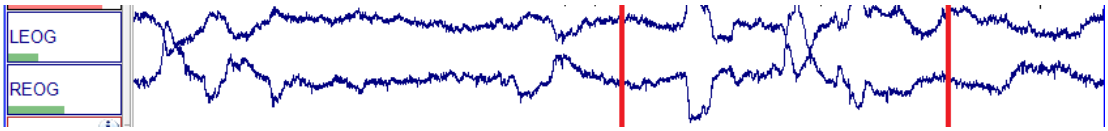


Figure 17. Screenshot of a PSG for a person in REM sleep. Retrieved March 3, 2015 from http://commons.wikimedia.org/wiki/File:Sleep_Stage_REM.png

The use of an electromyogram can also differentiate between NREM and REM sleep. Electrodes are used to determine the amount of tension within the muscles and REM sleep is detected by the reduction of muscle tension. Electrodes connected to the chin measure movement within the jawbone along with electrodes connected to the leg. The reduction in muscle tone initiated by the onset of a REM sleep period is used to determine when the REM sleep cycle occurs (Larsen and Foulkes, 1969).

Further monitoring is undertaken to measure heart rate and nasal/oral airflow during sleep. These results are predominantly designed with the diagnosis of sleep disorders such as sleep apnea and as such are outside of the scope of this report.

2.3.3 Impact of reduced sleep on physical and mental performance

Hornes hypothesis, 1993 states that a 'minimum amount of sleep required to satisfy the brains physiological need for recuperation is 4.5 hours' although optimal levels of sleep have been found to lie within the 8 hour range (National Sleep Foundation, 2002). If this level is not achieved it can result in reduced performance during daytime activities; impacting on both health and safety and productivity.

A study undertaken in 2002 by Belenky, Wesensten, Thorne, Thomas, Sing, Redmond, Russo and Balkin evaluated performance degradation and restoration as a result of sleep restriction. Sleep levels were restricted across four groups to 3 hours, 5 hours, 7 hours and 9 hours respectively, for a period of seven days. Psychomotor vigilance testing was undertaken on all groups with reaction time being measured using a visual stimulus.

It was identified that participants within the 5 hour and 7 hour groups showed initial increases in reaction times although stabilisation occurred after the first few days. Participants within the 3 hour group showed continual increases in reaction time across all days; participants within the 9 hour group showed no increased reaction time across the duration of the experiment (Table 1).

Table 1.

Standard deviations of mean speed for each day and time in bed

Day	3 hour sleep	5 hour sleep	7 hour sleep	9 hour sleep
B	0.5032	0.7173	0.5711	0.528
Day 1	0.6972	008667	0.5335	0.5001
Day 2	0.7412	0.8144	0.5275	0.4632
Day 3	0.9471	0.8925	0.6275	0.5028
Day 4	1.0648	1.1022	0.6469	0.4626
Day 5	0.9453	1.1022	0.6469	0.4431
Day 6	0.9205	1.0715	0.7728	0.4119
Day 7	1.0131	1.0149	0.7619	0.4723
Recovery day 1	0.8825	0.9543	0.7575	0.4673
Recovery day 2	0.7227	1.0193	0.8799	0.5169
Recovery day 3	0.8296	1.1119	0.8544	0.4492

Note*:* Adapted from Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study. *Journal of Sleep Research, 12(1)*, 1-12. Copyright 2003 by John Wiley and Sons. Reprinted with permission.

Results indicate that over a seven day period with limited sleep, reaction times or 'level of alertness' increase resulting in a delay in response to visual stimulus. The effect of limited sleep is shown to be cumulative; increases in reaction time of 0.5099 milliseconds (98.6%) over a7 day duration in the 3 hour study group.

Three hours sleep is minimal in comparison to that achieved by individuals in a real life context even when a perceived bad night's sleep has occurred. The majority of individuals achieve sleep within the 7 to 8 hour range; bad night's sleep usually being represented by 6 or fewer hours of sleep. Results from the Belenkey *et al.* study indicated cumulative increases in reaction time of 0.2976 (42%) milliseconds for a period of 5 hours and 0.1864 (25.5%) milliseconds for a 7 hour sleep periods over a 7 day period.

Similar increases in reaction time against sleep deprivation have been shown (Van Dongen, Mailsin, Mullington and Dinges, 2003; Lim and Dinges, 2008; Kim, Kim, Park, Choi and Lee, 2011) suggesting levels of sleep achieved by an individual can influence performance. Further studies have also shown that moderate sleep deprivation can impair performance similar to those levels found in alcohol intoxication (Williamson and Fryer, 2000).

Although levels of sleep required is on an individual need basis it is hypothesized that the further achieved sleep is from the individuals requirements, a decrease in reaction time will occur that is proportional to the sleep deficit. It may be possible to model the increase in reaction time against sleep time and use this as a predictor of productivity and/or risk identification.

2.4 Monitoring within the workplace

In this section we discuss the ethical implications of workplace monitoring, and how relationships between employer and employee can be impacted. Furthermore we explore the need for monitoring outside of the workplace, and how performance can be impacted by activities external to the workplace.

As long as there has been employment, employees have been monitored (Nebeker & Tatum, 1993). Managers have always strived to get the best from employees and achieve this by monitoring performance of individual employees. Monitoring has been undertaken in many forms from the casual 'approach and view' where managers simply walk up to an employee and view what they have accomplished, through to the detailed recording of task completion time.

Monitoring an employee can introduce tension between employer and employee. Botan and Vorvoreanu, (2000) found that the act of surveillance can send hidden messages to employees that are not intended. They reported employees seeing surveillance as a method for disciplinary proceedings or inferring that employees were thought of as children and couldn't be trusted.

The easiest management technique to overcome these issues and achieve 'buy in' from employees is through careful communication of intended change (Schmitz & Becker, 2012). Information should be provided to employees concerning the changes to be made and why as a company they are being undertaken.

2.4.1 Monitoring outside the workplace

Levels of activity both physical and mental have been shown to increase the level of fatigue experienced by an individual during the course of their day (Pichot *et al.*, Murata *et al.*). It has also been found that the quality of sleep an individual attains has an effect upon fatigue levels experienced during the day (Kerstedt *et al.*).

It must be remembered that activity continues throughout waking hours, it is not just limited to the working day. Individuals may be particularly active away from work, playing sports for example increases total activity undertaken throughout a day. If

one does not complete a rest cycle allowing recovery from activity, fatigue levels are not mitigated, only lessened (Pichot *et al.*). Higher levels of fatigue at the start of the working day can impact individual performance throughout the day as fatigue is cumulative by nature.

The opportunity to mine this data collected outside of work provides a complete picture of activity undertaken. Individuals who have limited sleep or periods of high activity outside of work can be suffering performance impairment through fatigue prior to starting their working day. Performance impairment such as slower reaction times can facilitate an increase in risk and as such an increase in accidents.

A prime example of how fatigue can impact on risk can be found in driving where high fatigue levels lead to higher error rates (Schleicher *et al*). Errors in judgment and slower reaction times increase the risk of accidents, for example:

In its simplest form the act of braking in a vehicle is comprised of three phases, first is the visual phase where the driver sees the hazard, second is the action phase where the driver applies the brakes and thirdly is the mechanical action of the vehicle during its braking phase. If the driver of a vehicle is experiencing high fatigue levels a delay in the first two phases can occur. This resultant delay is explained further below:

If a vehicle is travelling at 100km/h it will cover a distance of 100m in 4 seconds (Roads and Maritime Services, 2011), therefore a delay in reaction of 10% will allow the vehicle to cover an additional 10m prior to the application of the brakes. The resultant increase in distance travelled due to impaired reaction time can result in a vehicle collision.

The above illustrates possible consequences of fatigue whilst driving, similar increased risk exists across many activities. In the context of this report where individuals use both heavy and light equipment from which accidents can result in severe injury or even death it can be seen that impaired reaction time is a hazard that needs careful management.

2.4.2 Social impact of monitoring outside of the workplace

In a utopian society physiological monitoring could be undertaken as methodology of determining an individual's wellbeing. Information collected in real time combined with historical physiological data used to both monitor fatigue and indicate when rest is required. Information collected in this way and made available to employers to assess an individual's ability to perform their duties at work; this is the point at which monitoring becomes contentious.

Driven by suspicion, people are adverse to providing information that they feel may be used against them. This has been repeatedly demonstrated within industry where opposition to drug and alcohol testing remains strong. The feelings of 'why do they want to know' and 'what does it matter what I do in my own time' run strong. Monitoring is rarely seen as a method of risk management, rather a means of controlling the workforce. As stated by Botan and Vorvoreanu, (2000), the act of monitoring conveys unintended messages to employees.

It can be argued that fatigue is also a dynamic that needs to be monitored by employers to provide a safe working environment; as such monitoring can be performed under health and safety legislation. This opens the door for monitoring prior to commencement of work duties, and monitoring throughout the course of a

work period. The act of monitoring of an individual's activity outside of work still carries the stigma of 'big brother' and as such is deemed too intrusive to be undertaken as part of this study.

In this chapter we have provided an overview of the different fatigue types; mental and physical and examined related works investigating both the cause and impact of fatigue on an individual's ability and motivation to continue a task. Furthermore we have identified and discussed variables that may be used as causation, and indicators of fatigue within individuals. We have examined previous works undertaken on each of the identified variables and provided an overview of how fatigue negatively impacts performance. We have also discussed how the relationship between employer and employee can be impacted by after-hours monitoring, and explained the rationale as to the benefit of collecting data from both workplace and home.

CHAPTER 3 - ACTIVITY MONITORS AND REACTION TIME

In this chapter we discuss the increase in use of activity trackers; evaluate the most popular activity trackers currently (as of April, 2015) available and assess their suitability for gathering physiological data in the workplace. We examine the accuracy of these devices, ease of use; types of data collected and conclude with the device to be used during the course of the study. Furthermore we identify the applications that will be used for the determination of reaction time for phase one and phase three of the study.

3.1 Activity monitors

Fitness monitoring existing previously within the realms of athletes and the military has now become commonplace with individuals collecting biometric data for their own personal use. Driven by the expanding global fitness trend, over 131 million people worldwide are now thought to have gym memberships (Statistic Brain, 2015).

With such a large marketplace it was inevitable that the use of fitness monitoring devices would migrate to the general population. Supplemented by targeted health messages and reinforced by health statistics an expected 91.3 million fitness monitoring devices are to be sold in 2016 (Gartner, 2014).

Wearable devices currently fall into five categories, smart wristband, sports watch, dongles, chest strap and smart garments; each providing a multitude of biometric data measurements. Marketed as both fitness monitoring devices and fashionable items designed to be worn 24 hours a day, 7 days a week. This market does not consist of dedicated bangles or dongles alone, many cell phone manufacturers such as Samsung, Apple and Microsoft now bundle dedicated fitness apps with their devices.

Developed from the simple pedometer which proved popular in counting step rates; devices initially utilised accelerometers to determine cadence and proprietary algorithms based on height and weight to calculate calorific burn and distance travelled. Further developments have seen information being provided on both sleep duration and quality, again using algorithms to determine sleep levels, based on time stamp and movement data. Sleep interruptions are recorded when the accelerometer within the device registers movement at times during the night, where long periods of inactivity are defined as sleep periods.

Recently the incorporation of technology similar to that used in pulse oximeters into these devices allows the collection of heart rate data; LEDs illuminate an area of the skin (usually the wrist) and reflected light is measured by a photo electric cell. Variations in the amount of light reflected are due to the absorptive nature of blood are used to indicate a heartbeat; the amount of reflected light decreases as the volume of blood passing through the illuminated area of skin increases. This relationship between the amount of reflected light and the absorbance level of blood is used to infer a heartbeat. Heart rate accuracy levels of the current generation show variation when compared to measurements taken using a chest strap monitoring system; devices tend to take time to settle and have been found to drift at higher heart rates (Richmond, 2015).

The collection of data facilitated by these devices not only provides an overview of daily activity; both waking and sleeping, individual periods of activity can be identified, goals set and historical data reviewed. The ability to view ones data or goal completion rates drives the competitive nature of humans; the desire to achieve or surpass a goal is motivational. It is the manipulation of these drives that are targeted

by companies manufacturing the devices. When used in conjunction with positive and negative reinforcement (Skinner, 1991) reward given on goal completion is a powerful motivator.

Positive reinforcement is given by the award of badges, trophies or congratulatory messages designed to produce positive feelings of achievement and self-satisfaction within individuals. The flip side to this is the negative reinforcement where no awards are provided, thus encouraging the user to expend more effort into goal completion.

This reinforcement is supplemented with the majority of device manufactures offering the user the ability to share their results across many different social media applications. Challenges and goal settings can be created designed to be undertaken by multiple users thus increasing the addictive nature of using the device by competition. The provision of this service again supplements the positive/negative reinforcement reward cycle and further drives levels of addictiveness.

By nature large amounts of real time physiological data is collected unique to the individual using the device. Quantitative data such as step rates, heart rates, flights of stairs climbed recorded by the devices can be used to provide qualitative data such as activity levels and cardio zones. Continuous use of the device facilitates large amounts of physiological data collection, on which data mining operations can be undertaken identifying any trends or patterns that may exist. Comparison of data from one day to another can be used to identify periods of high activity or long periods of a sedentary nature.

3.2 Activity tracking

In our health obsessed society, the ability to automatically measure and record ones daily activity has become a trend over recent years. It allows individuals to monitor their daily activities and is generally associated with fitness measurement or weight loss goals. Using a combination of accelerometers, GPS readings and more recently heart rate sensors physical activity is tracked over time providing information to individuals; allowing goal orientated daily activity to be implemented.

Data provided by this type of monitoring has facilitated research into areas that lie beyond goal centred information with devices now providing the ability to report sleeping patterns. Currently there are a multitude of these self-monitoring devices available allowing users to monitor their activity in combination with their sleep patterns and allow results to be shared via such applications as Facebook and life logging communities.

Driven mainly by digital natives this self-elected sharing of information may pave the way for its use as a method of risk assessment in the workplace. Education in the benefits that monitoring of this type can bring to both an individual is the key to achieving buy in from employees.

3.3 Tracker evaluation

Prior to commencement of data collection evaluation of currently available monitoring devices was undertaken to determine the most suitable for both cost and durability. Sales figures from the 2013 – 2014 period indicate Fitbit, Jawbone and Nike as the leading providers of wearable bangle type fitness monitors (Danova, 2014), with each providing similar data to users. Each use a combination of

accelerometers and vibration monitors to record data which is then interpreted by custom built software with results being presented to users via a software interface. All of the manufacturers offer a number different products; all offering different functionality dependent upon price. The most popular device offered by each manufacturer is discussed below. It should be remembered that activity trackers are in a continual development cycle with new models being released regularly; as such only devices available as of April 2015 are reviewed.

Previous works on the use of activity trackers has been undertaken into the suitability of activity trackers as a means of collecting data (Bowen, Hinze, Cunningham and Parker, 2015). They identified that usability issues can exist with clip fastening devices; devices can become snagged or lost as the participant works. As such devices evaluated are designed to provide a more secure wrist fastening system, such as a buckle to preventing accidental removal.

3.2.1 Fitbit Flex

Consisting of a silicon band with a void used to hold the actual tracking unit the Fitbit Flex (Figure 18) is a wrist worn unit for measuring daily activity. The device itself is devoid of any visual feedback apart from a set of LED lights designed to indicate charge levels mode setting and goal completion. Results from monitoring are synched from the device to your account by way of Bluetooth or physical connection via a USB port on a computer. Visual feedback or results are presented to a user by means of a custom interface accessed by a personal computer or a cell phone application. The device is capable of tracking steps taken, calories burned, distance travelled, very active minutes, time asleep and number of times woken.

Figure 18. Fitbit Flex. Retrieved from http://sincerelykenz.com/jawbone-up2-vs-fitbit-flex/

3.2.2 Fitbit Charge HR

The FitBit Charge HR is a new entry to the market and provides the ability for continual heart rate monitoring and was evaluated as to add a further dimension to data collection.

Consisting of a silicon band into which the actual tracking unit is moulded, the Fitbit Charge HR (Figure 19) is the latest (as of April, 2015) device offered by Fitbit. The front of the device itself incorporates a small LCD screen that is used to provide visual feedback to the user. On the rear of the device is the monitoring hardware for the determination of heart rate and a charging point for the rechargeable battery. The heart rate monitor consists of two LED lights that illuminate the skin and an electro-optical cell that monitors the pulsing of blood through the illuminated area.

Figure 19. Fitbit Charge HR.

A small button on the side of the device facilitates access to the dual functionality offered by the device. A short press of the button provides access to each of the metrics captured by the device (Figure 20). Longer presses of the button place the device into activity mode designed to capture metrics in conjunction with exercise; a further long press places the device into its standard state.

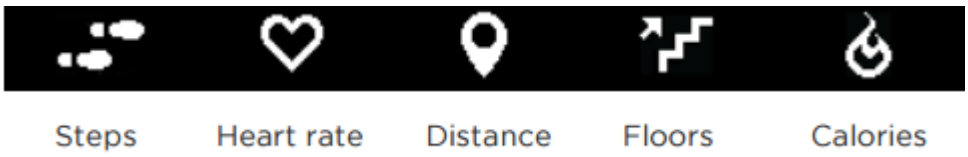


Figure 20. Indicative icons used to represent the different metrics collected by the Fitbit Charge HR monitoring device.

Results from monitoring are synched from the device to a web based account by way of Bluetooth or physical connection via a USB port on a computer. Visual feedback or results are presented to a user by means of a custom interface accessed by a personal computer or a cell phone application. The device is capable of tracking steps taken, calories burned, distance travelled, heart rate, flights of stairs climbed, time asleep and number of times awoken.

During exercise mode the device will actively track heart rate over time and display this information graphically via the web interface (Figure 21). Additional metrics such as elapsed time and heart rate zone are recorded whilst the device is in exercise mode. Heart rate monitoring data provides indications of high and low activity although the accuracy of individual readings can lack the accuracy of chest strap monitors.

Figure 21. Example of heart rate tracking undertaken by the Fitbit Charge HR whilst in exercise mode.

3.2.2.1Accuracy

The Fitbit range of products show high accuracy when used as a pedometer in comparison to the Yamax pedometer, widely regarded as the 'gold standard' of pedometer devices. In a recent study Tully, McBride, Heron and Hunter, 2014 found that there was no statistically significant difference between Fitbit pedometers and Yamax (Median (IQR) 7477 (3597) vs 6774 (3851); p = 0.11).

This level of accuracy was not repeated when measuring energy expenditure (calorie burn rates), Gusmer, Bosch, Osterrem Taylor and Dengel, 2014 found that 'FitBit and ActiGraph illustrated a strong correlation and a strong agreement for step counts; they only showed a moderate correlation and moderate agreement for energy expenditure.' This was somewhat corroborated in a study by Sasaki *et al.*, 2014 presented by Freedson, 2014 in which FitBit energy expenditure was measured against indirect calorimetry. Mean differences between the two methods of measurement yielded between -100% and +40%, task dependent (Figure 22).

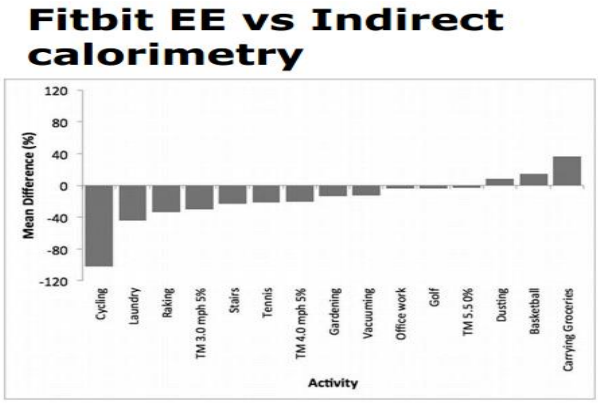


Figure 22. *Fitbit energy expenditure*. From Validation of the fitbit wireless activity tracker for the prediction of energy expenditure, by J. Sasaki et al. Journal of Physical Activity and Health, 12(2), 149 – 154. Copyright 2015 Elsevier B.V. Reprinted with permission.

Sleep monitoring offered by the Fitbit is based on movement and absence of movement being used to infer periods of sleeping and being awake; although its window accuracy is somewhat large. In a comparative study between polysomnography and the Fitbit products it was found that the Fitbit overestimated total sleep time by an average of 67.1 (SD ± 51.3) minutes (Montgomery-Downs, Isana and Bond, 2012).

3.2.2.2 Conclusion

In conclusion both the Fitbit Flex and Fitbit Charge HR are capable indicators of steps taken within a day but accuracy levels achieved for energy expenditure, and sleep monitoring need to be taken into account when determining levels of fatigue. If fatigue is to be inferred by either sleep cycles or energy expenditure care must be taken when interpreting results. Heart rate monitoring can be used as a reliable indicator of activity although individual readings can suffer from errors, especially at high heart rates.

The small form factor used by both devices is beneficial for use in the workplace, especially if the work is of a manual nature; catching of the device on environmental objects is minimized. Water proofing levels for each device allow their use in conditions that may occur when working outside; increasing their suitability for use in work places open to the elements. In relation to the Fitbit Charge HR heart rate monitoring may be possible at different locations on the body in the moulded strap is removed. This may be of particular use if the device is mounted within personal protective equipment such as a hard hat for use in the workplace. Recently (July, 2015) companies such as Lifebeam have released wearable products containing monitoring devices designed for forehead placement.

3.2.3 Jawbone UP

Consisting of a hypoallergenic thermoplastic polyurethane band into which the tracking unit is moulded, it is designed to be worn 24 hours a day and again presented as a fashionable item (Figure 23). The device itself is devoid of any visual feedback apart from two single colour LEDs that are used to indicate device monitoring mode and charge level.

Figure 23. Jawbone UP24 activity monitor. Retrieved from https://www.att.com/wearables/health-and-fitness/jawbone-up24-wireless-activity-tracker.html.

Results from monitoring are synched from the device to your account by way of Bluetooth or physical connection via a USB port on a computer. Visual feedback or results are presented to a user by means of a custom interface accessed by a personal computer or a cell phone application (Figure 24). The device is capable of tracking steps taken, calories burned, distance travelled, very active minutes, type of sleep either deep or light, time asleep and number of times woken.

Figure 24. Jawbone UP user interface showing both activity and sleep screens. Retrieved from http://www.gadfit.com/jawbone-up3-review/

3.2.3.1 Accuracy

The Jawbone UP shows a good correlation in readings between measured steps and actual steps taken. Stackpool, 2013 investigated the correlation between fitness tracker collected data and actual measurement. Data was collected across four categories; treadmill walking, treadmill running, elliptical, and agility; correlations of 0.98, 0.99, 0.99 and 0.34 were identified respectively. Further analysis was undertaken on the correlation between reported kilocalories by the devices and results produced by a portable metabolic gas analyser. The Jawbone UP produced correlations of 0.87, 0.69, 0.40 and 0.57 respectively across the test conditions listed above. This led Stackpool to conclude that the Jawbone UP was 'accurate with steps taken across all activities and was fairly accurate with kcals'.

Sleep monitoring offered by the Jawbone UP, uses similar movement and absence of movement in conjunction with time data to infer periods of sleep, waking and restlessness. As the device has not undergone any third party validation testing results provided can produce a general overview of sleep duration and restlessness.

3.2.3.2 Conclusion

In conclusion the Jawbone Up is a capable indicator of steps taken within and energy expenditure, poor sleep monitoring results need to be taken into account when determining levels of fatigue. If fatigue is to be inferred by sleep cycles care must be taken when interpreting results. The absence of heart rate monitoring removes important indicators of activity (heart rate over time) and recovery (resting heart rate). The small form factor used by the device is beneficial for use in the workplace, especially if the work is of a manual nature; catching of the device on environmental objects is minimized. The pre-moulded shape of the device and location of its mode

setting button prevents its use in areas other than the wrist. Water proofing levels for each device allow their use in conditions that may occur when working outside; increasing their suitability for use in work places open to the elements.

3.2.4 Nike+ Fuelband

Consisting of a thermoplastic polyurethane band into which the tracking unit is built, it is designed to be worn 24 hours a day and again presented as a fashionable item (Figure 25). The device features two separate feedback areas; one on top of the device consisting of an array of 100 LED lights, with a second edge mounted consisting of an array of 20 LED lights. The larger array is designed to provide information on steps taken and calories burned, with the smaller array used to indicate goal completion progress.

Figure 25. Nike Fuelband. Retrieved from http://www.amazon.com/Nike-Fuel-Band/dp/B007FSEMPY

Visual feedback or augmented results are presented to a user by means of a custom interface accessed by a personal computer or a cell phone application (Figure 26). The device is capable of tracking steps taken, calories burned, distance travelled, very active minutes and sleep duration.

Figure 26. Nike Fuelband+ user interface. Retrieved from http://www.blisstree.com/2012/08/29/fitness/fitness-tracker-nike-fuel-band-fitbit-body-media-fit-687/2/

3.2.4.1 Accuracy

The Nike Fuelband appears to have issues when counting steps, repeatedly under reporting the number of steps taken. A recent study identified an error rate of eight percent in testing when compared with manual step counting, (Guo, Li, Kankanhalli and Brown, 2013). Similar large error rates were reported by Duffy, 2014 in a review of the Nike+ Fuelband. In a comparison with manual step counting consisting of 3093 steps the device reported a step count of 1893.

Sleep tracking provides data on total sleep and does not include information on quality of sleep such as estimation of times awake or restlessness. Using its proprietary system of Nike Fuel points to identify activity, the lack of awarded points is used to infer sleep. The device has not undergone any third party validation testing and as such results provided can only produce a general overview of sleep duration and restlessness.

3.2.4.2 Conclusion

In conclusion the Nike Fuelband+ shows issues with step counting and energy expenditure, poor sleep monitoring results need to be taken into account when determining levels of fatigue. The lack of sleep analysis provided by the other reviewed devices render the Nike Fuelband+ inadequate for the determination of fatigue by broken sleep cycles. The absence of heart rate monitoring removes important indicators of activity (heart rate over time) and recovery (resting heart rate). Having a larger form factor the device is more likely to cause inconvenience to users in the workplace, especially if the work is of a manual nature. The pre-moulded shape of the device prevents its use in areas other than the wrist. Water proofing levels for each device allow their use in conditions that may occur when working outside; increasing their suitability for use in work places open to the elements.

3.3 Summary of evaluation

Based on the above reviews and previous study it was determined that the FitBit range of products provide the better accuracy. The addition of real time heart rate monitoring offered by the FitBit Charge HR provides another variable for use in the determination of fatigue. Although the device is moulded into a strap and designed to be worn on wrist, the use of optical pulse tracking facilitates its use on other areas of the body. This opens possibilities for placement of optical monitoring devices into existing personal protective equipment such as hard hats; during our study it was noted that protective equipment is generally removed during break times, as such would create interruptions in continual monitoring.

3.4 Reaction time monitoring

In Sections 2.2.1 and 2.2.2 we discussed the relevance of reaction time as an indicator of physiological change produced by high levels of activity. In this section we evaluate the software solutions used for data capture in phase one and phase three of this study.

The overall factor in the identification of fatigue was to be the measurement of reaction time determined at set intervals over the course of the work period; as such any methodology used must to determine reaction time must remain consistent throughout the course of the study. Testing must be undertaken in a way that is both user friendly and quick to complete, in-order to minimize the nuisance factor on participants. It is with this in mind that a simple test that can be performed in under a minute was sourced.

For the first phase of the experiment simple reaction to a visual stimulus time was undertaken by means of 'Reaction Time' a third party application developed by The Community Coder. It is an application designed to measure the time taken to respond to visual stimulus (colour change) and screen touch (response); running on a Samsung S5 Mini mobile phone. It was felt that due to the necessity of undertaking reaction time measurements within a working environment a portable device that utilizes a small form factor would not cause disruption to the experimenters work tasks.

The user is presented with a picture of the android logo and asked to touch the image on colour change (Figure 27). The time difference between the appearance of the visual stimulus and contact with the screen is recorded as reaction time. Delay time

between presentation of the visual stimulus is randomized to prevent familiarity. On completion of five tests the user is presented with their average reaction time in milliseconds.

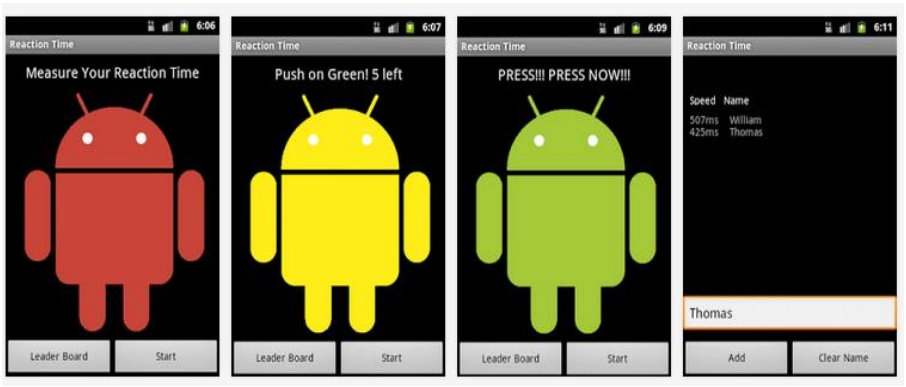


Figure 27. Reaction Time user screens. Retrieved from https://play.google.com/store/apps/details?id=com.chingy1788.reactiontime&hl=en

A secondary application 'Alertometer' was also used for the determination of alertness by reaction time. It is an application developed by Bowes – Langley Technology and uses a dynamic graphic to measure reaction time and infer impairment. Accoring to Bowes – Langley Technology 'This App measures your reaction time, shape recognition speed, decision making and other brain functions to compute your baseline level of alertness'.

During the setup phase of the application reaction time and decision making speed are used to create a baseline score, from which deviation is an indicator of impairment. The application uses a simple interface consisting of rotating shapes partially obscured by a revolving disc. Basic testing presents 30 different screens from which a user determines if the shapes are identical. On completion of testing results are presented as a numerical value. A graphical representation of level of alertness is also presented to the user (Figure 28).

Figure 28. Alertometer screens indicating test condition and result screens. Retrieved from https://play.google.com/store/apps/details?id=com.alertometer.

3.4.1 Deary-Liewald Reaction time

Developed by the Centre for Cognitive Ageing and Cognitive Epidemiology based at the University of Edinburgh. It is a free application that experimenters can use to conduct a study and allows for the adjustment of experimental parameters. Results are written as a comma-separtated values (CSV) file allowing import of data into Microsoft Excel for analysis. The application interface is intuitive to use for both setup and test and is shown in Figure 29.

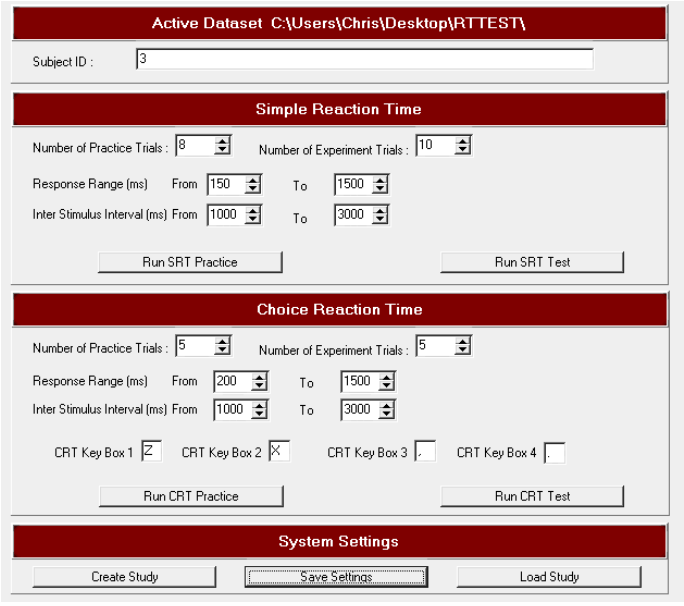


Figure 29. Deary-Liewald reaction time test application.

The application allows for the determination of both simple reaction time and choice reaction time with participants being prompted to press a key on the appearance of a visual stimulus; that being the appearance of a black X in a white box (Figure 30).

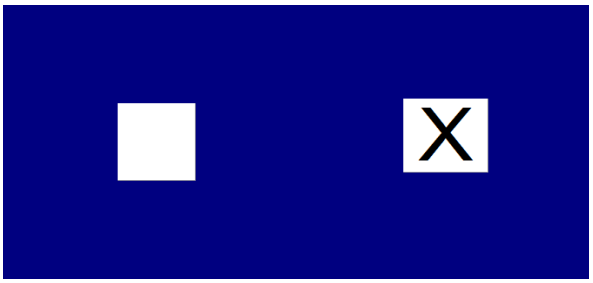


Figure 30. Test conditions Deary-Liewald reaction time test.

On completion of testing the resultant individual reaction times are saved as a CSV file for analysis.

3.4.1.1 Validation

Using 150 participants Deary, Liewald and Nissan evaluated the test against the numbers-based reaction time test developed by Cox, Huppert and Whichelow, 1993 which was used as in the UK Health and Lifestyle Survey. Deary *et al* state:

> "With regard to the Simple reaction time (SRT) tasks, there was a large, significant positive correlation between the mean response times of the Deary-Liewald task and the numbers task ($r[148] = .68$, $p < 0.01$). There was also a significant positive correlation between the standard deviations (SD) of response times of the Deary-Liewald task and the numbers task ($r[148] = .40$, $p < 0.01$). The correlations between the means and SDs within both reaction time tasks were also significant: Deary-Liewald task ($r[148] = .56$, $p < 0.01$); numbers task ($r[148] = .56$, $p < 0.01$)."

On reliability of the test method Deary *et al* state:

> "Internal consistency for the Deary-Liewald task was measured using Cronbach's alpha and was very high for both the SRT ($\alpha = .94$) and for correct responses on the CRT ($\alpha = .97$)."

3.4.1.2 Conclusion

The Deary-Liewald reaction time task is a validated test method that allows experimenters to perform studies into both simple and choice reaction time tests. The ease of setup and parameter adjustment, facilitated by the application is advantageous, especially when conducting tests of short duration; such as those proposed by phase 3 of this study. Reliability and validation of the test method allows the experimenter to conduct testing with a measure of confidence within the collected values. The use of comma-separated values as a file format allows for the easy import of data into packages such as Microsoft Excel for analysis.

In this chapter we have presented an overview of both activity trackers and reaction time measurement. We have identified the preferred activity tracker to be used for the study and furthermore identified software applications used within phases one and three of the study. The importance of a validated method for collecting data has been explained and provided for the Deary-Liewald reaction time test used in phase three of the study.

CHAPTER 4 - METHODOLOGY

This chapter presents the methodology used during the three phases of the study; it provides demographic and location information for each phase of the study. Further information is provided for phase three of the study where data collection was undertaken at varying locations each providing unique environments. General observations by the experimenter are also present as an adage to the participant groups.

The aim of the experiment is to determine the effectiveness of physiological monitoring by use of commercially available fitness trackers in combination with simple reaction time testing to determine levels of fatigue within individuals. Previous work as discussed in chapter 2, has indicated that simple reaction time is adversely affected as levels of fatigue increase. This increase in reaction time can be a contributor to both increased risk and accident frequency within the workplace. This research investigates the relationship between fatigue and physiological change, allowing for construction of individual regression models for employees. Deviations from the regression model will be used as an indicator of current fatigue levels, from which impairment may result. The experiment is comprised of three phases; the first phase examines the relationship between activity and simple reaction time as a proof of concept, the second phase comprises self-reporting of fatigue indicators; the third phase being the collection of physiological data.

4.1 Apparatus

Following evaluation of commercially available activity monitoring devices, discussed in chapter 2 it was decided to use the FitBit Charge HR activity tracker for workplace monitoring activities. Phase 1 of the study used the 'Reaction Time' application running on a Samsung S5 mini smart phone running the Android operating system version 4.4.2. The device contains a Quad-core Cortex-A7 processor running at 1.4GHz.

Phase 2 of the study was internet based and designed to be completed by participants using their own devices; no specific apparatus was supplied.

Phase 3 of the study used the Deary-Liewald Reaction time test application running on a 15.6 inch Hewlet Packard Laptop running Windows 10 Operating System. The device utilizes an Intel core i3 processor running at 2.0GHz and contains 4 GB RAM; no other user selected applications were running at the time of the testing.

4.2 Phase 1

Initial self-monitoring was undertaken by the experimenter using the FitBit Charge HR device in order to collect heart rate data to facilitate its use as an additional identifier of fatigue. The device was worn on the non-dominant hand of the experimenter for a three week duration with monitoring being undertaken over 24 hour periods. Where charging of the device was required no data was recorded for the duration of the charging period.

Monitoring was undertaken between the 21st February and 15th March 2015 and encompasses all activities undertaken by the experimenter, providing a balance between workplace activity and that outside of the workplace. This phase of the study

can be divided into three one week periods each comprised of two eight hour work periods, one four hour work period, and the remainder being activity out of the workplace.

The experimenters' duties in the workplace are comprised of satisfying customer service requirements; as such large amounts of physical activity (steps) are performed over the course of a work period. This is somewhat different to activity outside of the workplace as the experimenter is currently completing this Thesis; as such large amounts of time are spent sedentary during research.

Simple reaction to a visual stimulus testing was performed throughout the course of the day. Initial readings were taken at 7am providing an indication of reaction time on completion of a sleep cycle. This process was repeated throughout the course of the day at times designed to measure both the level of activity and reaction time. Readings were undertaken at 10am, 12pm, 3pm, 5pm, 7pm and 9pm to determine how reaction time is influenced as both activity and time passes between sleep cycles.

Access to collected data was provided by the use of the Firebug add on to the Firefox browser. Fitbit.com utilizes JSON arrays to create visual representations of activity via Google Charts as such anaylsis by Firebug allows access to the returned JSON array (Figure 31). The returned array was converted to a CSV file by means of an online JSON to CSV convertor and imported into Microsoft Excel for analysis (Figure 32).

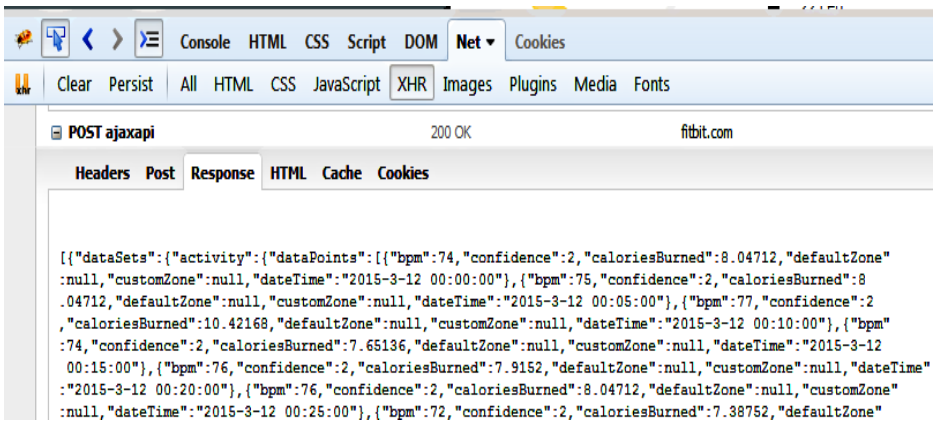


Figure 31. Example of returned JSON array used by Fitbit.com in graph generation.

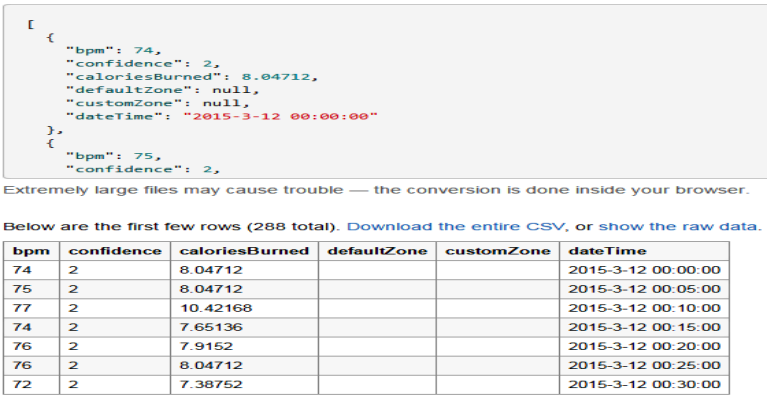


Figure 32. Converted JSON array for export to Microsoft Excel.

4.2.1 Participants

Phase one of the study was undertaken by the experimenter; male 49 years old who works part time (20hrs per week) as a retail assistant at The Warehouse, Papamoa.

4.2.2 Location – phase 1

The location at which monitoring was undertaken during work periods was The Warehouse, Papamoa. It is part of The Warehouse Group of companies and is classified as a medium sized store by the company. The experimenter approached the store manager of The Warehouse, Papamoa explaining the need for the research as being a requirement for a university course being undertaken by the experimenter.

The experimenter explained how the use of physiological data collected from passive monitoring exercises may be used in the prediction of fatigue. The experimenter also informed the Store Manager that the collection of data was passive and would not interfere with their work duties.

Activity monitoring was collected across the course of a waking period as such there is no single location at which monitoring took place. As the monitoring was passively undertaken over the course of a three week period it comprises data from both home and work.

4.3 Phase 2

Phase 2 was designed to identify individuals who self-report signs of fatigue by means of completing an online survey. The survey is split into two distinct parts, one is designed to collect data on sleep quantity and quality; the other designed to collect data on activity and feelings of fatigue.

Questions within section one are adapted from sleep study questionnaires such as The Pittsburgh Sleep Quality Index developed by Buysse, Reynolds, Monk, Berman, & Kupfer (1989), and are designed to identify possible increased fatigue states caused by sleep debt. They focus on time asleep as quantity; sleep latency and times awoken are used as indicators of sleep quality.

The second section of the questionnaire focuses on activity with information being collected on daily duties and feelings of fatigue. Questions are based in the Checklist for Individual Strength (Vercoulen and Alberts, 1999) and Fatigue Severity Scale (Krupp, LaRocca, Muir-Nash and Steinberg, 1989) questionnaires designed to identify periods of fatigue at work.

The survey was constructed using Lime Survey a purpose built survey creation tool and hosted on http://www.gweb.co.nz; a copy of which is contained within appendix A. Participants were asked to complete the survey over a period of six days in order to encompass a weekend for comparison with the working week. Responses to the survey were used to identify individuals who had indicated either sleep quality/quantity issues or identified symptoms that suggested they may be suffering from fatigue at work. These individuals were then invited to participate in phase three of the experiment where physiological data would be collected.

4.3.1 Participants

Participants were individuals taking part in phase three of the study and were based across three separate sub-contractors performing forestry operations. All participants were male with ages ranging from 17 – 62 years. Participants performed a variety of tasks on site ranging from more manual types through to mechanized operations. Participant roles along with environmental conditions are discussed further in phase three.

4.3.2 Location – phase 2

The online survey was designed to allow for completion as and where was convenient for the participant, and wherever they had access to an internet connection. This was found to be problematic; the online survey having a poor completion rate. This could possibly be due to either a lack of familiarity with online surveys or, lack of internet access. In order to overcome these issues a hard copy of the survey was provided to participants as an alternative method of data collection; this method also proved problematic with minimal completion rates.

4.4 Phase 3

Phase three of the study was the collection of physiological data by means of a Fitbit Charge HR wrist worn monitoring device and determination of simple reaction time to a visual stimulus testing. Participants were chosen by the likelihood of experiencing fatigue as indicated in phase 2 of the study; where possible all members of a forestry crew were tested.

Participants were given an alpha-numeric identifier in order to protect their identities and an account created for them on the Fitbit.com web application. Biometric data across all participants was standardised as height being 177cm and weight 88kg; age was recorded as 25 Accounts were created using the same alpha-numeric identifier which provided the link between the reaction time component of the study and the physiological component.

The Fitbit Charge HR was given to participants at the start of the work day and they were instructed to wear on the wrist of the non-dominant hand; physiological data would be collected automatically over the course of the day. At the end of the working day the experimenter collected the Fitbit Charge HR devices from the participants for synching and re-charging purposes. Results of monitoring were sourced from the Fitbit.com web based application on a daily basis.

Simple and Choice Reaction Time measurements were undertaken at commencement of the employees work period, break time and on completion of the participants work day. Ambient temperature readings were undertaken at the same time as to capture the range of temperatures employees were exposed to throughout the course of a work period.

It was decided that a more robust and validated methodology be used for the determination of simple reaction time, rather than a timer based app running on an Android phone; as used within the phase 1 proof of concept testing. The Deary-Liewald Reaction Time Task application developed by the Centre for Cognitive Ageing and Cognitive Epidemology, at the University of Edinburgh was chosen to perform reaction time testing for phase 3.

The application allows the creation of a study and requires a folder location in which to save results. This allows for hierarchal filing to be undertaken; day of testing and time of testing created separately.

Reaction time testing sessions were in two parts; Simple Reaction Time testing was completed first with the participant undertaking 15 individual tests. Choice Reaction Time testing was performed secondly with participants undertaking 20 individual tests. Results were referenced as start, break or end and saved electronically within their respective folder.

4.4.1 Participants

PF Olsen Limited a forestry management company, invited applications of interest for participation in the study, by way of Wood Matters, a monthly newsletter provided to individuals working within the forestry industry. Contractors were shortlisted and invited to participate by PF Olsen Limited, based on their harvesting methodology; mechanized, hauler and manual. Once a contractor was selected they nominated a harvesting crew in which the study would take place; individual participants being sourced from the crew. The only stipulation placed on crew member selection was that at least one participant must be a loader operator.

All participants were male with ages between 17 and 62; the large age range is a result of plant operators generally being in an older demographic, whereas more manual operations are performed by younger crew members. The exception to this is the tree feller who is generally older due to the high levels of skill and experience being required by the task.

A total of five participants from each crew were selected to participate in the monitoring phase. If any of the selected participants were absent from work they were not replaced; no data being recorded during the period of absence. Demographic information for the participants is shown in Table 2.

Table 2.

Participant demographic.

Crew	Participant	Role	Age Group
1 Paengaroa	CG1	Loader Operator	40 - 50
	PF1	Loader Operator	50 - 60
	PF2	Quality Control	<20
	JB1	Manual Feller	>60
	JB2	Process Operator	20 - 30
2 Taupo	$CG1^{-T}$	Loader Operator	40 - 50
	$PF1^{-T}$	Log Maker	20 - 30
	$PF2^{-T}$	Log Maker	20 - 30
	$JB1^{-T}$	Manual Feller	30 - 40
	$JB2^{-T}$	Process Operator	20 - 30
3 Taneatua	$CG1^{-Tan}$	Quality Control	50 - 60
	$PF1^{-Tan}$	Quality Control	20 - 30
	$PF2^{-Tan}$	Manual Feller	30 - 40
	$JB1^{-Tan}$	Loader Operator	30 - 40
	$JB2^{-Tan}$	Loader Operator	40 - 50

4.4.2 Crew 1 – Paengaroa, Bay of Plenty

Crew 1 is a fully mechanized crew with the majority of operations being performed using plant, requiring minimal 'boots on the ground time'. The crew is comprised of 8 individuals (7 male and one female) who work under the direction of a supervisor. Daily duties commence at 5am for the two loader operators who are required to be present on site early to commence loading operations for early truck arrivals.

The crew are expected to achieve 15 – 16 loads per day which equates to a daily production level of 250 tonnes of processed logs. If production levels are not met the site supervisor and another crew member will accompany the loader operators, arriving early to increase daily production levels. The remaining members of the crew arrive at 6.45am at which time the 'toolbox' meeting takes place where daily tasks are planned and assigned. On completion of the 'toolbox' meeting the crew move to their respective plant and operations commence at 7am.

Production continues for a 4 hour period with operators remaining in their vehicles for the duration of the work period. On completion of the first work period the crew return to the 'cabin' for their only break of the day. This break is 45minute duration at which time crew members have lunch and prepare for the afternoon work period.

Lunch mainly consists of sandwiches and snack food types; there is a two ring gas powered element that the crew can cook hot food on, although this was seldom used during the course of the study. Rehydration is mainly by water or coffee/tea with no energy/soft drink types seen during the course of the study.

Break is completed at 11.45am at which time the crew return to their vehicles for the afternoon shift. The end of the workday is at 3.45pm at which time crew members leave the site and begin the commute home.

Monitoring was undertaken between the 20th July and 23rd July 2015 with a second monitoring period being undertaken between the 24th August and 28th August 2015.

4.4.2.1 General Observations

Due to the remote locations at which operations are performed there are very limited welfare facilities. Those that are present are contained within a metal shipping container that is used as both the site office and lunch room (Figure 33). This container travels with the crew from production site to production site as the crew moves around.

Figure 33. Site office and lunch area.

There are no fresh water or toilet facilities at this location; drinks must be brought to site and toilet facilities are provided by the environment. Power is not supplied to the container as such no heating is available and crews protect themselves from adverse temperatures by use of clothing layers.

The crew, especially loader operators state there is quite a lot of waiting time between trucks after the initial loading phase where there is not a great deal to do. This is somewhat opposite to process operators who de-branch and trim the harvested trees; this being a more continual process. Occasionally plant cannot get to trees requiring harvesting due to the nature of the terrain; at this time a crew member will fell trees using a chainsaw.

Travel time for the crew consists of approximately an hour a day; early presence on site requires a 6am start time and arrival at home is usually around 4.30pm. This produces a total work day for general crew members in the region of 10.5 hours. Loader operators have longer days due to the early site presence requirements; one operator travels a substantial distance to the site that requires leaving home at 3.30am and arriving back at around 5.30pm, producing a total working day length of 14 hours.

4.4.3 Crew 2 - Taupo, Bay of Plenty

Crew 2 operates using more manual techniques with the majority of operations being performed by hand. The crew is comprised of six individuals (all male) who work under the direction of the company owner. Daily duties commence at 3.30am for the loader operator who is required to be present on site early to commence loading operations for early truck arrivals.

The crew usually achieve 6 – 8 loads per day equating to an average production of 120 – 150 tonnes of processed log; dependent upon truck arrivals as no scheduling is present and trucks are requested as and when needed. This somewhat removes the pressure to produce found in crew 1.

Remaining members of the crew arrive at 7.00am at which time the ‘toolbox’ meeting takes place where daily tasks are planned and assigned. On completion of the ‘toolbox’ meeting the crew move to their respective plant and operations commence at 7.15am.

Production continues for a 4 hour period, machine operators remain in their vehicles; log makers travel to and from the skid for preparation of recently felled trees, as such waiting periods allow the log makers intermittent break periods. Log making is of a manual nature with trees being first measured to determine cut points and then cutting to length by way of chainsaw. This operation is usually performed by 2 operators working alongside each other (Figure 34).

Figure 34. Log making operation.

As in crew 1 tree felling occurs in remote locations with the feller operating alone. Felling locations are challenging (Figure 35) and performed in multiple locations; the feeler having to move between each as harvesting operations dictate. On completion of the 4 hour work period the crew have a 45 minute break.

Figure 35. Felling operation showing example of difficult terrain.

Lunch mainly consists of sandwiches and snack food types; crew often bring a camping gas cooker to site for heating food. Rehydration is mainly by water or coffee/tea with no energy/soft drink types seen during the course of the study.

Break is completed at 11.45am at which time the crew return to work for the afternoon shift. The end of the workday is at 3.30pm at which time crew members leave the site and begin the commute home. Monitoring was undertaken between the 28th July and 30th July 2015.

4.4.3.1 General Observations

As with the other crews participating in the study, operations are again performed at remote locations; the only welfare facilities available to the crew are the vehicles they travel to work in. Fresh water must be brought to site and toilet facilities are provided by the environment. The vehicles are the only source of shelter available; crews again protect themselves from adverse temperatures by use of clothing layers.

Travel time for the crew is similar to that of crew 1, travel time of an hour requires early start times; usual pickup of crew members is 6am and arrival at home is usually around 4.30pm. Loader operators have longer days due to the early site presence requirements; one operator travels a substantial distance to the site that requires leaving home at 2.30am and arriving back at around 4.30pm, producing a total working day length of 14 hours.

4.4.4 Crew 3 – Taneatua, Bay of Plenty

Crew 3 is a hauler crew, designed to operate in steep terrain using cabling techniques to drag fallen trees to the skid site for processing. The crew is comprised of eight individuals (all male) who work under the direction of a site supervisor. Daily duties commence at 2.00am (first monitoring session) or 5.00am (second monitoring session) for the loader operator who is required to be present on site early to commence loading operations for early truck arrivals.

The crew generally achieves 15 – 20 loads per day equating to an average production in excess of 250 tonnes of processed logs. This is similar to the production levels found in crew 1 which appears to be consistent with mechanized production types.

Remaining members of the crew arrive at 7.00am at which time the 'toolbox' meeting takes place where daily tasks are planned and assigned. On completion of the 'toolbox' meeting the crew move to their respective plant and operations commence at 7.15am.

Production continues for a 4 hour period, machine operators remain in their vehicles; QC operators travel to and from the skid for preparation of recently made logs and as such waiting periods allow the log makers intermittent break periods. The QC

operation is of a manual nature with logs being examined for quality, any remaining branch stems are removed by way of chainsaw. This operation is usually performed by 2 operators working alongside each other (Figure 36).

Figure 36. Quality control operation.

Tree felling is undertaken manually in remote locations, with felled trees being cable hauled to the skid for processing. These locations can be challenging requiring large amounts of slope work (Figure 37). On completion of the 4 hour work period the crew have a 45 minute break.

Figure 37. Felling operations showing example of difficult terrain.

Lunch mainly consists of sandwiches and snack food types; crew often brings a camping gas cooker to site for heating food. Rehydration is mainly by water or coffee/tea with no energy/soft drink types seen during the course of the study. Break is completed at 11.45am at which time the crew return to work for the afternoon shift. The end of the workday is at 3.30pm at which time crew members leave the site and begin the commute home. Monitoring was undertaken between the 4th August and 6th August 2015 with a second monitoring period being undertaken between the 31st August and 4th September 2015.

4.4.4.1 General Observations

As with crew 1 and 2 operations are performed at remote locations and the only welfare facilitates available to the crew are the vehicles they travel to work in. There are no fresh water or toilet facilities at this location; drinks must be brought to site and toilet facilities are provided by the environment. Power is not supplied to the container as such no heating is available and crews protect themselves from adverse temperatures by use of clothing layers.

Travel time for the crew consists of approximately three hours a day; early presence on site requires a 5am start time and arrival at home is usually around 5.00pm. This produces a total work day for general crew members in the region of 12 hours. Loader operators have longer days due to the early site presence requirements; one operator travels a substantial distance to the site that requires leaving home at 1.15am (session 1) or 4.15am (session 2) and arriving back at around 3.30pm (session 1) or 4.15pm (session 2), producing a total working day length of between 12 and 14 hours.

The working day across all crews starts with a toolbox meeting, planning the day's activities, it is attended by all crew members. On completion of this meeting activity trackers were handed to participants and both simple and choice reaction time measurements were taken. This monitoring point is designed to identify initial response times with employees yet to commence work; and to act as a baseline from which activity will be monitored.

Monitoring undertaken at break time occurs after approximately four hours, both simple and choice reaction time measurements are taken to assess the impact of the morning's activities on reaction time. On completion of the workday additional measurements of simple and choice reaction time are taken to further assess the impact of daily activities on reaction time. It is at this time the activity monitors are removed from the participants for synching and recharging

4.4.5 Location – phase 3

As this phase of the study required data collection whilst the participant was at their place of employment, this phase of the survey was conducted in the field. Each set of participants to be monitored were based at their operational locations. Location details and environmental conditions are provided above within Section 4.4 of this chapter.

In this chapter we have discussed the methodology employed for the collection of data for the three phases of our study. We have provided details for locations at which data collection took place and discussed both environmental conditions and site operation. In the following chapter we present the results of the three phases of our study.

CHAPTER 5 - RESULTS

This chapter presents the results of the self-monitoring, questionnaire and field study; it provides details on both physiological monitoring and measured Simple and Choice Reaction Times. Large amounts of data are available for each individual participating in the study and are included in Appendices C and D only results pertaining to the above areas are included in this chapter. Results are taken over the course of the working day for participants except for the loader drivers whose early start prevented initial data collection.

5.1 Phase 1

Results from the three week monitoring period provide a breakdown of daily activity recorded as heart rate, calorie burn and steps taken reported as total and incremental. Sleep duration and restlessness, reaction time, alertness and type of activity were also recorded. As this phase of the experiment was conducted predominantly in an internal environment ambient temperature readings were not taken.

Results are summarized for both activity and physiological data on a per day basis in Table 3; individual results are presented in Appendix B

Table 3.

Physiological data phase one

Date	Total Sleep	Awakenings	Mean Daily Heart Rate	Steps	Calories	Mean SRT
25th February	5hr 56min	16	88	14,123	3,879	318
26th February	7hr 01min	21	84	10,321	3,321	369
27th February	6hr 04min	9	82	7,198	3,115	360
28th February	5hr 44min	8	85	16,237	4,051	342
1st March	6hr 30min	22	84	4,113	2,880	343
2nd March	6hr 29min	18	89	16,146	4,009	376
3rd March	6hr 40min	16	77	7,410	3,164	343
4th March	4hr 55min	7	93	18,450	4,615	345
5th March	6hr 25min	8	77	4,850	2,812	338
6th March	5hr 52min	9	79	4,049	2,784	345
7th March	6hr 04min	15	93	19,490	4,492	340
8th March	5hr 38min	14	76	3,986	2,736	351
9th March	6hr 04min	17	85	12,512	3,705	343
10th March	5hr 38min	14	84	7,304	3,173	336
11th March	5hr 39min	21	91	14,390	4,142	355
12th March	6hr 27min	27	80	4,225	2,700	342
13th March	N/A	N/A	74	6,880	3,037	348
14th March	6hr 55min	15	89	17,244	4,294	348

As stated in the 4.2.1 the participant was the experimenter who works part time in a retail environment. Periods of both high and low activity can be seen with work days providing the higher step rates. The highest step rate encountered was 19,490 on the 7th March whilst lowest step rate was measured at 3,986 on the 8th March. Mean heart rate and calorific burn rates also indicate higher values on days of high (>10,000 steps) activity levels. The fastest mean reaction time was measured as 318msec on 25th February; slowest reaction time was measured as 369msec on the 26th February.

5.1.1 Reaction time v activity

When examining reaction time of the lowest v highest activity rates encountered in phase one we can see that reaction time appears to be similar throughout the course of the morning however tends to slow over the rest of the day. Figure 38 provides a comparison between the measured reaction time for lowest and highest activity measured as steps.

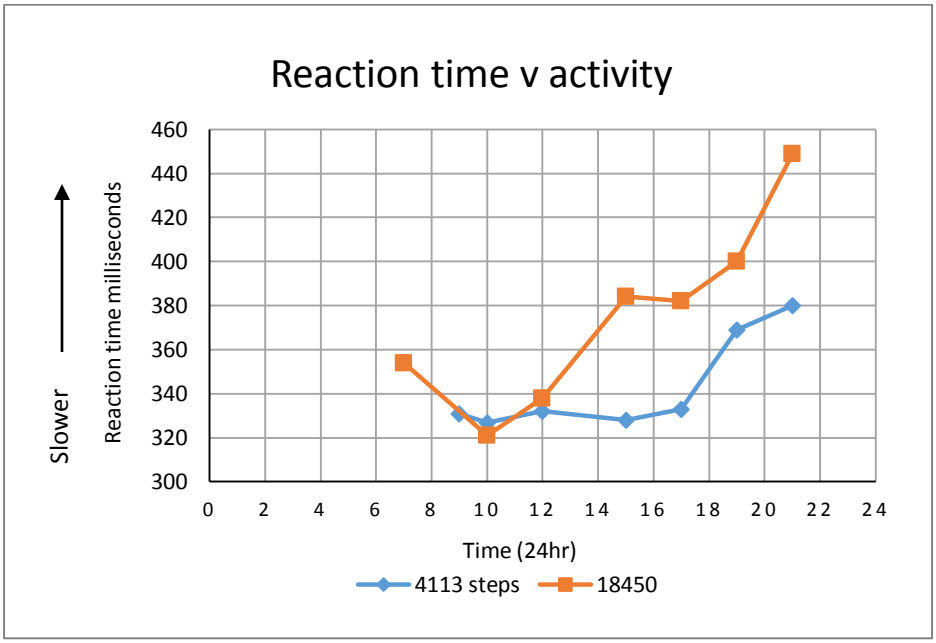


Figure 38. Reaction time v activity, low and high activity periods.

When examining the mean reaction time plotted against time using the means of the collected data we see an inverse curve relationship yielding a coefficient of determination, R^2 = 0·9662. Fastest response times occur between 10am and 3pm, after which reaction time tends to slow, a difference in means of 61msec between fastest (Figure 39)

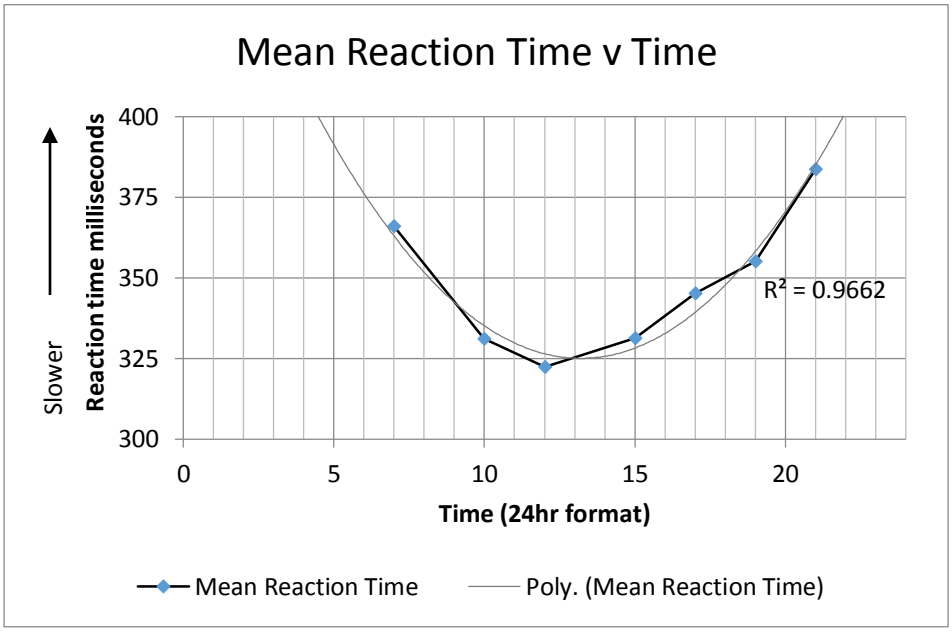


Figure 39. Mean reaction time v time across phase one of the study.

5.1.2 Reaction time v sleep

In phase one of the study sleep data was collected as the experimenter was the participant; this removed the ethical implications for the collection of data outside of the workplace. Figure 40 provides information on the difference in reaction time for both levels of sleep. During periods of low sleep duration it can be seen that reaction time decreases throughout the course of the following day. This is somewhat different than in periods of high sleep duration; reaction time tends to vary throughout the course of the following day.

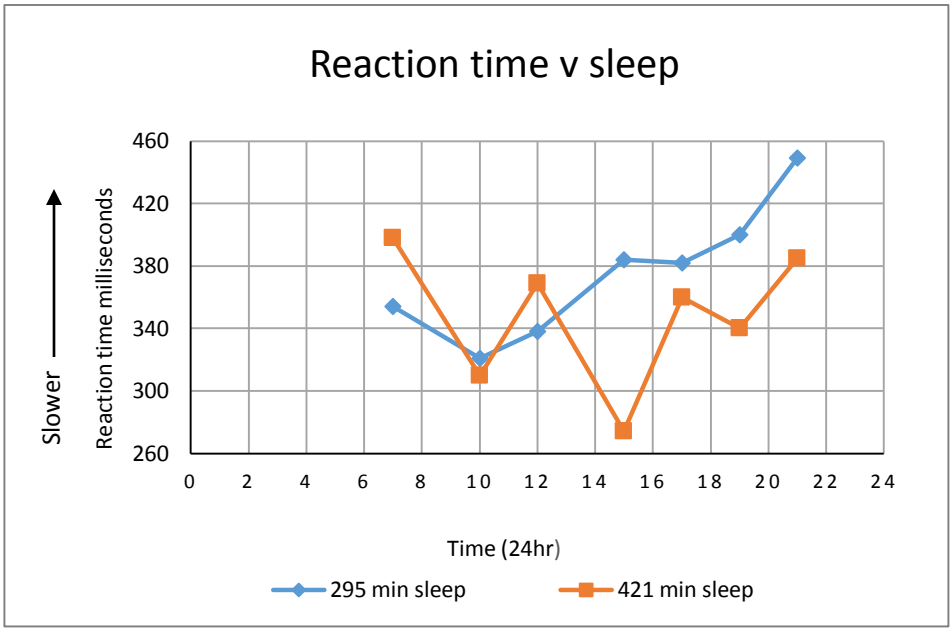


Figure 40. Reaction time v sleep duration.

5.2 Phase 2

The second phase of the experiment designed to capture both sleep quantity and quality had little success for the first crew participating in the study. The online questionnaire was not completed as hard copies of the questionnaire were provided to participants with the intention of the office staff entering the answers on their behalf. This provided difficult as questionnaires were not completed by all the participants over the required period; only 37 of 175, results based on the completed questionnaires are summarized in Table 4 below.

Table 4.

Summary of questionnaire results

Question 1	Response (%)				
What time did you go to bed last night	Before 9pm	9 – 10pm	10 – 11pm	11pm – 12am	>12am
	11	24	43	16	5

Question 2	Response (%)				
How long did it take you to fall asleep	5 – 15mins	15 – 30mins	30 – 45mins	45 – 60mins	>60mins
	32	46	14	5	3

Question 3	Response (%)				
How many times did you wake through the night	0	1 – 3	4 – 6	7 – 9	>9
	24	49	22	5	0

Question 4	Response (%)				
What time did you wake up	<5am	5 – 5.30am	5.30 – 6.00am	6.00 – 6.30am	6.30 – 7.00am
	73	27	0	0	

Question 5	Response (%)				
How would you rate the quality of your sleep last night	Excellent	Very good	Average	Below average	Poor
	12	22	41	11	14

Question 6	Planting	Felling	QC	Loader	Processor
What was your main function at work today	This question caused confusion amongst participants, responses included work hard, keep up with the crew, not let my mates down; as such this question was removed from the results.				

Question 7	Response (%)				
At any time during the day did you feel physically tired	0	1	2	3	>4
	24	38	30	5	3

Question 8	Response (%)				
At any time during the day did you find your motivation to complete tasks low	0	1	2	3	>4
	19	54	19	8	0

5.3 Phase 3 In-situ testing

This section details the collection of data in the field with the forestry crews; it provides data on weather, temperature, physiological monitoring and reaction time.

5.3.1 Crew 1 Paengaroa visit 1

Monitoring took place over a four day period; 20th July to 23rd July 2015 commencing at 06.45 and finishing at 15.45 each day. During the study 1 participant was absent for one day of the study; physiological data for a second participant was not recorded due to removal of the monitoring device for a day of the study. Participants CG1 and PF1 were loader drivers starting at 04.00, as such data collected and reported as start of the day do not represent the actual starting time of these participants but rather are the start of daily data collection at 06.45. Remaining participants commence their duties at 06.45 as such data collected encompasses the full working day.

5.3.2 Ambient Temperature

Temperature across the course of the study varied between 1.7ºC and 13.9ºC with the weather being mainly fine with no rain during the monitoring period. Results suggest both Choice and Simple Reaction time appears to be impaired at temperatures below 4ºC with each participant showing improving reaction times as temperature increases (Table 5).

Table 5.

Paengaroa visit 1, simple and choice reaction time by temperature

Temperature °C	Participant									
	CG1		PF1		PF2		JB1		JB2	
	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT
1.7	481	661	N/A	N/A	326	457	480	704	399	480
3.3	333	619	388	775	388	419	359	583	322	447
3.4	377	554	386	902	285	433	331	547	324	394
4.7	329	645	N/A	N/A	354	418	492	662	320	464
7.9	359	571	359	843	320	398	369	572	328	475
10.2	390	535	398	861	336	424	N/A	N/A	324	408
11	367	552	432	830	304	420	338	584	279	393
12.2	385	562	388	927	307	399	364	579	329	417
13.3	325	676	N/A	N/A	315	398	N/A	N/A	307	427
13.9	461	575	366	739	299	383	389	565	311	440

Note: CG1 loader driver, PF1 loader driver, PF2 Quality Control, JB1 manual feller, JB2 processor. All figures for reaction time are reported in milliseconds and lower numbers represent faster reaction times.

Largest decrease in Simple Reaction Time was 152 milliseconds recorded between 1.7ºC and 4.7ºC for participant CG1; largest decrease in Choice Reaction Time was 42 milliseconds for participant JB1.

Mean reaction time results across all participants indicate the general trend across individual participants; improving reaction time at temperatures below 4oC. Reaction times appear to show less variation between 4ºC and 13ºC at which point reaction times indicate a marked improvement; 40msec for SRT and 76msec for CRT (Figure 41).

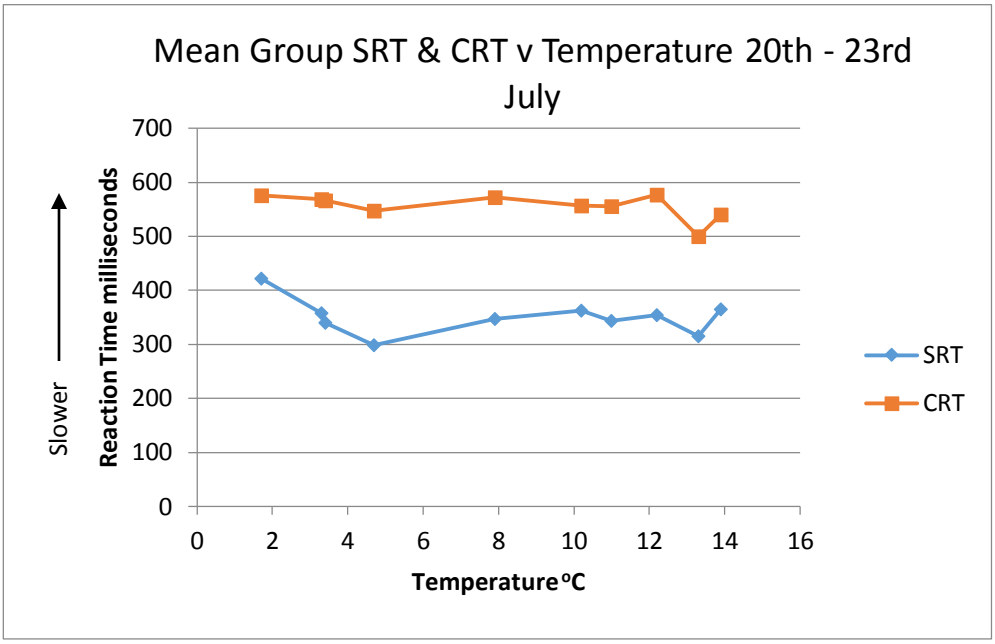


Figure 41. Mean group SRT and CRT v temperature.

It should be remembered that this improvement falls in a time period that is associated with a rest period; as such improved results can be due to this period, lessening any effects of task induced fatigue, we discuss this further in Chapter 6.

Examples of Simple and Choice Reaction Time v temperature results are given in appendix D.

5.3.3Activity

Activity was monitored using a step count over the course of the monitoring period with both daily and cumulative steps being counted. Heart rate, calorific burn rates and stairs climbed were also recorded; a large variation in step rates exists due to the respective tasks performed by the participants. Being a mechanized crew the majority of tasks are performed by plant with the exception of manual felling and quality control.

Table 6 details the amount of steps taken by each participant over the course of the working period. Again it should be noted that participants CG1 and PF1 are loader operators starting work at 04:00 as such step rates reported do not include the period between 04:00 and 06:45.

The Fitbit monitoring device contains an altimeter and represents increases in height of around 10 feet as flights climbed (Fitbit, 2015); here it represents inclines in terrain rather than flights of stairs. It should also be noted that the Fitbit device only counts increases in elevation, not decreases in elevation.

Table 6.

Paengaroa visit 1, step rate and flights climbed, daily and cumulative.

Date	Participant									
	CG1		PF1		PF2		JB1		JB2	
	Step	Flight	Step	Flight	Step	Flight	Step	Flight	Step	Flight
20th July	2247	5	N/A	N/A	16334	33	15950	22	3555	10
21st July	4298	25	1688	7	16340	57	16431	32	2624	14
22nd July	2746	12	3381	7	14550	41	N/A	N/A	3202	12
23rd July	2153	12	5357	9	16644	38	15510	59	3192	16
Cumulative	11642	54	10246	23	63868	169	47891	113	12573	52

It can be seen from Table 6 that participants PF2 and JB1 have the largest step rates; both participants perform manual operations on the site. Participant PF2 performs quality control operations, requiring constant climbing on and off of logs to both measure and remove and remaining branches after trimming. Participant JB1

performs manual felling operations operating autonomously away from the crew. The working environment for the participant is on the forest floor, felling trees by hand in locations that cannot be reached by mechanized plant; as such there is a large amount walking and slope work. This can be seen by both the high step rate and the large amount of flights climbed.

Although participant CG1 has a large amount of flights climbed he is a loader operator, it is suggested that the high flights of stairs result for the 21st July is due to constant exiting and entering the vehicle. This usually occurs if the vehicle is undergoing maintenance or repairs; in general operators only leave the vehicles at breaks or during refueling operations. This was the case on the 21st July as the vehicle was undergoing maintenance requiring removal from the operational area.

The highest daily step rate was recorded as 16,664 by participant PF2 and the lowest step rate was recorded as 1,688 by participant PF1. Cumulative step rates over the course of the monitoring period show crew members performing manual tasks have the largest step rates; PF2 having the highest step rate of 63,868; conversely participant PF1 has the lowest step rate, 10,246. Mean step rates for participants show CG1 as 2,911, PF1 as 3,415, PF2 as 15,967, JB1 as 15,963 and JB2 as 3,143.

The difference between crew members who perform manual operations and those that perform mechanized operations are easily distinguishable; plant operators step rates are generally in the <5,000 range and manual operations are generally in the >15,000 step range.

5.3.4 Reaction time v activity

In order to identify the impact of activity on reaction time, both Simple Reaction Time and Choice Reaction Time was determined at three periods throughout the working day. Readings were taken at the start of the shift, break time and end of the shift. Table 7 summarizes both the mean Simple Reaction Time and mean Choice Reaction Time results for recorded for participants.

Table 7.

Paengaroa visit 1, simple and choice reaction time.

Period	Participant	Age	Work Type	Mean SRT msec	Mean CRT msec
Start	CG1	40 - 50	Loader Operator	386	600
Break				352	578
End				377	587
Start	PF1	50 - 60	Loader Operator	403	879
Break				516	899
End				530	941
Start	PF2	<20	Quality Controller	321	436
Break				329	415
End				320	396
Start	JB1	>60	Manual Feller	341	611
Break				400	606
End				411	613
Start	JB2	20 - 30	Process Operator	343	449
Break				315	424
End				318	432

In general both Simple and Choice Reaction Time tends to vary across the working day; individuals are predominantly slower at the start of their shift, faster towards lunch and then slower as the shift comes to an end. Figures 42 and 43 show the trending of reaction time across the course of the work period. Individual reaction time data is given in appendix C.

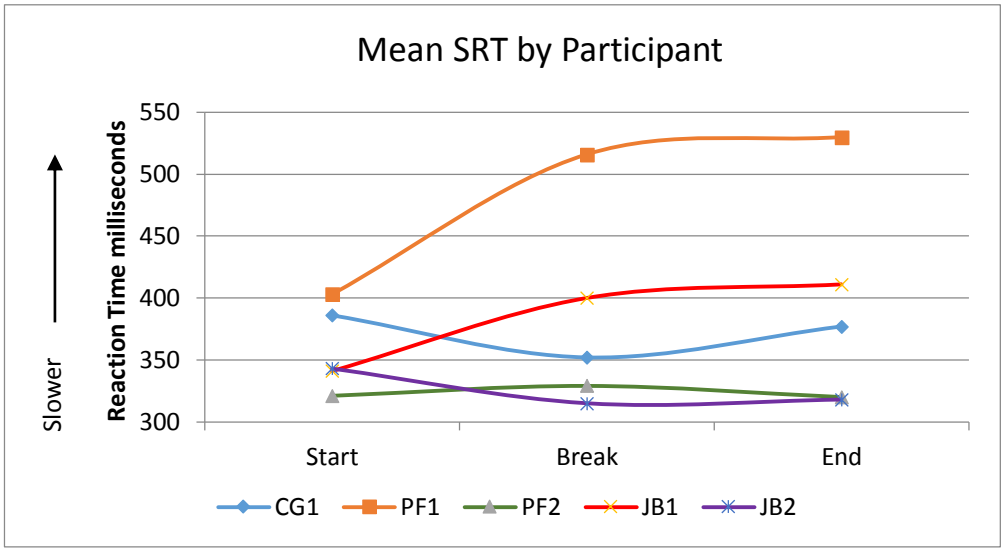


Figure 42. Mean simple reaction time by participant.

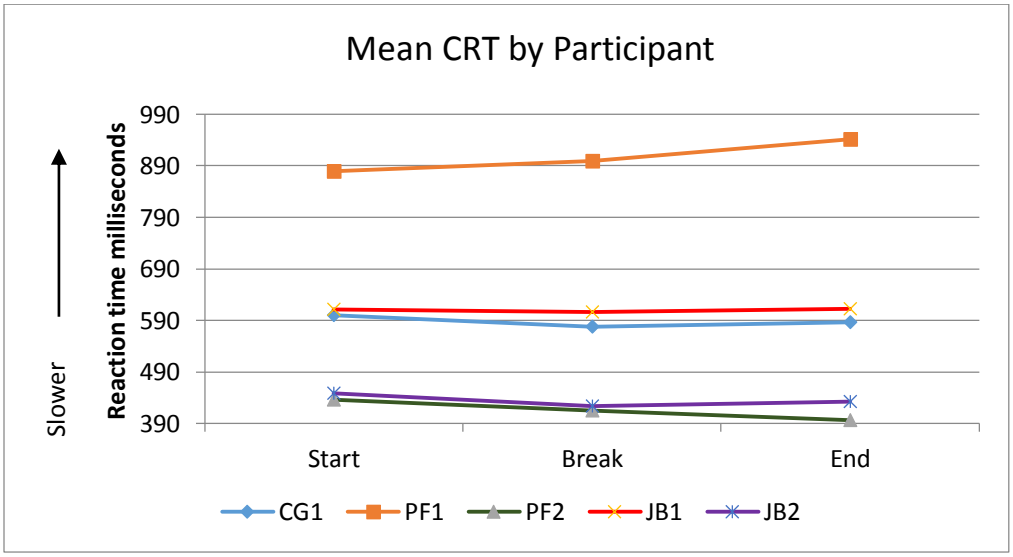


Figure 43. Mean choice reaction time by participant.

Simple Reaction time appears to show the most variation across the day with participant PF1 showing a 127 millisecond variation from start to completion of the working day. Choice Reaction Time does not appear to show as large a variation across the course of the day; largest variation being 62 milliseconds for participant PF1. Example reaction time results are presented in Appendix D.

5.4 Crew 1 Paengaroa visit 2

Monitoring took place over a five day period; 24th July to 28th August 2015 commencing at 06.45 and finishing at 15.45 each day. During the study 1 participant was absent for one day of the study and 1 participant was absent for two days. Participants CG1 and PF1 were loader drivers starting at 04.00, as such data collected and reported as start of the day do not represent the actual starting time of these participants. Remaining participants commence their duties at 06.45 as such data collected encompasses the full working day.

5.4.1 Ambient Temperature

Temperature across the course of the study varied between 0°C and 17°C with the weather being mainly fine with no rain during the monitoring period. As in visit one both Choice and Simple Reaction time appears to be impaired at temperatures below 4°C with each participant showing improving reaction times as the temperature increases.

Table 8.

Paengaroa visit 2, simple and choice reaction time by temperature.

Temperature °C	Participant									
	CG1		PF1		PF2		JB1		JB2	
	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT
0	381	515	380	749	319	438	N/A	N/A	367	447
2.2	387	501	349	796	299	379	N/A	N/A	327	407
7.8	389	516	477	737	342	403	414	555	304	418
7.9	465	603	465	603	N/A	N/A	357	578	323	401
10.0	436	521	436	840	289	388	328	624	311	407
10.6	N/A	N/A	346	683	327	386	N/A	N/A	333	407
10.8	N/A	N/A	407	840	N/A	N/A	357	577	356	433
11.2	365	530	342	680	323	419	N/A	N/A	387	423
12.8	420	633	471	813	314	385	N/A	N/A	348	449
13.0	366	545	439	720	310	394	325	597	328	411
13.3	435	500	384	878	N/A	N/A	N/A	N/A	362	417
14.1	360	564	489	783	293	385	342	622	295	420
15	411	598	325	617	323	375	N/A	N/A	349	463
16.7	403	544	397	807	311	424	330	559	N/A	N/A
17.2	392	630	386	772	327	418	316	668	349	444

Note: CG1 loader driver, PF1 loader driver, PF2 Quality Control, JB1 manual feller, JB2 processor. All figures for reaction time are reported in milliseconds

The largest decrease in Simple Reaction Time was 40 milliseconds recorded between 0°C and 2.2°C for participant JB2 and the largest decrease in Choice Reaction Time was 59 milliseconds for participant PF2. Remaining participants all showed increased reaction time as temperature increased.

Although not as pronounced as visit 1 mean reaction time results across all participants indicate the general trend of improving reaction times as temperature increases. Large increases in performance at temperatures below 4°C, as seen in visit 1, are not as pronounced for this visit. Reaction times at temperatures between 4°C and 13°C appear to show slightly more variation than that of visit 1; at which point reaction times indicate an improvement similar to that encountered in visit 1; 42 msec for SRT and 82 msec for CRT (Figure 44).

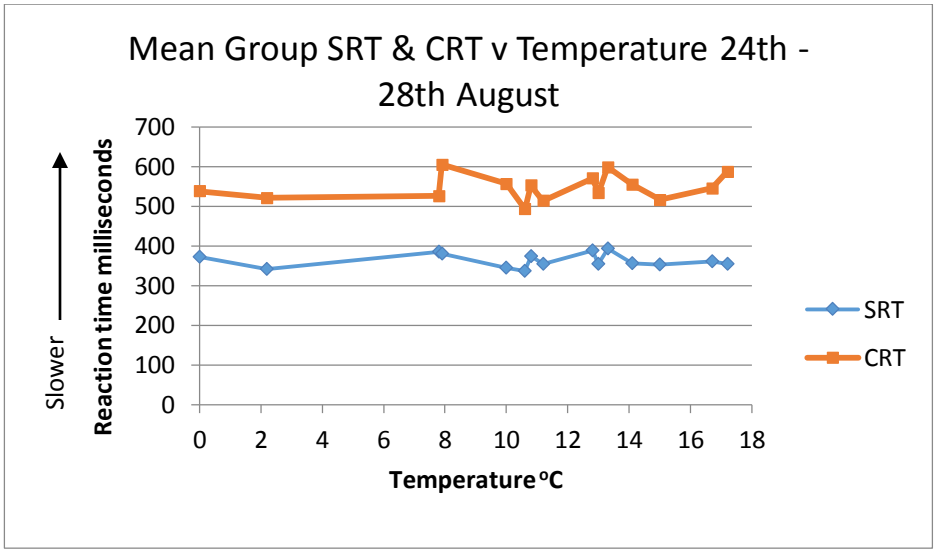


Figure 44. Mean group Simple reaction time and choice reaction time v temperature.

As in visit 1 it should be remembered that this improvement falls in a time period that is associated with a rest period; as such improved results can be due to this period, lessening any effects of task induced fatigue. Examples of Simple and Choice Reaction Time v temperature results are given in appendix D.

5.4.2 Activity

Activity was monitored using a step count over the course of the monitoring period with both daily and cumulative steps being counted. Heart rate, calorific burn rates and stairs climbed were also recorded; a large variation in step rates exists due to the respective tasks performed by the participants. Being a mechanized crew the majority of tasks are performed by plant with the exception of manual felling and quality control.

Table 9 details the amount of steps taken by each participant over the course of the working period. Again it should be noted that participants CG1 and PF1 are loader operators starting work at 04:00 as such step rates reported do not include the period between 04:00 and 06:45.

Table 9.

Paengaroa visit 2, step rate and flights climbed, daily and cumulative.

Date	Participant									
	CG1		PF1		PF2		JB1		JB2	
	Step	Flight	Step	Flight	Step	Flight	Step	Flight	Step	Flight
24th August	1984	7	1984	11	16595	61	23452	49	3084	18
25th August	2256	25	5360	14	11527	54	17493	49	3034	22
26th August	3847	31	5806	5	N/A	N/A	N/A	N/A	5196	15
27th August	5152	18	5652	5	14724	36	N/A	N/A	3192	6
28th August	2330	2	5731	2	15485	45	N/A	N/A	2394	5
Cumulative	15569	83	24553	37	58331	196	40945	98	16900	66

Note. All participants performed the same roles as in visit 1

It can be seen from Table 9 that participants PF2 and JB1 have the largest step rates; both participants perform manual operations on the site. Participant CG1 again shows a high flights climbed result, the operator was seen to exit the vehicle and assist the hauler driver numerous times on completion of loading. It is suggested that the high flights of stairs results for the 25th and 26th August are a result of the constant exiting and entering the vehicle.

The highest daily step rate was recorded as 23,452 by participant JB1 and the lowest step rate was recorded as 1,984 by participant CG1. Cumulative step rates over the course of the monitoring period show crew members performing manual tasks have the largest step rates; PF2 having the highest step rate of 58,331; conversely participant CG1 has the lowest step rate, 15,569. Mean step rates for participants show CG1 as 3,114 PF1 as 4,907, PF2 as 15,222, JB1 as 20,473 and JB2 as 3,380.

5.4.3 Reaction time v activity

The same methodology as in visit one was employed for Simple Reaction Time and Choice Reaction Time determination; readings taken at the start of the shift, break time and end of the shift. Table 10 summarizes both the mean Simple Reaction Time and mean Choice Reaction Time results for participants.

Table 10.

Paengaroa visit 2, simple and choice reaction time.

Period	Participant	Age	Work Type	Mean SRT msec	Mean CRT msec
Start	CG1	40 – 50	Loader Operator	420	531
Break				364	546
End				412	582
Start	PF1	50 - 60	Loader Operator	397	792
Break				404	736
End				394	777
Start	PF2	<20	Quality Controller	312	402
Break				329	397
End				313	402
Start	JB1	>60	Manual Feller	371	590
Break				333	610
End				324	614
Start	JB2	20 - 30	Process Operator	327	416
Break				340	418
End				352	432

In general both Simple and Choice Reaction Time tends to vary across the working day; individuals are predominantly slower at the start of their shift, faster towards lunch and then slower as the shift comes to an end. Figures 45 and 46 show the trending of reaction time across the course of the work period. Individual reaction time data is given in appendix C.

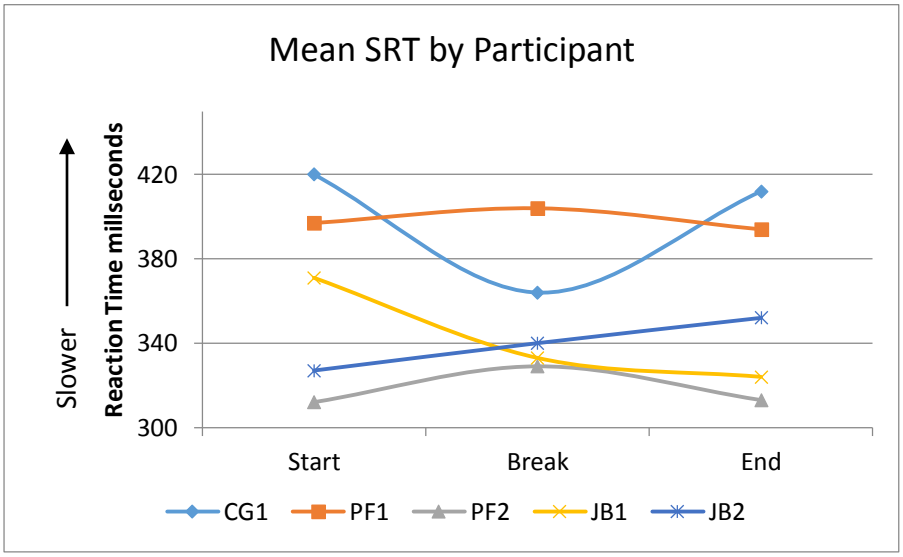


Figure 45. Mean simple reaction time by participant.

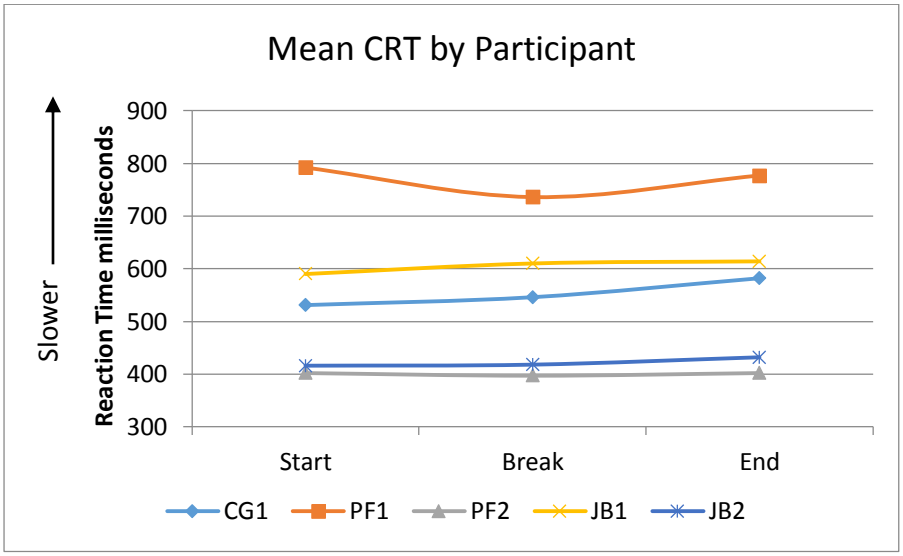


Figure 46. Mean choice reaction time by participant.

5.5 Crew 2 -Taupo

Monitoring took place over a three day period; 27th July to 29th July 2015 commencing at 06.45 and finishing at 15.45 each day. Participant identifications have been suffixed with $^{-T}$ to indicate location as Taupo. Participant CG1^{-T} was the loader driver starting at 04.00, as such data collected and reported as start of the day do not represent the actual starting time of these participants. Remaining participants

commence their duties at 06.45 as such data collected encompasses the full working day. Participant JB2^{-T} has a multifunctional role generally split between felling operations and plant operations.

5.5.1 Ambient Temperature

Temperature across the course of the study varied between 6^{o}C and 18^{o}C with the weather being mainly fine with occasional showers on the 28th July; participant JB2^{-T} was absent on the 28th July. Ambient temperatures were warmer during monitoring than those encountered with crew 1 as such comparisons between crews at lower ambient temperatures could not be performed. It is interesting to note that at temperatures above 18^{o}C both Simple and Choice Reaction Time tends to slow (Table 11).

Table 11.

Taupo simple and choice reaction time by temperature.

Temperature ^{o}C	Participant									
	CG1^{-T}		PF1^{-T}		PF2^{-T}		JB1^{-T}		JB2^{-T}	
	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT
5.6	339	534	296	494	372	590	294	489	345	457
8.3	399	535	306	442	298	390	302	396	N/A	N/A
9.9	346	553	274	399	270	N/A	268	393	N/A	N/A
10	480	555	312	481	340	470	286	449	370	711
12.2	337	500	280	414	272	351	305	420	N/A	N/A
13.4	331	496	333	490	360	505	338	517	327	455
14	402	469	291	406	342	392	293	440	373	719
17.7	354	560	309	405	316	403	277	412	399	682
18.3	422	570	N/A	N/A	314	437	314	441	485	466

Note: CG1^{-T} loader driver, PF1^{-T} log maker, PF2^{-T} log maker, JB1^{-T} manual feller, JB2^{-T} combination role, feller and operator. All figures for reaction time are reported in milliseconds

Largest decrease in Simple Reaction Time was 143milliseconds recorded between 10ºC and 12.2ºC for participant CG1^{-T}; largest decrease in Choice Reaction Time was 283milliseconds for participant JB2^{-T}. Remaining participants showed a general decrease in reaction times as temperature increases.

Mean reaction time results across all participants follow similar trending as crew 1 improving reaction time as temperature increases. There is however a large increase in both Simple and Choice Reaction Time around 10ºC; 68 and 85milliseconds respectively, this is somewhat reversed for both Simple and Choice Reaction Time as the temperature continues to rise; decreases of 59 and 112 milliseconds respectively (Figure 47).

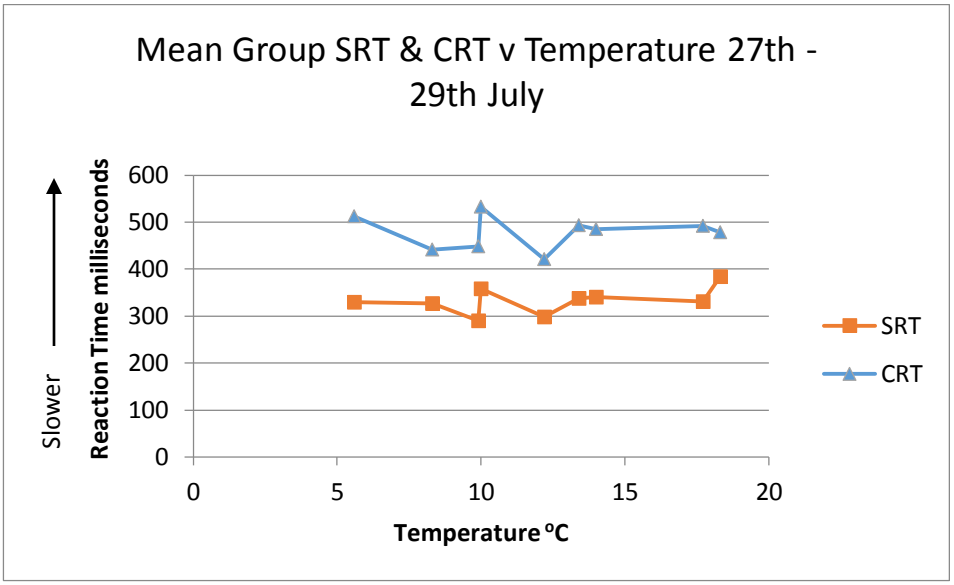


Figure 47. Mean group simple and choice reaction time v temperature.

Again improvements fall in a time period that is associated with a rest period; as such improved results can be due to this period, lessening any effects of task induced fatigue. Examples of Simple and Choice Reaction Time v temperature results are shown in appendix D.

5.5.2 Activity

Activity data was collected across the same physiological variables and timescales as in crew 1. Operations were performed adjacent to an access road, as such the level of plant onsite was minimal with the majority of site operations being performed manually.

Table 12 details the amount of steps taken by each participant over the course of the working period. It should be noted that participant $CG1^{-T}$ is a loader operator starting work at 04:00 as such step rates reported do not include the period between 04:00 and 06:45.

Table 12.

Taupo step rate and flights climbed, daily and cumulative.

Date	Participant									
	$CG1^{-T}$		$PF1^{-T}$		$PF2^{-T}$		$JB1^{-T}$		$JB2^{-T}$	
	Step	Flight	Step	Flight	Step	Flight	Step	Flight	Step	Flight
27th July	4329	34	24886	16	18202	12	22837	36	2544	5
28th July	1822	2	25100	12	18495	18	22907	22	14122	12
29th July	3001	7	24624	24	20014	22	22587	63	N/A	N/A
Cumulative	9152	43	74610	52	67940	56	68331	121	16666	17

It can be seen from Table 12 that participants $PF1^{-T}$, $PF2^{-T}$ and $JB1^{-T}$ have the largest step rates; this is to be expected as participants perform manual operations on the site. Participants $PF1^{-T}$ and $PF2^{-T}$ perform log making operations, requiring constant climbing on and off of logs to both measure and remove and remaining branches after trimming.

Participant JB1^{-T} performs manual felling operations operating autonomously away from the crew. The working environment for the participant is on the forest floor, felling trees by hand in locations that cannot be reached by mechanized plant; as such there is a large amount walking and slope work.

The highest daily step rate was recorded as 25,100 by participant JB1^{-T}, and the lowest step rate was recorded as 1,822 by participant CG1^{-T}. Cumulative step rates over the course of the monitoring period show crew members performing manual tasks have the largest step rates; PF1^{-T} having the highest step rate of 74,610; conversely participant CG1-T has the lowest step rate, 9,152.

Mean step rates for participants across the duration of the monitoring period show CG1-^{T} as 3,116 PF1^{-T} as 24,870, PF2^{-T} as 22,647, JB1^{-T} as 22,777 and JB2^{-T} as 5,555.

5.5.3 Reaction time v activity

Simple Reaction Time and Choice Reaction Time was determined at three periods throughout the working day; start, break and end. Table 13 summarizes the weekly means of Simple and Choice Reaction Times.

Table 13.

Taupo simple and choice reaction time.

Period	Participant	Age	Work Type	Mean SRT msec	Mean CRT msec
Start	$CG1^{-T}$	40 - 50	Loader Operator	406	531
Break				360	546
End				371	582
Start	$PF1^{-T}$	20 - 30	Log Maker	304	472
Break				299	431
End				295	409
Start	$PF2^{-T}$	20 - 30	Log Maker	334	460
Break				324	448
End				300	377
Start	$JB1^{-T}$	30 - 40	Manual Feller	294	445
Break				312	450
End				299	514
Start	$JB2^{-T}$	20 - 30	Process Operator	358	584
Break				350	587
End				442	574

Similar trending between crews for Simple and Choice Reaction Time is indicated; individuals are predominantly slower at the start of their shift, faster towards lunch and then slower as the shift comes to an end, however younger participants $PF1^{-T}$ and $PF2^{-T}$ show continual improvement in reaction times throughout the day. Figures 48 and 49 show the trending of reaction time across the course of the work period. Individual simple and choice reaction time data is given in appendix C.

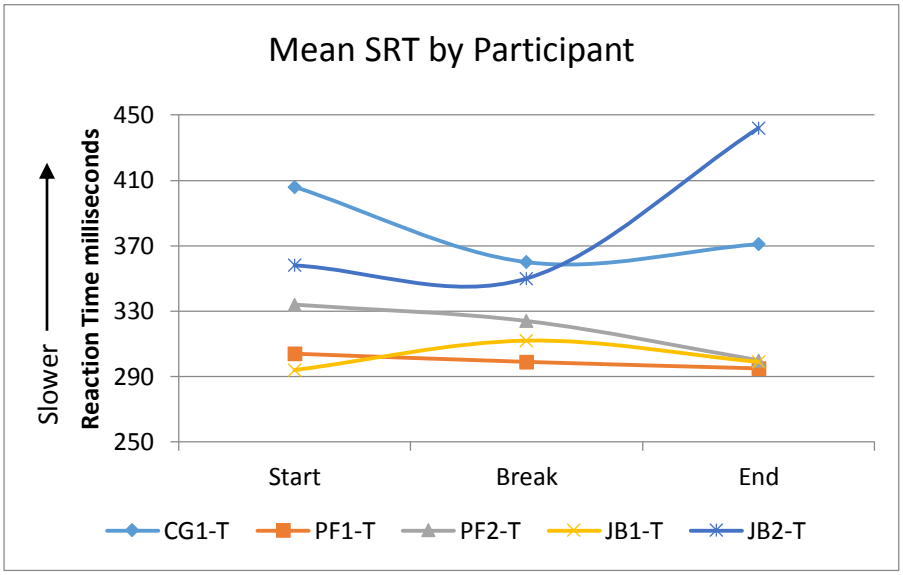


Figure 48. Mean simple reaction time by participant.

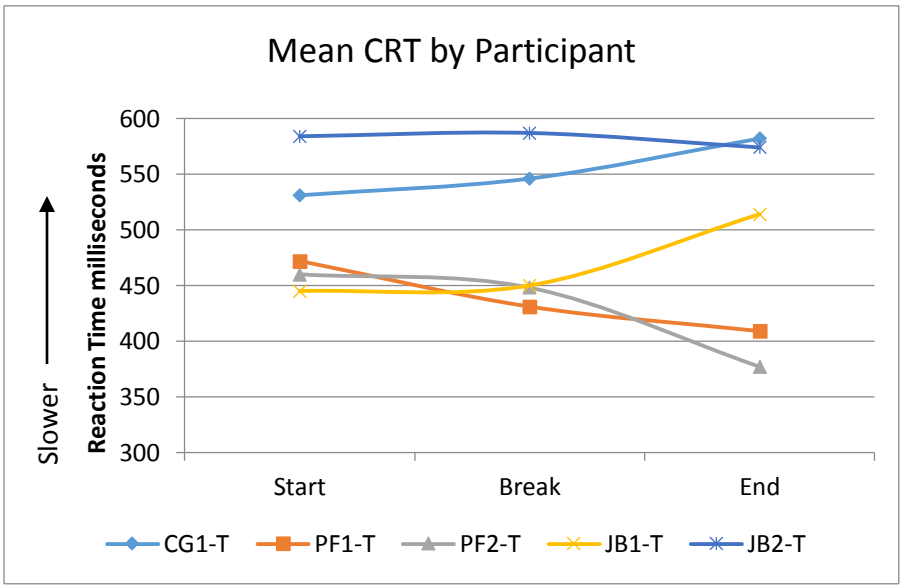


Figure 49. Mean choice reaction time by participant.

5.6 Crew 3 - Taneatua Visit 1

Monitoring took place over a three day period; 10th August to 12th August 2015 commencing at 06.45 and finishing at 15.45 each day. Participant identifications have been suffixed with $^{-Tan}$ to indicate location as Taneatua.

Participant JB2^{-Tan} was the loader driver starting at 02.00, as such data collected and reported as start of the day do not represent the actual starting time of these participants. Remaining participants commence their duties at 06.45 as such data collected encompasses the full working day.

5.6.1 Ambient Temperature

Temperature across the course of the study varied between -4^{o}C and 11^{o}C with the weather being fine throughout the monitoring period. Results suggest both Choice and Simple Reaction time appears to be impaired at temperatures below 4^{o}C with each participant showing improving reaction times as temperature increases (Table 14).

Table 14.

Taneatua visit 1, simple and choice reaction time by temperature.

Temperature ^{o}C	Participant									
	CG1^{-Tan}		PF1-^{Tan}		PF2^{-Tan}		JB1^{-Tan}		JB2^{-Tan}	
	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT
-4	445	622	309	559	414	559	340	489	1003	1007
-1	400	599	384	475	378	600	312	396	920	902
0	1259	765	575	838	383	539	281	393	1125	1292
3	363	643	309	507	367	557	360	449	479	803
4	466	745	414	583	406	610	315	420	825	986
5	317	560	366	542	385	532	290	517	403	671
9	393	516	393	544	371	592	278	440	468	921
11	408	547	395	562	362	602	281	412	423	704
11	371	512	400	498	338	514	272	441	381	602

Note: CG1 Quality Controller, PF1 Quality Controller, PF2 Cross Cutter, JB1 Loader Operator, JB2 Loader Operator. All figures for reaction time are reported in milliseconds.

Largest decrease in Simple Reaction Time was 896 milliseconds recorded between 0°C and 3°C for participant CG1-Tan, it should be noted that this was the first measurement undertaken, as such the values maybe a result of unfamiliarity; largest decrease in Choice Reaction Time was 489 milliseconds for participant JB2-Tan again between 0°C and 3°C. Remaining participants showed a general decrease in reaction times as temperature increases.

Mean reaction time results across all participants follow similar trending as crew 1 improving reaction time as temperature increases (Figure 50). There is a large increase in reaction time around 0°C; 296 milliseconds for Simple and 171 milliseconds for Choice Reaction Times.

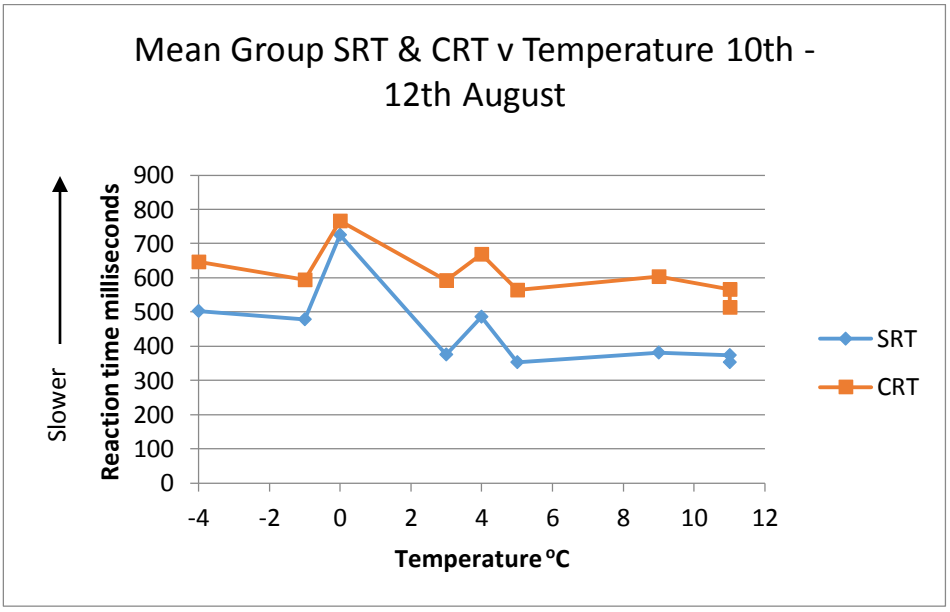


Figure 50. Mean group simple and choice reaction time v temperature.

Simple and Choice Reaction Time followed a similar trending to the other crews; improvement indicated through the midpoint of the temperature range that coincides with a break period Examples of Simple and Choice Reaction Time v temperature results are given in appendix D.

5.6.2 Activity

Monitoring was undertaken using the same methodology as in the other crews with reaction time being measured at start, break and end of the working day.

Table 15 details the amount of steps taken by each participant over the course of the working period. It should be noted that participant CG1-^{Tan} is a loader operators starting work at 02:00 as such step rates reported do not include the period between 02:00 and 06:45.

Table 15.

Taneatua visit 1, step rate and flights climbed, daily and cumulative.

Date	Participant									
	CG1^{-Tan}		PF1^{-Tan}		PF2^{-Tan}		JB1^{-Tan}		JB2^{-Tan}	
	Step	Flight	Step	Flight	Step	Flight	Step	Flight	Step	Flight
10th August	5973	9	11590	43	22413	89	6032	23	2626	6
11th August	17150	39	17246	21	26722	104	1758	5	3933	11
12th August	8298	54	19404	51	19386	24	2241	11	5991	N/A
Cumulative	31421	102	48240	115	68521	217	10031	39	16666	13

It can be seen from Table 15 that participants CG1^{-Tan}, PF1^{-Tan} and PF2^{-Tan} have the largest step rates; this is what would be expected as they perform quality control operations; grading logs by diameter, and removing any remaining branches.

Participant PF2 performs manual felling operations; again these operations are performed autonomously at locations distant from the main operational area. The working environment for the participant is on the forest floor, felling trees by hand in preparation for transport to the processing area.

The highest daily step rate was recorded as 26,722 by participant PF2^{-Tan}, and the lowest step rate was recorded as 1,758 by participant JB1-^{Tan}. Cumulative step rates over the course of the monitoring period show crew members performing manual tasks have the largest step rates; PF2^{-Tan} having the highest step rate of 68,521; conversely participant JB1^{-Tan} has the lowest step rate, 10,031. Mean step rates for participants across the duration of the study show CG1^{-Tan} as 10,473, PF1^{-Tan} as 16,080, PF2^{-Tan} as 22,840, JB1^{-Tan} as 3,343 and JB2^{-Tan} as 5,555.

As demonstrated in the previous crews activity levels (steps) are higher in participants performing manual operations. Step rates of <5000 are indicative of plant operators and >15,000 by participants involved in more manual type operations.

5.6.3 Reaction time v activity

Simple Reaction Time and Choice Reaction Time was determined at three periods throughout the working day. Readings were taken at the start of the shift, break time and end of the shift. Table 16 summarizes the weekly means of Simple and Choice Reaction Times.

Table 16.

Taneatua visit 1, simple and choice reaction time.

Period	Participant	Age	Work Type	Mean SRT msec	Mean CRT msec
Start	CG1^{-Tan}	50 - 60	Quality Control	701	662
Break				382	649
End				390	525
Start	PF1^{-Tan}	20 - 30	Quality Control	445	624
Break				363	544
End				396	534
Start	PF2^{-Tan}	30 - 40	Manual Feller	392	566
Break				386	566
End				357	569
Start	JB1^{-Tan}	30 - 40	Loader Operator	311	520
Break				321	456
End				277	458
Start	JB2^{-Tan}	40 - 50	Loader Operator	1016	1067
Break				569	820
End				424	742

In general both Simple and Choice Reaction Time tends to vary across the working day; individuals are predominantly slower at the start of their shift, and faster throughout the work day. This is somewhat different than the other crews and it is suggested that the lower temperatures encountered during the monitoring period results in progressively faster reaction times as the temperature increases. Figures 51 and 52 show the trending of reaction time across the course of the work period. Individual reaction time data is given in appendix C.

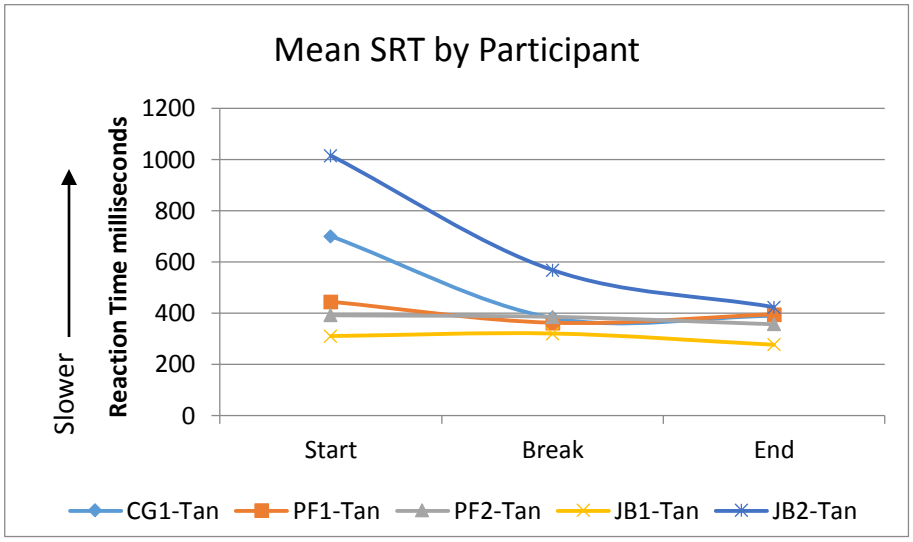


Figure 51. Mean simple reaction time by participant.

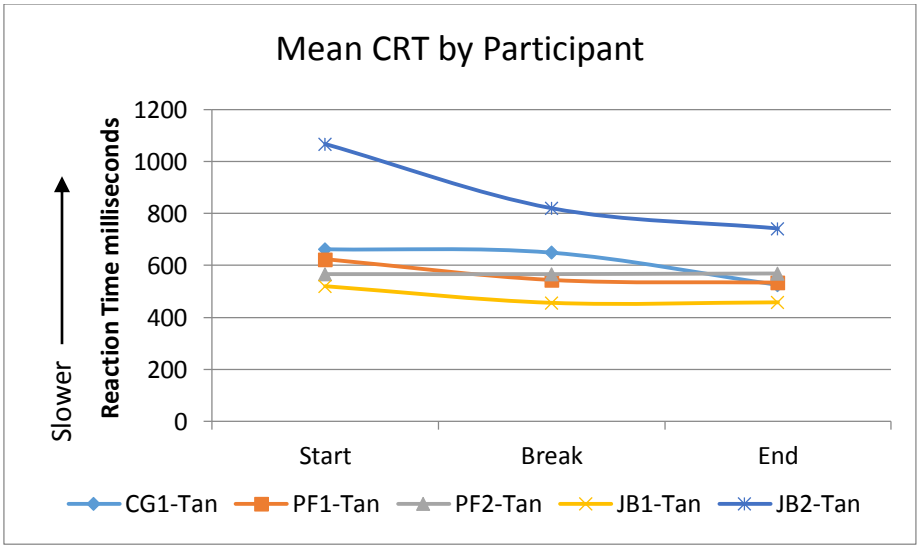


Figure 52. Mean choice reaction time by participant.

5.7 Crew 3 Taneatua Visit 2

Monitoring took place over a two day period; 31st August to 4th September 2015 commencing at 06.45 and finishing at 15.45 each day. The site was in the same area as the first visit however the location had moved closer to habited areas, as such operational time constraints were in place; all participants commencing work at the same start time.

5.7.1 Ambient Temperature

Temperature across the course of the study varied between 3.3ºC and 15ºC with the weather being fine throughout the monitoring period. Results suggest that generally both Choice and Simple Reaction time improves with increasing temperature (Table 17).

Table 17.

Taneatua visit 2, simple and choice reaction time by temperature.

Temperature ºC	Participant									
	CG1^{-Tan}		PF1^{-Tan}		PF2^{-Tan}		JB1^{-Tan}		JB2^{-Tan}	
	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT	SRT	CRT
3.3	349	493	402	467	376	573	313	511	418	597
9.4	466	596	427	559	498	591	301	451	531	635
10.1	405	469	410	514	416	604	290	444	368	637
12.3	333	488	380	415	585	626	301	474	341	563
12.8	492	565	372	493	389	514	298	459	N/A	N/A
15	332	546	461	498	409	592	305	445	421	547

Note: CG1^{-Tan} Quality Controller, PF1^{-Tan} Quality Controller, PF2^{-Tan} Manual Feller, JB1^{-Tan} Loader Operator, JB2^{-Tan} Loader Operator. All figures for reaction time are reported in milliseconds.

Largest decrease in Simple Reaction Time was 160 milliseconds recorded between 12.8ºC and 15ºC for participant CG1^{-Tan}; largest decrease in Choice Reaction Time was 74 milliseconds for participant JB2^{-Tan} between 10.1ºC and 12.3ºC. Remaining participants showed a general decrease in reaction times as temperature increases (Figure 53).

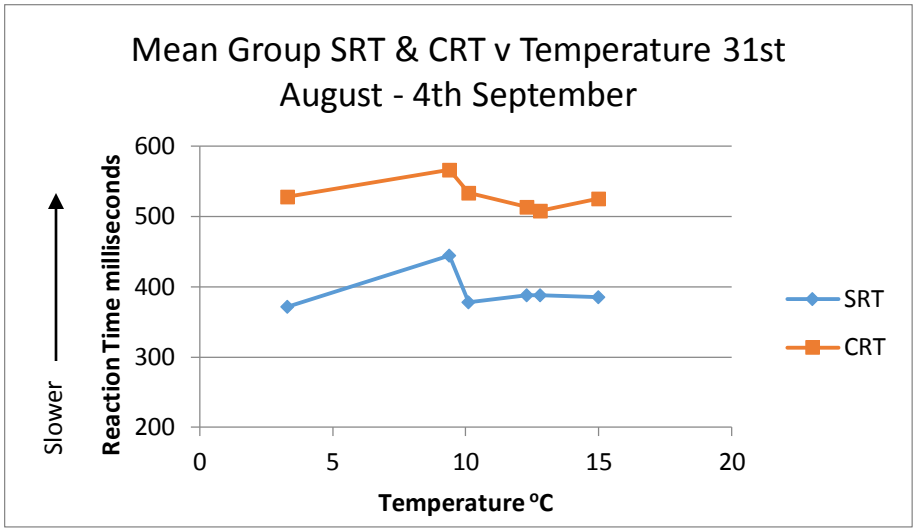


Figure 53. Mean group simple and choice reaction time v temperature.

A similar trending to the first visit and that found in other crews is indicated in the temperature range coinciding with the crews break time. Examples of Simple and Choice Reaction Time v temperature results are given in appendix D.

5.7.2 Activity

Activity monitoring was undertaken following the same procedure as visit one, reaction time measurements performed at the start, break and end of the working day. Table 18 details the amount of steps taken by each participant over the course of the working period.

Table 18.

Taneatua visit 2, step rates and flights climbed, daily and cumulative.

Date	Participant									
	CG1-Tan		PF1-Tan		PF2-Tan		JB1-Tan		JB2-Tan	
	Step	Flight	Step	Flight	Step	Flight	Step	Flight	Step	Flights
31st August	8514	14	18936	45	23139	45	3125	3	2421	4
4th Sept	18900	10	18453	57	17448	56	1857	2	1945	0
Cumulative	27414	24	37389	102	40587	101	4982	5	4336	4

It can be seen from Table 18 that participants performing manual site operations have the higher step rates (CG1^{-Tan}, PF1^{-Tan} and PF2^{-Tan}). Participants CG1-^{Tan} and PF1^{-Tan} perform quality control operations, requiring constant climbing on and off of logs to measure, grade, and remove any remaining branches after trimming. As in visit 1 participant PF2^{-Tan} performs manual felling operations.

The highest daily step rate was recorded as 18,900 by participant CG1^{-Tan}, and the lowest step rate was recorded as 1,857 by participant JB1^{-Tan}. Cumulative step rates over the course of the monitoring period show crew members performing manual tasks have the largest step rates; PF2^{-Tan} having the highest step rate of 40,587; conversely participant JB2^{-Tan} has the lowest step rate, 4,336. Mean step rates for participants across the duration of the study show CG1^{-Tan} as 13,707 PF1^{-Tan} as 19,195 PF2^{-Tan} as 20,293, JB1^{-Tan} as 2,491 and JB2^{-Tan} as 2,168. Similar high – low step rates between manual operators and plant operators exist as was found in the other crews.

5.7.3 Reaction time v activity

Simple Reaction Time and Choice Reaction Time was determined at three periods throughout the working day. Readings were taken at the start of the shift, break time and end of the shift. Table 19 summarizes the weekly means of Simple and Choice Reaction Times.

Table 19.

Taneatua visit 2, simple and choice reaction time.

Period	Participant	Age	Work Type	Mean SRT msec	Mean CRT msec
Start	CG1^{-Tan}	50 - 60	Quality Control	408	545
Break				369	478
End				412	556
Start	PF1^{-Tan}	20 - 30	Quality Control	415	513
Break				395	464
End				417	496
Start	PF2^{-Tan}	30 - 40	Manual Feller	437	582
Break				501	615
End				399	553
Start	JB1^{-Tan}	30 - 40	Loader Operator	307	481
Break				296	459
End				302	452
Start	JB2^{-Tan}	40 - 50	Loader Operator	475	616
Break				355	600
End				421	547

Similar slow-fast-slow daily trending of reaction times as demonstrated by the other crews is indicated. Figures 54 and 55 show the trending of reaction time across the course of the work period. Individual reaction time data is given in appendix C.

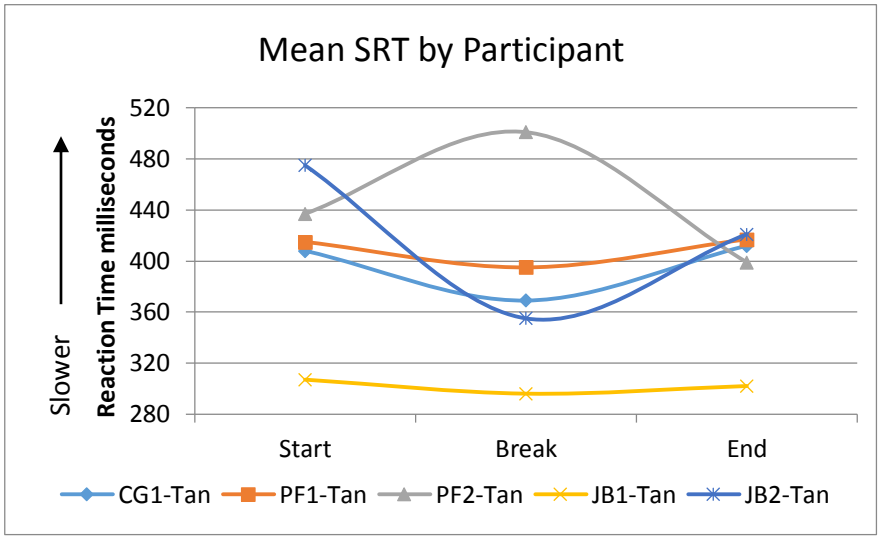


Figure 54. Mean simple reaction time by participant.

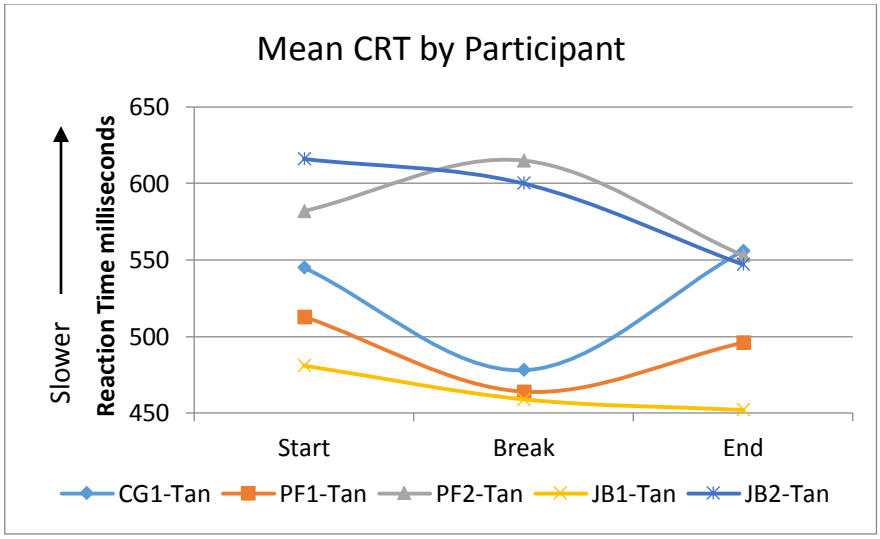


Figure 55. Mean choice reaction time by participant.

5.8 Crew 4 Planting Crew – Activity only

A further request was made by PF Olsen to collect data from one of the crews used in silviculture operations; due to time constraints only activity monitoring was undertaken. Monitoring took place over a two day period; 24th and 25th September 2015 commencing at 06.45 and finishing at 15.45 each day. The crew was based at Taupo requiring an hour travel time between home and the operational location.

5.8.1 Activity

As with the other crews, activity was monitored using a step count over the course of the monitoring period with both daily and cumulative steps being counted. Heart rate, calorific burn rates and stairs climbed were also recorded. Being a planting crew there is no mechanisation present; all operations are performed manually. Table 20 details the amount of steps taken by each participant over the course of the working period.

Table 20.

Planting crew, step rate and flights climbed, daily and cumulative.

Date	Participant									
	CG1		PF1		PF2		JB1		JB2	
	Step	Flight	Step	Flight	Step	Flight	Step	Flight	Step	Flight
24th Sept	25543	60	28210	56	15556	51	19331	48	35021	23
25th Sept	N/A	N/A	29339	114	12071	51	17062	72	40014	115
Total	25543	60	57549	170	27627	102	36393	120	75035	138

It can be seen from Table 20, all participants indicate high step rates; this would be expected as operations require constant walking between planting locations. High flights results again would be expected as planting generally occurs in uneven areas with large amounts of slope work required.

The highest daily step rate was recorded as 40,014 by participant JB2, and the lowest step rate was recorded as 12, 071 by participant JB1. Cumulative step rates over the course of the monitoring period show all crew member as having large step rates; JB2 having the highest step rate of 75,035; conversely participant JB2 has the lowest step rate, 25,543. Mean step rates for participants show CG1 as 25,543 PF1 as 28,774, PF2 as 13,813, JB1 as 18,197 and JB2 as 37,517.

As with the other crews, the difference between crew members who perform manual operations and those that perform mechanized operations are easily distinguishable; plant operators step rates are generally in the <5,000 and manual operations are generally in the >15,000 step range. It is interesting to note that silviculture operations requires by far the largest amount of physical activity with step rates being much higher than the other tasks encountered whilst performing the study; task activity requirements are discussed further in chapter 6

5.9 Mean results all crews

In this section we present the means of the measured data collected during phase three of the study. By pooling the data from individual crews we can further examine the impact of temperature on reaction time, and also examine the effect of activity on reaction time by role.

5.9.1 Temperature

When we compare reaction time against temperature across the duration of the study we can identify much slower reaction times at temperatures below 0^{o}C Measured reaction times indicate a difference of up to 33% slower reaction times in colder temperatures when compared with the sample mean. Differences tend to be smaller throughout the temperature range of 2 -14^{o}C with a maximum of 12.7% and minimum of 2.7% variation from the sample mean (Figure 56).

It is interesting to note that with SRT there appears to be a marked slowdown in reaction time in the 14 – 16^{o}C temperature range with an increase of 12.1% in reaction time from the mean or, 20% if compared with the previous temperature range. It should be remembered that reaction time measurements taken at these

temperatures usually coincide with shift completion as such the effects of work induced fatigue may contribute to the slower reaction times.

When examining Choice Reaction Time against temperature we again find that at temperatures below 0°C reaction time is somewhat slower (12.4%) than that of temperatures above 0°C when compared to the mean reaction time across all temperature ranges. It is interesting to note that Choice Reaction Time continues to improve with increasing temperature.

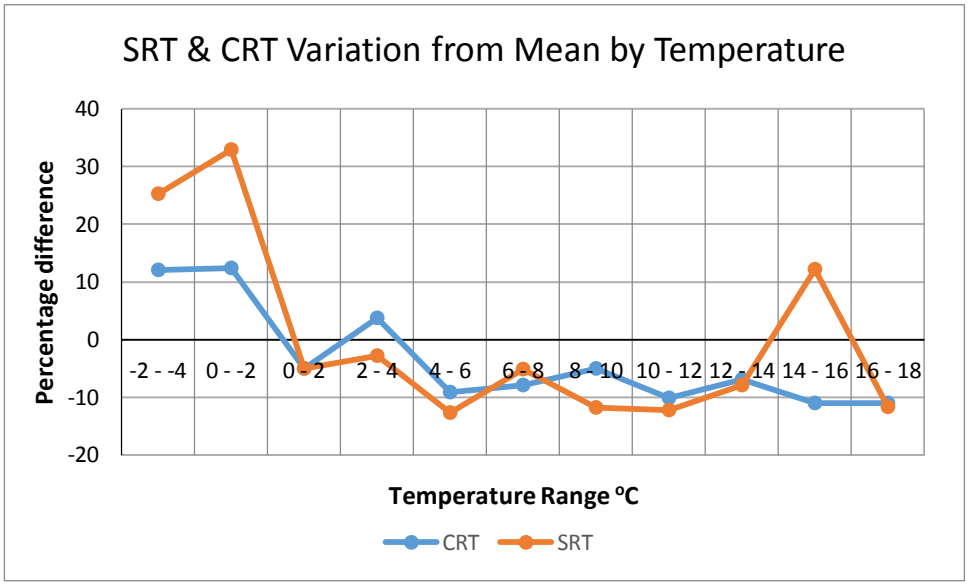


Figure 56. Simple and choice reaction time variation across all participants' v temperature

5.9.2 Activity as steps

Results from this study indicate four separate bands for levels of step rates performed by individuals; each dependent upon the task being performed. Loader operators and mechanized process operators tend to show the lowest mean step rates; this is expected as the majority of their work period sees them in a seated position operating various types of machinery. Quality control and log making activities fall into a mid-

range mean step rate due constant travelling to the operational area. Planting crews experience the highest mean step rates as the continually move between planting locations; Figure 57 provides an indication of step rates v workplace role.

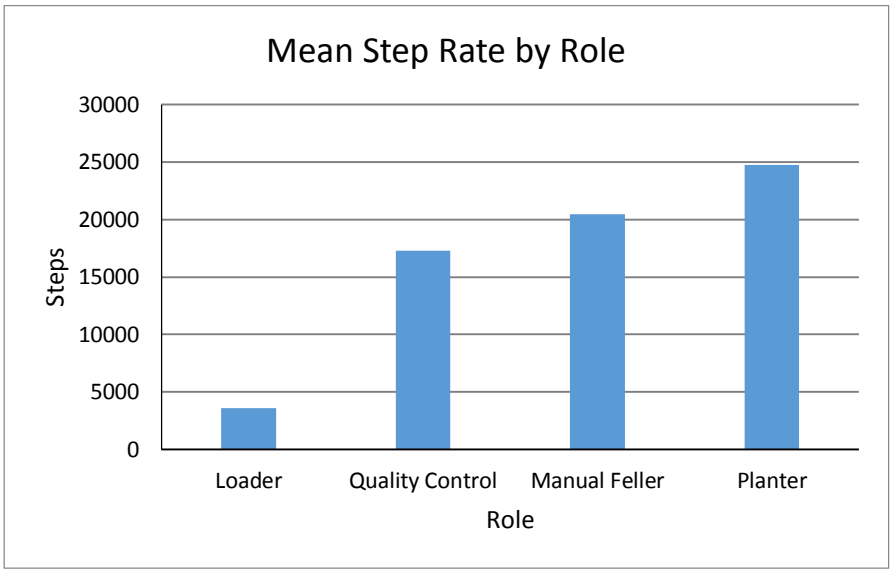


Figure 57. Mean step rate by role.

Both Simple and Choice Reaction time measurements were taken for each activity band with the exception of the planting crew, to investigate the impact of differing activity levels. Figures 58 and 59 show the mean Simple and Choice Reaction Times taken across the daily monitoring frequency for the duration of the study. It can be seen that both loader operators and quality control/log maker roles produce the standard U shape model with reaction times being slow at the start of the shift, faster at break time and slowing toward the end of the day.

The manual feller category produces a different result, rather than showing a decrease in reaction time at break time as with the other categories it indicates a slowing of reaction time to break time, followed by a speed up at the end of the day. It is suggested that manual log fellers tend to pack up for the day earlier than other crew

members as they have to travel from their remote working location back to the muster area. The effect of an early pack up, in conjunction with the travel time back to the muster area, provides a certain amount of recovery time resulting in faster reaction times.

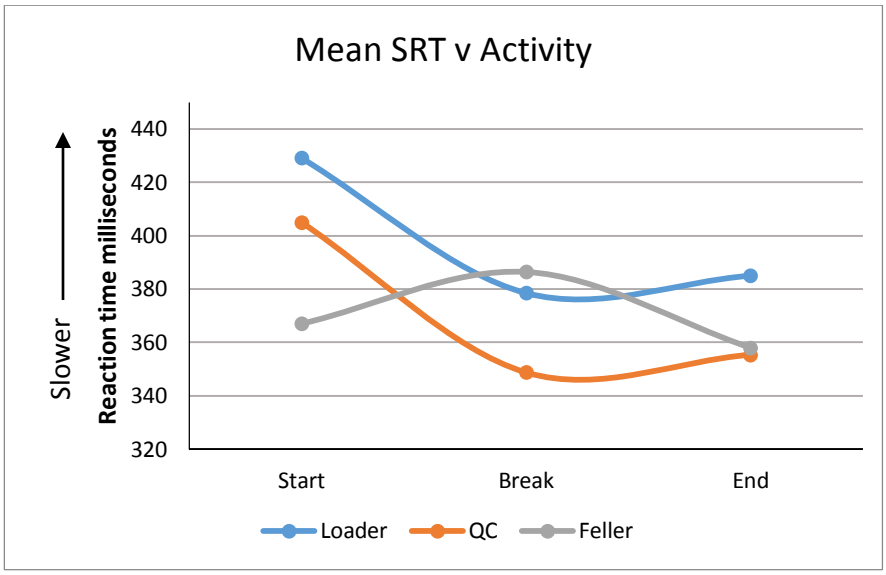


Figure 58. Mean simple reaction time by role v activity

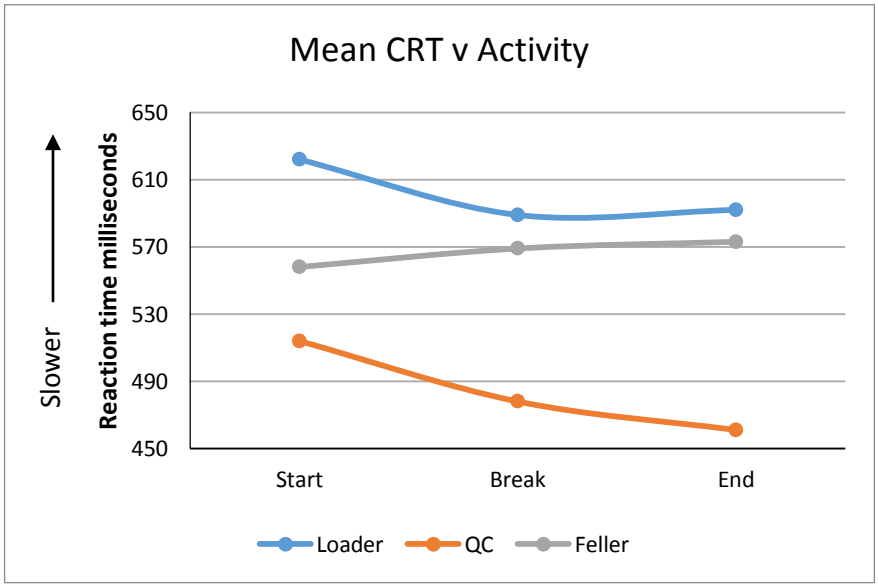


Figure 59. Mean choice reaction time by role v activity.

When examining Choice Reaction Time against categories the mean results are somewhat different. Loader operators follow a similar trend as with Simple Reaction Time; slow – fast – slow however, Quality Controllers tend to increase in performance throughout the course of the working day.

The Manual feller category indicates a continual slowing throughout the course of the working day. It is suggested that manual feeling operations require a large amount of cognitive processing; planning tree fall, escape route, fall direction and saw placement. This can place a large cognitive demand on individuals performing felling operations especially as they are working remotely. It is suggested that this large cognitive demand may result in the slowing of Choice Reaction Time as seen in this category.

5.9.3 Activity by Heart rate

Heart rate is one of the better indicators of activity as is a direct measurement form the individual concerned; it does not rely on additional information such as height and weight to calculate a value. Periods of high activity are denoted by higher heart rates; low activity having lower heart rates.

Heart rate values have commonly been used in the sport and fitness industry to identify exercise intensity; a target zone aimed for by athletes in order to improve performance. The American Heart Association, 2015 classify heart rate zones by percentage of maximum heart rate; peak intensity (>85%), high intensity (70 – 84%), moderate intensity (50 – 69%) and low intensity (<50%).

When examining the mean heart rate data across the duration of the study we can identify the workload intensities of separate roles. It can be seen in Figure 60 that planting is by far the more demanding role; workers spend 69% of their working day with heart rates above 50% conversely plant operators spend the least time undergoing moderate activity (11%).

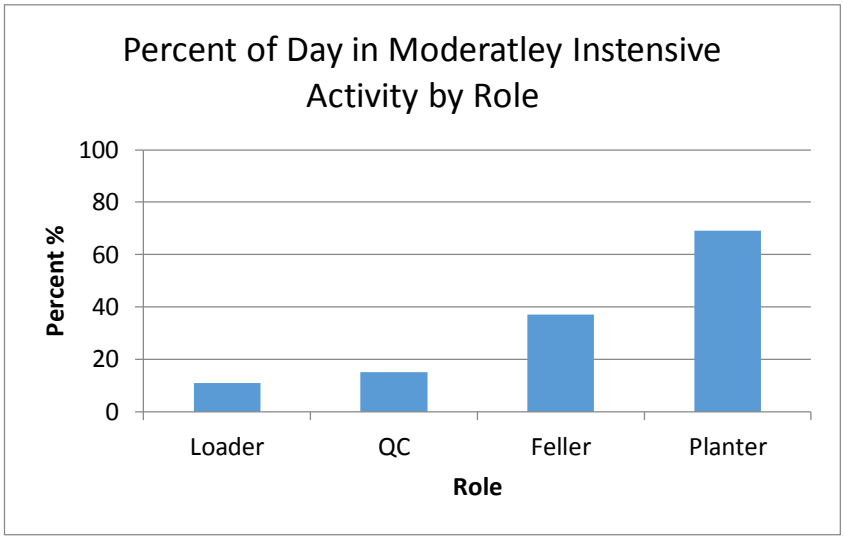


Figure 60. Summary of activity by role.

Recovery time is an important factor in minimizing the amount of fatigue felt by an individual; it can be suggested that due to large periods of inactive time plant operators suffer the impact of fatigue especially physical that the levels experienced by planting crews.

5.9.4 Activity by calorific burn rate

Calorific burn rates are a product of measured activity and basal metabolic rate as such they rely heavily on the data collected by the monitoring device. In the context of this study collected data collected is designed as informative; used for educational purposes for crews in the importance of nutrition. Figure 61 provides the mean calorie burn per role, it should be noted that the values are taken during the

monitoring period as such do not represent daily calorific requirements. As would be expected plant operators burn the least calories during the working day as their role has low activity requirements; conversely planting operations show the largest calorie use as the role demands large amount of activity.

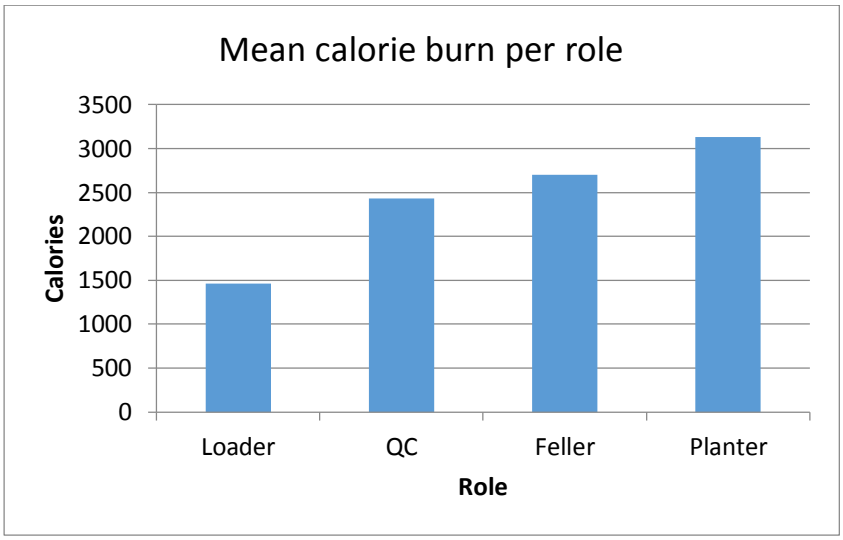


Figure 61. Mean calorie burn by role.

In this chapter we have presented the results of the three phases of the study, both individual and pooled. We have shown that reaction time can be negatively impacted by both temperature and activity; furthermore we have identified different task intensities by way of activity, heart rate and calorific burn. In the following chapter we discuss our findings and how they compare with other related works. We further discuss the results in a workplace context; how impaired reaction time can impact risk, supplement the risk assessment process and be used as an educational tool.

CHAPTER 6 - DISCUSSION

In this chapter, we examine the results obtained during the monitoring sessions and compare and contrast them with previous studies on reaction time. We examine how the quantitative data obtained can be used as identifiers of task intensity, and discuss the impact of impaired reaction time on increased risk. Furthermore we discuss how the collected data can be used as an educational tool to highlight the importance of rest and nutrition for employees.

6.1 Ambient Temperature

The impact of temperature extremes on reaction time has been demonstrated in numerous studies:-, e.g. Pilcher *et al.* (2002) identified that both hot and cold temperatures have negative effects on performance. Results obtained from our study follow similar trending across temperature, both low and high temperatures encountered in our study also produce impaired reaction times.

They reported a -13.91% difference in reaction time when exposure time was reported as long (>120mins) and temperature was reported as cold (<10^{o}C). This is surprisingly similar to our experimental results with an overall difference from mean being measured at 13.7% for SRT and 7.9% for CRT (see data in Section 5.9.1).

Furthermore it was observed that temperatures in the range of 10 – 18.3^{o}C also result in slower reaction times however the effect is not as pronounced as in the <10oC range. Results obtained from our study also indicate a similar decrement in performance; an overall difference from the sample mean of 10.8% for SRT and 9.7% for CRT.

When combining cold temperature ranges they state ‘cold exposure resulted in worse performance (10.06% decrement)’. When combining our results for both SRT and CRT in this same cold range, we observe an overall decrement in performance of 9.4%; again similar to those reported by Pilcher *et al*, 2002.

It should be remembered however the study conducted by Pilcher *et al* results are based on a neutral temperature range of 18.33 – 23.89^{o}C. Our study being conducted insitu does not include a neutral temperature range; measurements are based on the mean reaction time value across all temperature ranges. It also needs to be remembered that our study was conducted in the winter months where no high temperature values could be obtained.

6.2 Activity

Workplace activity is inherently dependent upon tasks being performed, some employees work in stationary positions such as production line operators, some work in very active conditions such as mail delivery workers. Although step rates may indicate high activity the question is are they more active than individuals with low step rates?

For example an employee working in a stationary position such as bricklaying may indicate a low step rate for a work period however; their activity levels may be the same if not higher than individuals having high step rates. It is with this in mind that three indicators of activity were chosen to be monitored; step rate, calorific burn rate and heart rate.

6.2.1 Activity comparison forestry vs other occupations

The forestry industry encompasses a multitude of roles; either based on manual labour, requiring a boots-on-the-ground approach or mechanized, requiring operators to remain in a seated position for large amounts of time. As such it is useful to contextualize the industry against other professions to provide a comparison between activity levels.

Porcari & Ekhwan, (2006) conducted a study for the American Council on Exercise into the amount of steps taken by employees in 10 common occupations. They found a wide variation in the step rates of these professions ranging from 4,300 steps for secretaries through to 15,251 for mail carriers.

These figures are substantially lower than those encountered by employees in the forestry industry where daily step rates can reach 35,000. Table 21 details compares the step rates found in ten common occupations against step rates found for roles in the forestry industry. Indicated values are represented as a percentage of activity undertaken in comparison to roles measured in our study. We can see loader operators have minimal step rates; all reported occupations showing higher step rates (see data in Section 5.9.2).

Table 21.

Average step rates for 10 common occupations v forestry roles.

Occupation	Steps taken/8 hours	% step rate comparison to forestry industry.			
		Loader	QC	Feller	Planter
Secretaries	4,300 ± 1,595	119.7	24.9	21.0	17.4
Teachers	4,675 ± 1,844	130.1	27.0	22.9	18.9
Lawyers	5,062 ± 1,837	140.9	29.3	24.8	20.4
Police officers	5,304 ± 1,819	147.8	30.7	25.9	21.4
Nurses	7,889 ± 1,984	219.7	45.6	38.6	31.9
Factory workers	7,914 ± 1,997	220.4	45.8	38.7	32.0
Construction workers	9,646 ± 2,719	268.5	55.8	47.2	38.9
Custodians	12,991 ± 4,902	361.6	75.2	63.5	52.4
Restaurant servers	14,175 ± 4,693	394.6	82.0	69.3	57.2
Mail carriers	15,251 ± 3,542	424.6	88.2	74.6	61.6

Note: From "Do you do 10k a day?" by J. Pocari & R. Ekhwan, 2006, *American Council on Exercise, Fitness Matters, 12*(4).9 – 12.

6.2.2 Activity as steps

There have been many studies that have identified a reduction in performance through continual physical activity (Allen & Westerbauld, 2001, Eberstien & Sandow, 1963, Graham *et al*, 1998, Kumar *et al*, 2002). Results obtained from phase one of our study indicate a similar reduction in performance through activity. Furthermore we identify that reduction in performance is larger in periods of high activity that that of low activity (see data in Section 5.1.1).

When comparing the mean reaction time data from phase one and phase three across the 06.45 – 15.45 time frame we typically see similar slow-fast-slow relationships although point to point variation is not as pronounced as that of full day monitoring. It is suggested that expanded monitoring to encompass a wider time frame along with more points may better indicate variances in reaction time.

6.2.3 Activity as heart rate

When examining heart rate we can typically see periods of high activity having higher heart rates and conversely low activity having lower heart rates. In chapter 2 we proposed that heart rate traces could not only be used to differentiate between activity levels but also indicate periods of rest.

Using resting heart rate Chang *et al*, 2007 identified differences in mean heart rate amongst employees working in different occupations in a construction environment (see Section 2.2.5). We have identified similar differences exist between occupations in the forestry industry (see Section 6.4) however, our results use mean daily heart rates whilst at work, not resting heart rate. We found that minimum intensity tasks are performed by loader operators and maximum intensity tasks are performed by individuals in silviculture operations.

Bates and Schnieider (2006) used heart rate as part of a study into physiological responses of construction workers in thermally stressful environments. They found no significant difference between morning and afternoon work periods they did identify that periods of rest could be seen in the heart rate traces. We have found similar rest periods present in heart rate traces collected during our study. Figure 62 provides heart rate data for an individual performing silviculture operations; the break period is

identifiable by the reduced heart rate during the 11.00 – 11.45 time period. This period is even more identifiable if combined with step rate data as shown in Figure 63. Example data is given in appendix D.

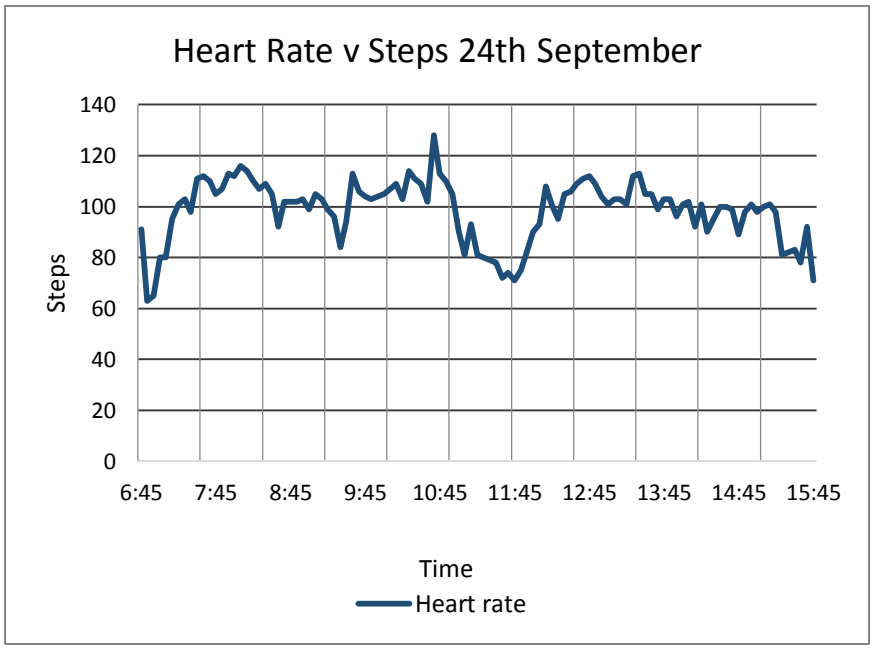


Figure 62. Example heart rate trace for silviculture operator.

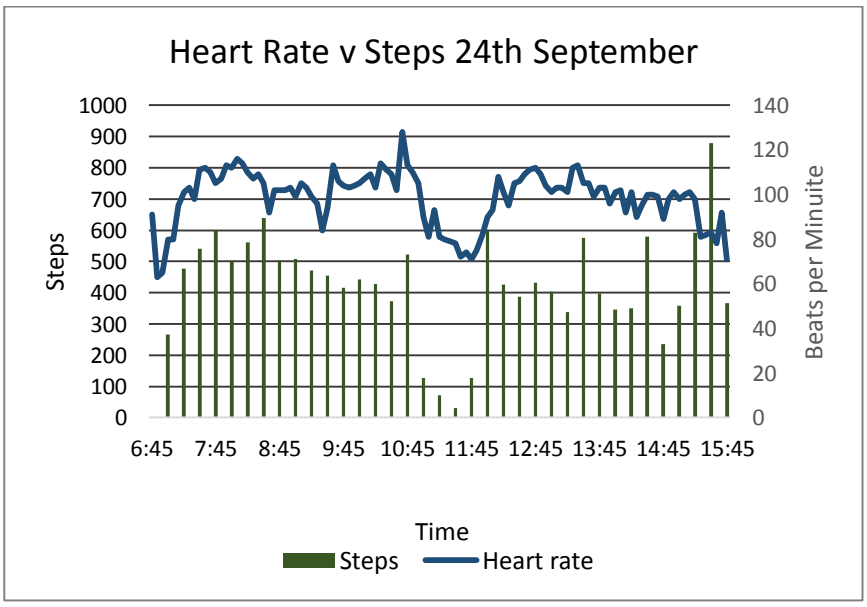


Figure 63. Combined heart rate and step data for silviculture operator.

6.2.4 Activity as calorie burn

As discussed in Section 8.2.4 calorific burn data has been collected as an informative exercise, to be used in demonstrating the importance of nutrition to employees. As would be expected we see similar trending as with step rates; high values are indicative of high calorie burn.

Cheatham *et al*, 2009 found that restricted calorie intake does not impact an individual's simple reaction time however Gutierrez *et al*, 2001 state that restricted calorie intake can impact an individual's physical workload capacity. We have identified that the majority of roles investigated have high calorific burn rates (see

data in Section 8.2.4), as such require high calorie intakes. Results of our study can be used to profile energy requirements of industry roles; as such nutritional requirements can be passed to crews on a 'energy in = energy out' basis.

6.3 Reaction time and incident rates

Results of our study indicate a predominantly slow-fast-slow relationship for reaction time; slower reaction times being present at the start and end of the working day. When we examine incidents by time of day as reported by FICA, 2014 we can see two definite spikes in time periods of incident occurrence (Figure 64). Having identified the trending of reaction time across the working day it can be seen that high incident rates start to increase in periods that coincide with slower reaction times. It is also interesting to note that between 10am and 3.50pm incident rates also follow an inverse curve relationship suggesting that workplace fatigue, manifested as slower reaction times may be a contributor to the periods of increased incident rates.

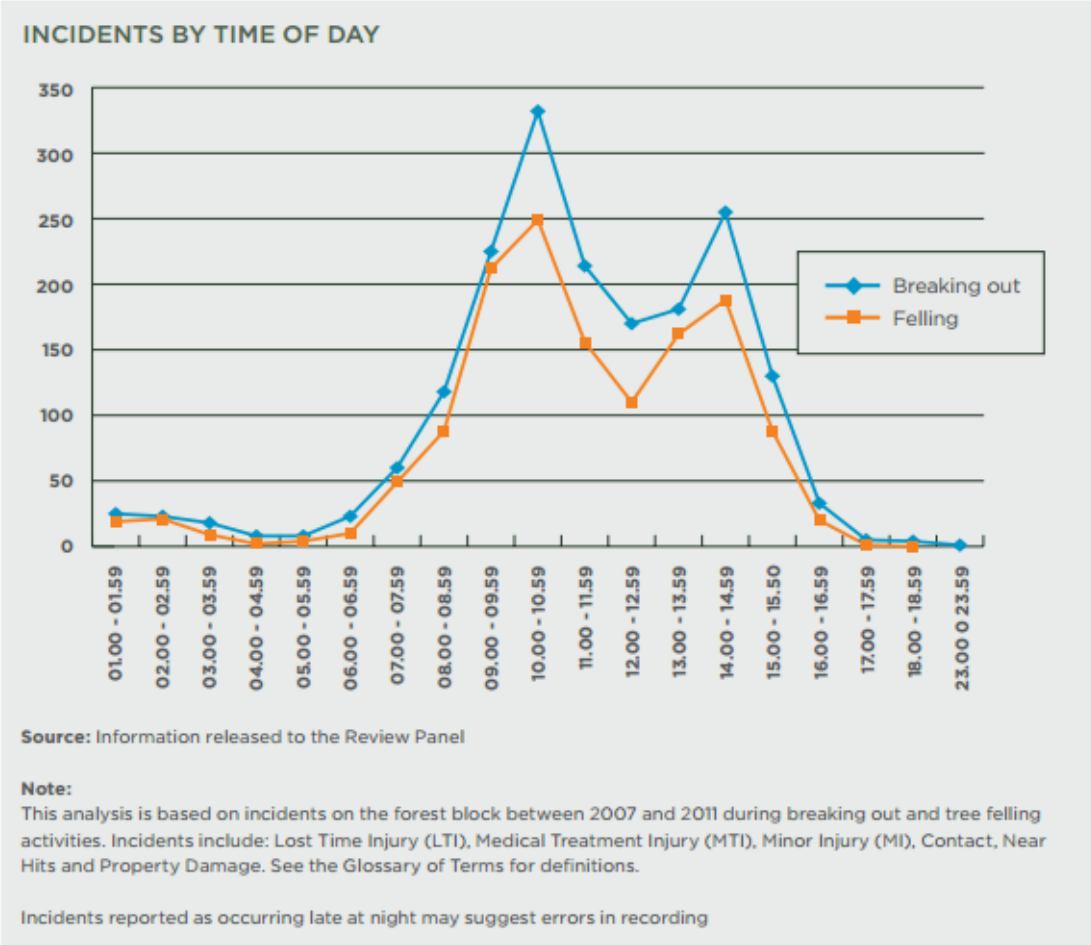


Figure 64. Incidents by time of day

6.4 Reaction time variation

When examining variation in simple reaction time per role it can be seen that quality controllers have a mean daily variation of 6 milliseconds, loader operators 26 milliseconds and fellers 22 milliseconds (Table 22). The majority of quality controllers are in the young demographic, as such tend to have faster reaction times and require lower recovery times; it is suggested that although performing high amounts of daily activity the impact is minimal due to age. Conversely loader operators are in the older demographic, generally between 45 and 55; it is suggested that the variation is due to a combination of age and cognitive load generated by plant

operation. Tree fellers generally fall within the 30 – 40 age group and again it is suggested that the variation is a result of a combination of physical and mental load required by the role in conjunction with age.

Similar variation in mean choice reaction time can be seen across the three roles, plant operators 32 milliseconds, quality controllers 52 milliseconds and fellers 13 milliseconds (Table 22). This is somewhat opposite to simple reaction time; quality controllers having the largest variation. It is suggested that as the role is multidimensional; requiring both physical and mental aspects; chainsaw use during log finishing providing the physical load; product grading and spatial awareness due to working amongst operational plant providing the mental load. It is suggested that the combination of both physical and mental loads manifests itself in large swings in choice reaction time over the course of a working period.

Table 22.

Mean daily variation by role.

Role	Variation milliseconds	
	SRT	CRT
Loader Operator	26	32
Quality Controller	6	52
Tree Feller	22	13

Findings from the study concur with the work of Brisswalter *et al* (1997); they identified a decrease in cognitive performance however simple reaction time showed no significant difference.

6.5 Reaction time and sleep

There have been many studies investigating the impact of restricted sleep (Belenky *et al*, 2002; Van Dongen *et al*, 2003; Kim *et al*, 2011) that have identified limited sleep can impair performance. During phase one of our study we collected sleep data for a three week period and measured simple reaction time throughout the course of the day. In our study we have also identified limited sleep can impair performance. Our results show periods of low sleep duration (<5 hrs) can impair performance; simple reaction time measurements are slower over the course of a day, with continual degradation as the time between sleep periods increases. This is somewhat different than in periods of high (>7) hrs sleep duration, performance degradation occurs although the relationship between simple reaction time and time between sleep periods shows no trending; measurements being both fast and slow. When examining our findings in phase two we see that participants generally retire between 10 and 11pm (43%) and awake before 5am (73%), yielding typical sleep durations of approximately 6hrs. Such limited sleep durations can contribute to performance degradation, especially in the later part of the day.

Belenkey *et al.* (2002) further identified that the effects of restricted sleep are cumulative; performance degradation occurs over restricted sleep periods. In our study we have identified that limited sleep is prevalent in the forestry industry; late nights and early starts required for travel time. This can create a cumulative sleep deficit over the course of the week again contributing to impaired performance and workplace fatigue.

6.6 The impact of fatigue

Throughout the course of this report we have seen that fatigue can affect an individual's reaction time; high levels of activity combined with low sleep durations can increase the level of workplace risk.

The highest mechanisms for serious harm injuries reported by FICA (2014) are being struck by moving or falling objects. In this thesis we have demonstrated that fatigue has the ability to negatively impact ones performance, as such levels of risk are increased. If we translate this increased risk into terminology understandable to forestry crews we can illustrate the importance of recognizing fatigue as a valid contributor to workplace risk.

One of the better examples of increased risk through fatigue is through tree felling; using the law of energy conservation we can calculate a reduction in the distance an individual can move if reaction time is impaired by fatigue. For example if we imagine a tree of 30m in length with a 30 degree angle to the ground we can calculate that the speed of the tip at impact is 31.91 m/sec, given by:

Kinetic Energy(final) = Potential Energy(initial)

As such $1/2mv^2 = mgh$

$v = \sqrt{2gh}$

$v = \sqrt{254.61}$

$v = 15.96$ m/s

By $v = r\omega$

$\Rightarrow \omega = 15.96/15 = 1.06$ rad/sec

Thus velocity of top (V) = $r\omega = 30 \times 1.06 = 31.91$ m/s

If we know the speed at impact is 31.91 m/sec we can calculate that for every millisecond of impairment the distance an individual can move from the impact zone is reduced by 0.03191 meters. As such impairments in the region of 100msec would reduce movement distance by 3.1meters.

Similarly if we investigate the impact of impaired reaction time on driving when travelling at 100kmh we can see that an impairment of 100msec increases stopping distance on a dry sealed road is 2.78 meters, given by:

Driving at 100km/hr

=>1.66666667 km/min or 1666667 m/min

=>0.02777778 km/sec or 27.8m/sec

=>0.00002778km/msec or 0.02778 m/msec

Thus increase in stopping distance = 0.02778*100 = 2.78 meters

Both of the above examples provide contextual information on the impact of reduced performance by fatigue.

6.7 Fatigue and risk assessment

Fatigue has been seen to negatively impact employee wellbeing, increase risk of accident and negatively impact performance (Graham, *et al*, 1998, Kumar, *et al*, 2002, Akerstedt, *et al*, 2003); as such consideration is required by employers when undertaking risk assessments. The risk assessment process for the impact of fatigue is usually undertaken by use of questionnaires, designed to gather details regarding specific task demands in conjunction with an employee's ability to perform the task.

This method has many pitfalls as it is subjective by nature, the assessor of a task may have a different view of the energy requirements for task completion rather than the

true energy requirements. Levels of fatigue through task completion are different for every individual and encompass not only the task itself but is also dependent upon external conditions such as levels of sleep along with health and fitness levels. The method is in danger of creating a generic view of a task that in reality is unique to the individual performing the task. As we have identified in our study, roles within the forestry industry have large variations in energy requirements. We propose that the incorporation of quantitative data by role can supplement the risk assessment process highlighting roles susceptible to the effects of fatigue.

In this chapter we have presented a discussion of the results from our study, we have discussed how quantitative data obtained can be used as identifiers of task intensity and their impact on reaction time. We have presented real world examples how impairment can impact workplace safety in a context that is understandable to forestry industry crews. Furthermore we have suggested that the incorporation of physiological data can improve the accuracy of the risk assessment process.

CHAPTER 7 - CONCLUSIONS AND FUTURE WORK

In this chapter we present the conclusions of our study and suggest future work that can positively contribute to our findings. Furthermore we suggest solutions in how collected data can be provided to crew supervisors in a format that allows early identification of risk and provides suggestions on risk mitigation.

7.1 Conclusions

Our research question was in two parts firstly we asked if the use of physiological data can be used as a basis for determining an individual's ability to perform a given task; if so can this information be used to better identify risk, and be used as an early indicator of fatigue. Secondly, our research question asked if commercially available activity trackers could be used as a method for collecting quantitative physiological data.

We collected physiological data by way of commercially available activity monitors worn by participants as they went about their daily duties. Using simple and choice reaction time, measured at the start, mid-point, and end of the working day, we examined the relationship between activity and performance.

Having evaluated the current generation of activity monitors (as of April 2015), we found the Fitbit Charge HR is both minimally intrusive to the user, and of sufficient durability to withstand a hostile working environment (see Section 3.3). Our evaluation identified that physiological data collected by the Fitbit Charge HR comprehensive in nature with large amounts of data being recorded. The ability to access captured data via a proprietary application programming interface (API) facilitates easy extraction of specific data types for incorporation into third party

applications. It was found that the device can have limited accuracy in high heart rate zones, however, our study uses data predominantly within the low to medium heart rate zones; data captured by the device is of sufficient granularity to differentiate between operational roles.

We identified diverse roles within the forestry industry, each of which have different energy requirements. Roles are typically split between mechanized (loading, harvesting) and manual (quality control, felling) types. Furthermore we found that crew member's working in mechanized operations show limited activity levels; their duties being predominantly performed in a stationary seated position. This is somewhat different to more manual type operations such as tree felling and planting; tasks require large amounts of activity with individuals regularly achieving step rates of over 20,000 (see data in Section 5.9.2). We suggest that workplace activity is directly related to calorific requirements, high periods of activity generate high calorific requirement; conversely low activity periods generates low calorific requirement.

Using the physiological data collected during phase three of our study we found profiling of role types by calories is possible; tasks requiring more activity to complete produce higher calorific burn rates. The collection of quantitative data facilitated by the use of activity trackers can be used to profile energy requirements by role type, (see data in Section 5.9.4).

Data captured on calorific burn rates have facilitated a better understanding of nutritional requirements required by individuals as they perform their duties; higher levels of activity requiring higher calorie intakes.

This data when supplied to crew members can allow for better planning of lunch type, combating calorie deficit, ensuring calorie intake is sufficient to cover calorie expenditure.

We have demonstrated how physiological variables can be used to indicate workplace activity; and discussed their impact on both simple and choice reaction time. Furthermore we have demonstrated how activity levels can impact performance, and discussed the relevance of both sleep duration and quality.

We also identified that variations in reaction time exist across the working day; generally following an inverse curve relationship with time. This relationship is further demonstrated if monitoring occurs over extended daily time periods (see data in Section 5.1.1). Furthermore we found a similar inverse curve relationships exists in accident occurrence and time of day (see data in Section 6.3). High accident rates are seen mid-morning, dropping through the mid-point of the day and increasing toward the end of the working day.

Similar to previous research (Tun & Lachman, 2009), we identified that a person's age is a factor influencing reaction time. Older participants were found to have both slower simple and choice reaction times, in comparison to younger participants.

Furthermore our study has found that an individual's ability to react is impaired by low temperature; temperatures below $0^{o}C$ showing highest impairment levels; and levels of impairment decrease as temperature increases. Similar research by Pilcher *et al*. (2002) found that performance is also impaired by higher temperature ranges; our study being undertaken during the winter months of 2015 prevented data capture in

high temperature ranges however, future investigation into the effect of temperature on reaction time is planned for summer 2016.

We have provided contextual examples of impairment that can be used as illustrators for the impact of fatigue in forestry operations and suggested physiological data collected throughout the course of the study can supplement the risk assessment process.

In conclusion we investigated tools and methods for data capture of forestry workers, we believe we have identified the use of activity trackers in conjunction with reaction time can prove to be valuable in the identification of workplace fatigue. Furthermore we suggested how a custom built solution could obtain data using WiFi transmission of data, and provide real time data to supervisors. We also propose a method of visual presentation that is easily understandable, and can provide additional information to supervisors, as suggestions, that can be employed for risk reduction.

7.2 Future work

Our study has provided a snap shot of physiological and reaction time data across a limited time period, during the winter of 2015. We found that reaction time was impaired at temperatures below $0^{o}C$, even though individuals did not state they felt fatigued through this colder period. However, the majority of participants did indicate that they felt more fatigued in the summer months; as such it is recommended that the monitoring exercise be also conducted in the summer months to identify any differences between prevailing environmental conditions.

In phase two of our study we attempted to gain an insight into self-reported sleep and impairment levels through use of a questionnaire. We found that this method of data

collection to be problematic; failure to complete levels were high, even when switching from an online questionnaire to a hard copy questionnaire. We suggest that any future works incorporating self-assessment use methods more suitable to the participant demographic, such as incorporation into the daily 'toolbox' meeting.

Biometric data was standardized across the study in order to both further anonymize participants and collect standardized physiological data. It is suggested that future works collect actual physiological data on participants to better identify quantitative variables that are based on calculation such as calorific burn.

It must be remembered that the activity tracker industry is in a state of continual development; each iteration offering updated hardware, and refined algorithms for data processing. Devices used in our study were current as of April 2015 as such data is based on device accuracy at the time of collection. We recommend any future studies using activity trackers must incorporate an evaluation process to identify levels of accuracy.

Monitoring undertaken during our study was brief; as such extended data collection over longer time frames is suggested in order to identify any trends that maybe present, and not indicated by our limited study duration. As we demonstrated in phase one of our study variation in reaction time decreases as time between sleep periods increases, and that sleep duration can negatively impact performance. We suggest extended monitoring of individuals to encompass both activity outside of the workplace and sleep duration to identify if the relationships found in phase one are replicated in a larger scale study.

Throughout our study we have seen that both simple and choice reaction time varies across the working day, and is unique to the individual concerned. We suggest that long term data collection be used to profile individual performance against time. Mining of this data can be used to identify performance against time and as such facilitate the generation performance calibration curves. Deviations from these curves can indicate possible performance impairment and be used as both an early indicator of fatigue and increased risk.

We have also identified activity by role, loader operators have low activity levels, and planting crews have high activity levels. We further suggest that large deviations from our identified activity levels can be used as an indicator of increased risk; high activity measured in a role typically requiring low activity levels can increase the risk of impairment through fatigue.

Our study demonstrated that we can reliably collect data on steps travelled, flights climbed and heart rate; all of which contribute to calorific burn rates. Furthermore we have identified that variation in reaction time can be used as an indicator of impairment. Calorific burn rate is determined in real time by algorithm; inputs being physiological data collected by the monitoring device. If we further consider Fitbit allow access to their API for developers, we have the ability to use calorific burn rate as an input into a custom built software solution for identifying potential impairment.

We also identified role specific activity levels exist for crew members; using this data we can identify if higher than usual activity has occurred, and if so notify crew supervisors of possible impairment. Once alerted, a supervisor can instruct the individual to perform a reaction time test in-situ using a portable device. If results of this test indicate large deviations from an aforementioned performance profile,

remedial actions can be taken by the supervisor, minimizing both risk to the employee and other crew members.

When examining a possible solution we have to consider the type of data to use as indicators of activity, and how collect this data. We have identified that different placement of devices on one's person can facilitate data collection (see Section 3.2.2.2), and suggested that monitoring equipment could be placed within safety equipment such as a hard hat. During phase three of our study we noted that protective equipment is generally removed during rest periods, and not worn by plant operators whilst 'in the cab'. This somewhat negates the effectiveness of collecting data using protective equipment; repeated removal facilitates the collection of intermittent data only.

We have however identified that wrist worn monitoring devices prove to be minimally invasive to the user and hard wearing enough to be used in the field. The use of a buckle fastening system prevents snagging, and easy removal adding a 'sense of security' to the individual. Participants using these wrist worn devices reported no issues in their use and likened it to wearing a watch. We suggest that data collection from wrist worn devices as a preferred method for monitoring an individual's activity levels.

Furthermore we have identified that low temperatures can adversely impact an individual's performance (see Section 5.9.1), similarly Pilcher *et al*. (2002) identified high temperatures can also contribute to performance impairment. Our study was performed in the winter months as such we have no data for high temperatures, however all participants did state that they felt more fatigued in hotter rather than colder weather.

Temperature monitoring devices currently exist that can both log and display temperature data. The use of such systems facilitate temperature readings to be provided to crew members at toolbox meetings; low temperatures recorded at the start of a shift can be identified as a hazard, allowing for mitigation through additional clothing layers. Temperature monitoring devices can also be programmed to provide alerts via SMS messaging or email notification once pre-determined thresholds are reached. If high temperature readings are recorded, alerts can be automatically sent to crew supervisors indicating increased risk; once this information is disseminated to crew member's awareness levels are raised, as such mitigating risk.

Our proposed solution is twofold, taking temperature and activity data as inputs via a wireless connection and use this data to alert supervisors of increasing levels of risk. High levels of activity over time in crew members would also be used as an indicator of individual risk. Once identified, crew supervisors can request the individual undertake reaction time testing to determine if any impairment exists.

Reaction time testing would be undertaken in-situ by the individual, using a custom built cell phone application in which the user touches the screen in response to a visual stimulus. There are two reasons for performing this test in-situ; operational disruption would be minimized and reaction time testing would not be influenced by any recovery period facilitated by travel to a testing location. Results of the reaction time testing would be passed to a proposed solution where they are assessed against the individual's performance profile. Large deviations would be identified as higher risk levels for the individual; allowing the supervisor to take remedial actions to lessen the risk.

Data presented to the supervisor would be in a format that is both easily recognizable and understandable; it is suggested that a traffic light system for presenting risk be used as the associations are widely understood. Each colour would also be used as a link to further information where suggestions are presented on possible actions which can be employed to minimize risk; a similar colour coding system would be used for individual testing, again with suggestions on reducing individual risk.

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APPENDIX A – SLEEP QUESTIONNAIRE

Online version available at http://gweb.co.nz

Fatigue Questionnaire

What time did you go to bed last night

Generic question designed to gain information on what time a participant went to bed, responses will be used to assess participants length of time in bed.

Possible answers: Before 9pm, 9.00 – 10.00pm, 10.00 – 11.00pm, 11.00pm – 12.00pm, After 12

How long did it take you to fall asleep

Used to determine if the participant had any problems falling asleep, can be used as an indicator of sleep quality

Possible answers: 5 – 15mins, 15 – 30mins, 30 – 45mins, 45 – 60mins, Over 60mins

How many times did you wake through the night

Used to determine the participants quality of sleep

Possible answers: I didn't wake, 1 – 3, 4 – 6, 7 – 9, 9 or more

What time did you wake up

Used in conjunction with what time a participant went to bed and how long did it take you to fall asleep questions to gain information of quality of sleep.

Possible answers: Before 5am, 5.00 – 5.30am, 5.30 – 6.00am, 6.00 – 6.30am, 6.30 – 7.00am, After 7.00am

How would you rate your quality of sleep last night

Used to determine the participants self assessed quality of sleep

Possible answers: Excellent, Very Good, Average, Below Average, Poor

What was your main function at work today?

Question based on the Checklist for Individual Strength questionnaire used generally for patients with chronic fatigue. It provides information regarding the participants work tasks and will allow comparison between task activity and fatigue via heart rate and activity.

Possible answers: Text are to be completed by participant

At any time throughout your day did you find it difficult to concentrate?

Question based on the Checklist for Individual Strength questionnaire used generally for patients with chronic fatigue. It provides information regarding the participants self assessed levels of concentration. Uses the CIS subscale for evaluation of fatigue for concentration.

Possible answers: I never found it difficult to concentrate, I found it difficult to concentrate at least once, I found it difficult to concentrate at least twice, I found it difficult to concentrate at least three times, I found it difficult to concentrate four or more times.

At any time during the day did you feel physically tired?

Question based on the Checklist for Individual Strength questionnaire used generally for patients with chronic fatigue. It provides information regarding the participants self assessed levels of physical activity. Uses the CIS subscale for evaluation of fatigue for physical activity.

Possible answers: I never felt physically tired, I felt physically tired at least once, I physically felt tired at least twice, I felt physically tired at least three times, I felt physically tired four or more times

At any time during the day did you find your motivation to complete tasks low?

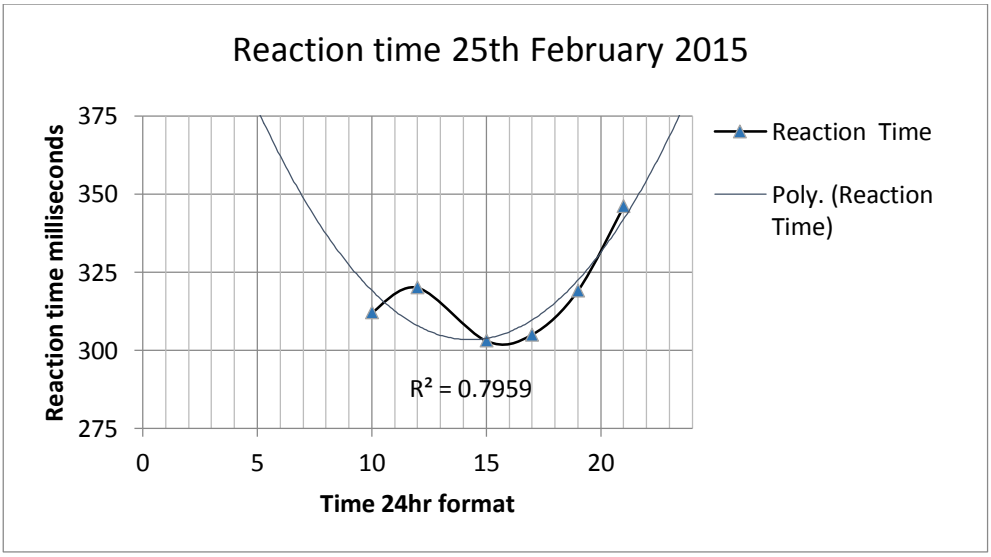
Question based on the Fatigue Severity Scale questionnaire used generally for patients with chronic fatigue. It provides information regarding the participants self assessed levels of motivation. Uses the FSS subscale for evaluation of fatigue for physical activity.

Possible answers: My motivation to complete tasks was never low, My motivation to complete tasks was low at least once, My motivation to complete tasks was low at least twice, My motivation to complete tasks was low at least three times, My motivation to complete tasks was low four or more times.

APPENDIX B – PHASE ONE PHYSIOLOGICAL AND REACTION TIME DATA

Physiological Information 25th February

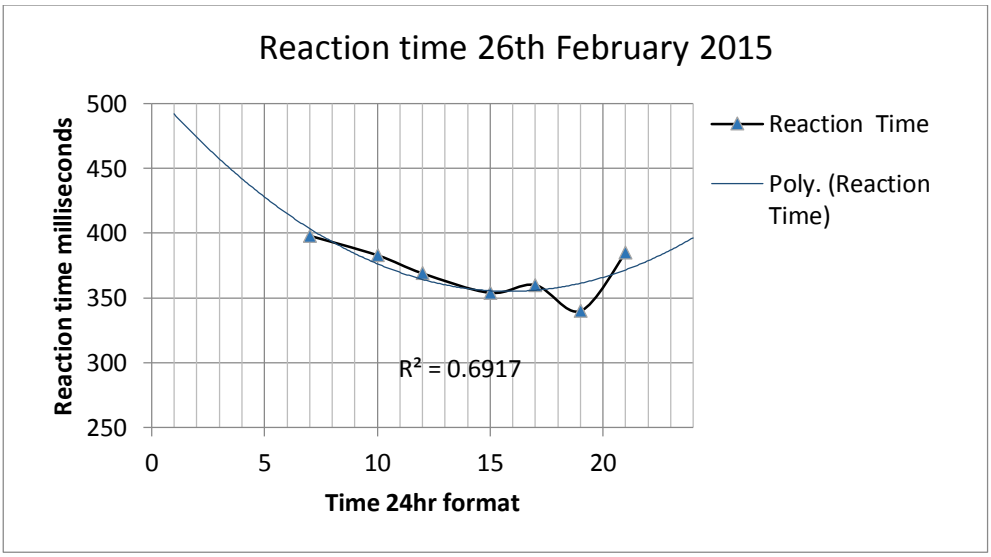
Sleep: 5hr 56min Awakenings: 16 Resting heart rate: 68bpm Total Calories: 3,879 Total Steps: 14,123					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
10.00	4850	4850	97	312	0.52
12.00	2146	6966	102	320	0.57
15.00	2099	9095	93	303	0.65
17.00	2412	11507	85	305	0.63
19.00	695	12202	80	319	0.62
21.00	518	12720	84	346	0.53

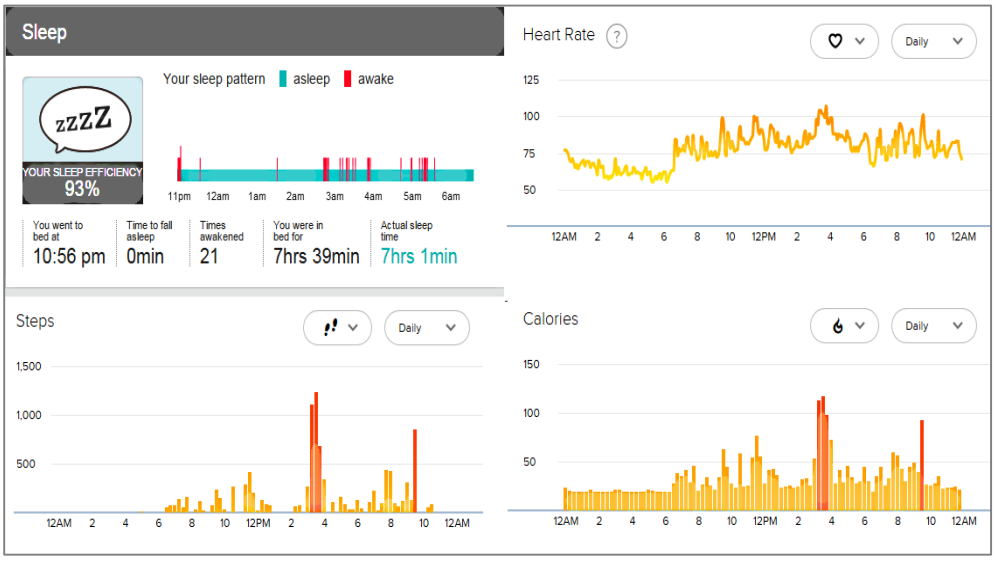


Sleep
Your sleep pattern
asleep
awake
zzzZ
YOUR SLEEP EFFICIENCY
87%
11pm 12am 1am 2am 3am 4am 5am
You went to bed at
10:53 pm
Time to fall asleep
0min
Times awakened
18
You were in bed for
6hrs 50min
Actual sleep time
5hrs 56min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,500
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 26th February

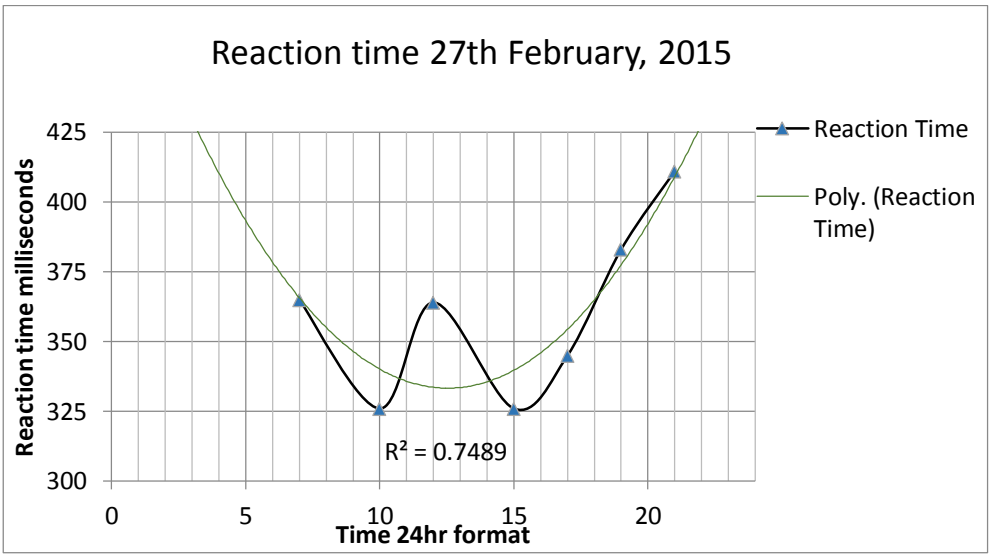
Sleep: 7hr 01min Awakenings: 21 Resting heart rate: 68bpm Total Calories: 3,321 Total Steps: 10,321					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
0.700	155	155	65	398	0.63
10.00	962	1117	80	383	0.57
12.00	106	1223	85	369	0.59
15.00	1647	2780	85	354	0.64
17.00	988	3858	86	360	0.67
19.00	1513	5371	85	340	0.67
21.00	3239	8610	90	385	N/A

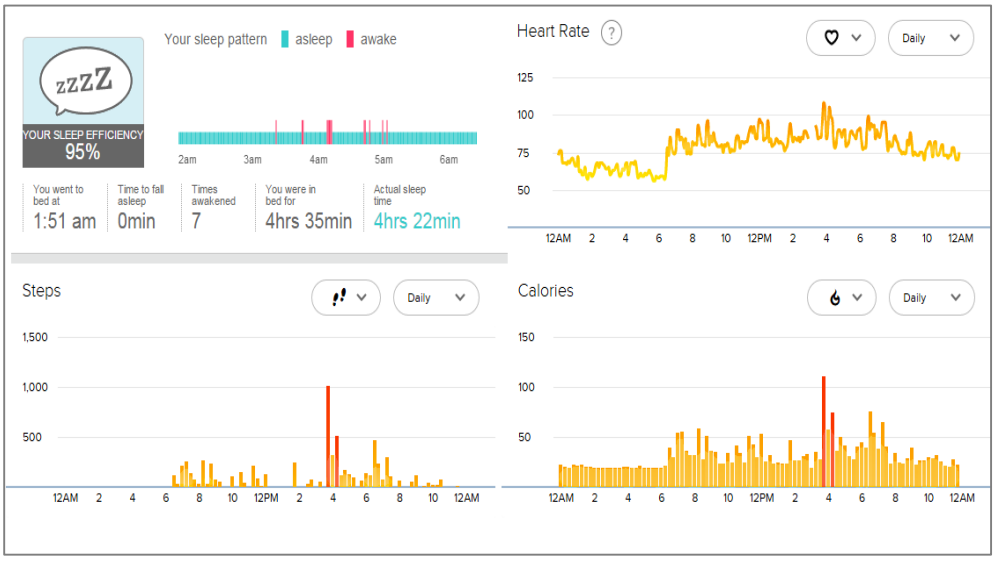



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
93%
Your sleep pattern
asleep
awake
11pm 12am 1am 2am 3am 4am 5am 6am
You went to bed at
10:56 pm
Time to fall asleep
0min
Times awakened
21
You were in bed for
7hrs 39min
Actual sleep time
7hrs 1min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,500
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 27th February

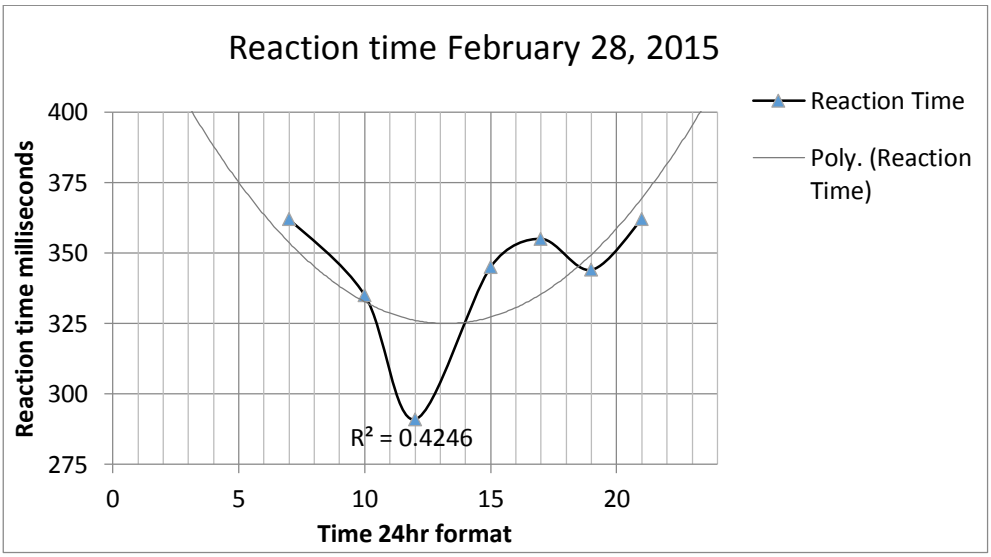
Sleep: 6hr 04min Awakenings: 9, Resting heart rate: 68bpm Total Calories: 3,115 Total Steps: 7,198					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
0.700	147	147	74	365	0.51
10.00	1523	1670	76	326	0.53
12.00	637	2307	95	364	0.58
15.00	407	2714	84	326	0.56
17.00	2229	4943	81	345	0.57
19.00	1244	6187	82	383	0.56
21.00	646	6833	82	411	0.58




zZzZ
YOUR SLEEP EFFICIENCY
95%
Your sleep pattern
asleep
awake
2am
3am
4am
5am
6am
You went to bed at
1:51 am
Time to fall asleep
0min
Times awakened
7
You were in bed for
4hrs 35min
Actual sleep time
4hrs 22min
Heart Rate
Daily
125
100
75
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Steps
Daily
1,500
1,000
500
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Calories
Daily
150
100
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM

Physiological Information 28th February

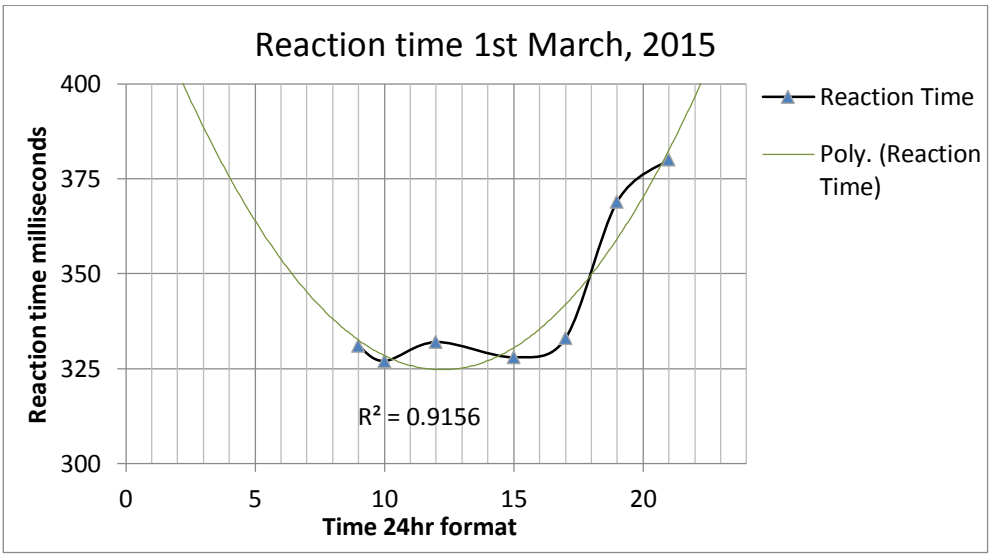
Sleep: 5hr 44min Awakenings: 8, Resting heart rate: 67bpm Total Calories: 4,051, Total Steps: 16,237					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
0.700	237	237	78	362	0.61
10.00	3852	4089	82	335	0.59
12.00	2602	6691	82	291	0.59
15.00	3697	10388	88	345	0.58
17.00	3073	13461	87	355	0.52
19.00	880	14341	86	344	0.59
21.00	1435	15776	89	362	0.58

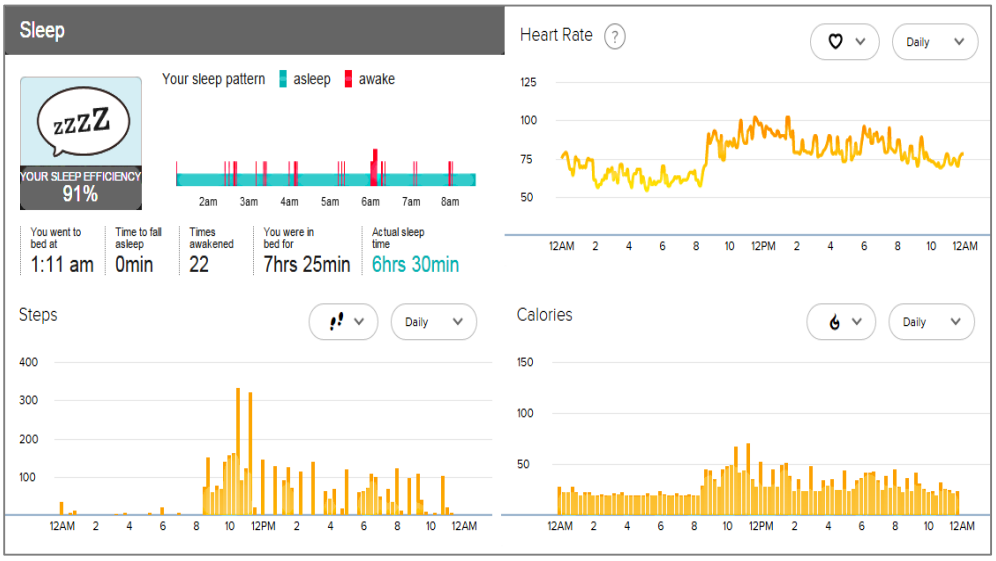


Sleep
zzzZ
YOUR SLEEP EFFICIENCY
92%
Your sleep pattern
asleep
awake
1am
2am
3am
4am
5am
6am
You went to bed at
12:05 am
Time to fall asleep
0min
Times awakened
8
You were in bed for
6hrs 21min
Actual sleep time
5hrs 44min
Heart Rate
Daily
125
100
75
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Steps
Daily
1,000
750
500
250
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Calories
Daily
150
100
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM

Physiological Information 1st March

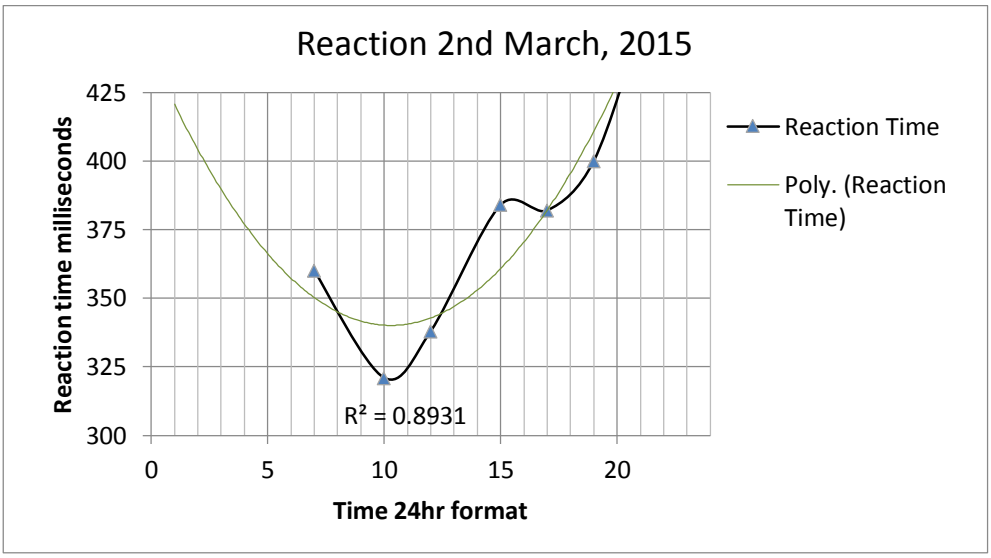
Sleep: 6hr 30min Awakenings: 22, Resting heart rate: 67bpm Total Calories: 2,880, Total Steps: 4,113					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
09.00	N/A	N/A	87	331	0.65
10.00	446	446	89	327	0.60
12.00	1176	1622	98	332	0.67
15.00	786	2408	87	328	0.53
17.00	327	2735	89	333	0.62
19.00	391	3126	86	369	0.63
21.00	391	3517	82	380	0.64




Sleep
zzzZ
YOUR SLEEP EFFICIENCY
91%
Your sleep pattern
asleep
awake
2am 3am 4am 5am 6am 7am 8am
You went to bed at
1:11 am
Time to fall asleep
0min
Times awakened
22
You were in bed for
7hrs 25min
Actual sleep time
6hrs 30min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
400
300
200
100
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 2nd March

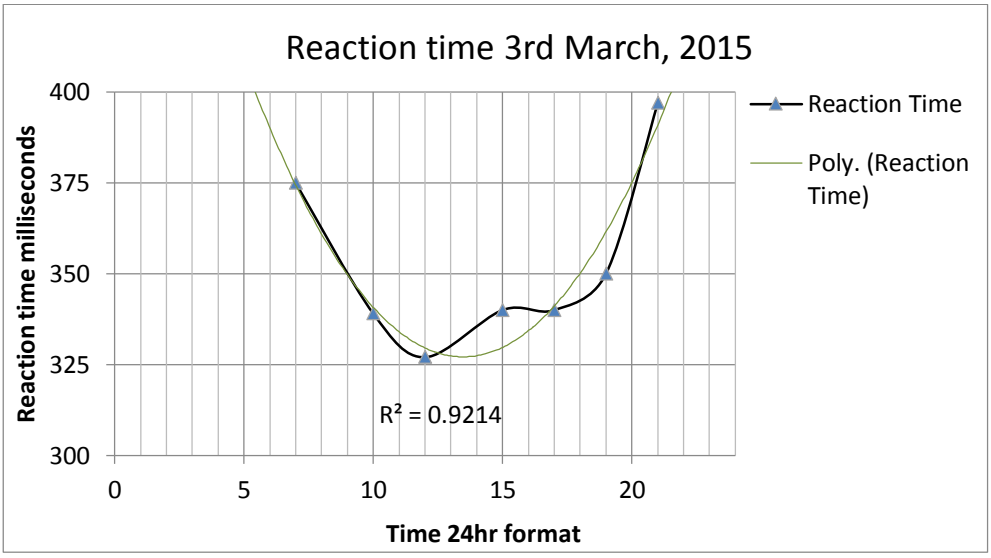
Sleep: 6hr 29min Awakenings: 18, Resting heart rate: 67bpm Total Calories: 4,009, Total Steps: 16,146					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	360	360	N/A	360	0.59
10.00	2693	3053	86	321	0.63
12.00	3914	6967	90	338	0.63
15.00	3872	10839	80	384	0.62
17.00	2470	13309	88	382	0.54
19.00	1314	14263	81	400	0.64
21.00	1140	15763	92	449	0.58

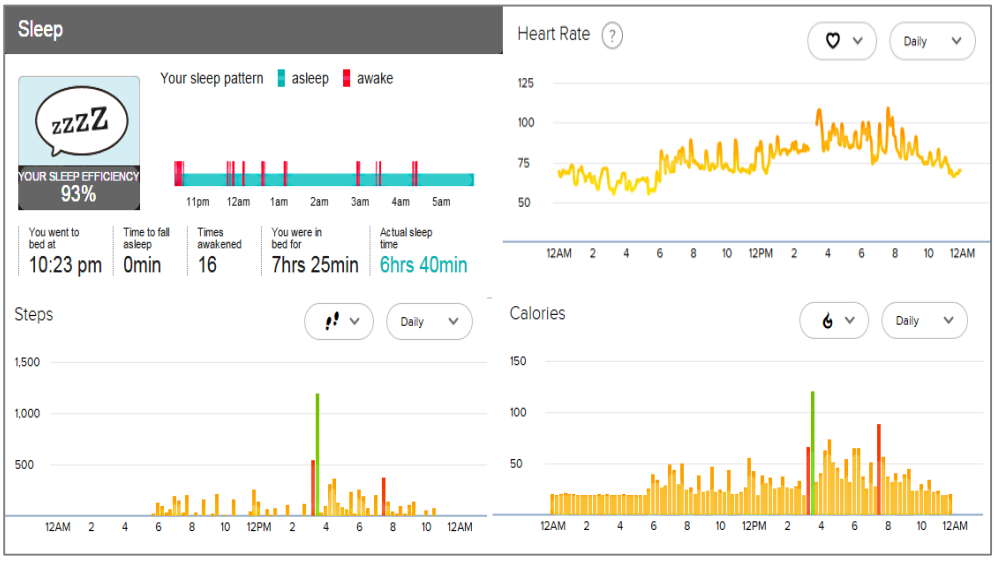


Sleep
zzzZ
YOUR SLEEP EFFICIENCY
92%
Your sleep pattern
asleep
awake
12am 1am 2am 3am 4am 5am 6am 7am
You went to bed at
11:37 pm
Time to fall asleep
0min
Times awakened
18
You were in bed for
7hrs 24min
Actual sleep time
6hrs 29min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,000
750
500
250
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 3rd March

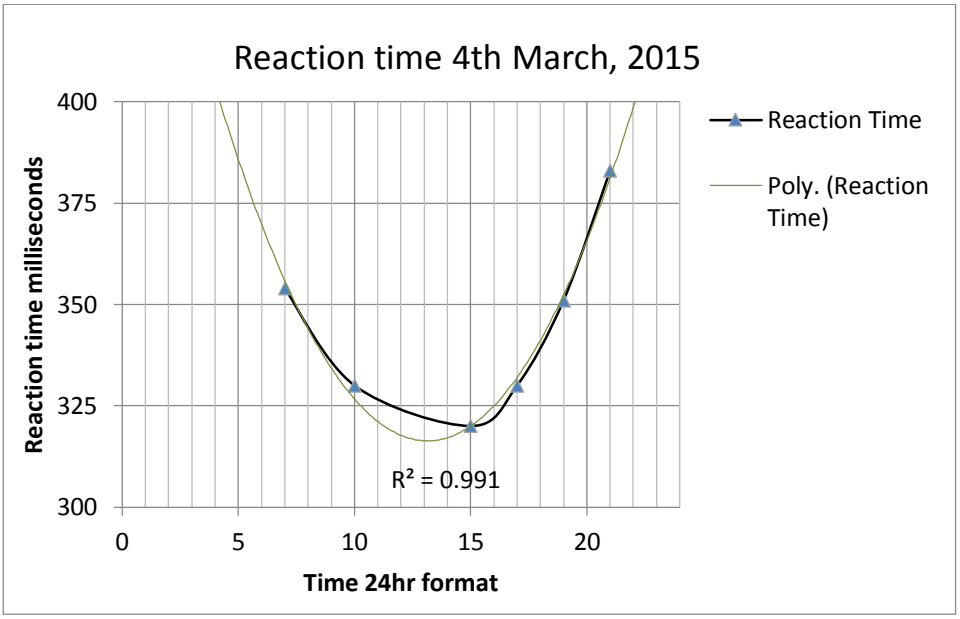
Sleep: 6hr 30min Awakenings: 22, Resting heart rate: 67bpm Total Calories: 2,880, Total Steps: 4,113					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
09.00	N/A	N/A	87	331	0.65
10.00	446	446	89	327	0.60
12.00	1176	1622	98	332	0.67
15.00	786	2408	87	328	0.53
17.00	327	2735	89	333	0.62
19.00	391	3126	86	369	0.63
21.00	391	3517	82	380	0.64

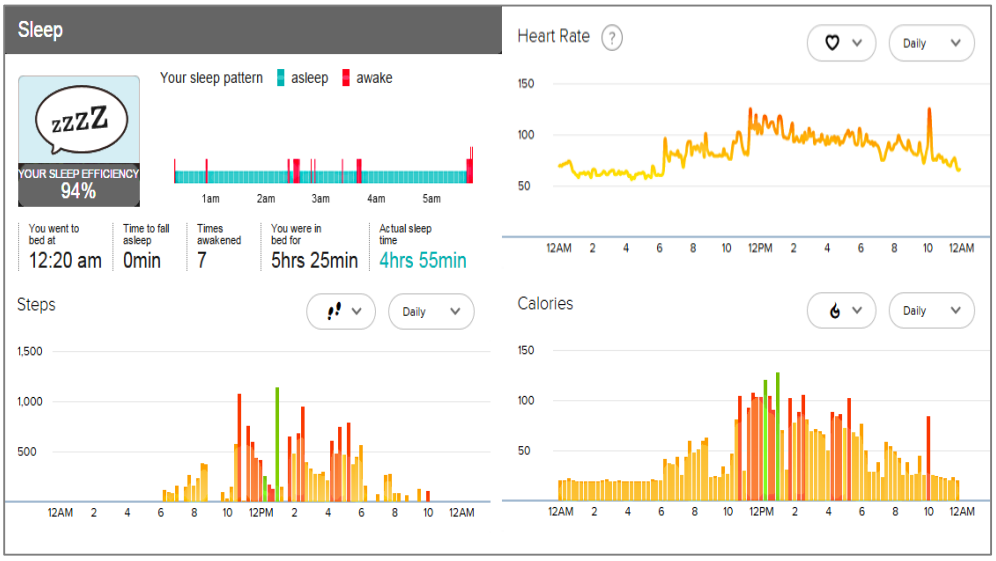



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
93%
Your sleep pattern
asleep
awake
11pm 12am 1am 2am 3am 4am 5am
You went to bed at
10:23 pm
Time to fall asleep
0min
Times awakened
16
You were in bed for
7hrs 25min
Actual sleep time
6hrs 40min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,500
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 4th March

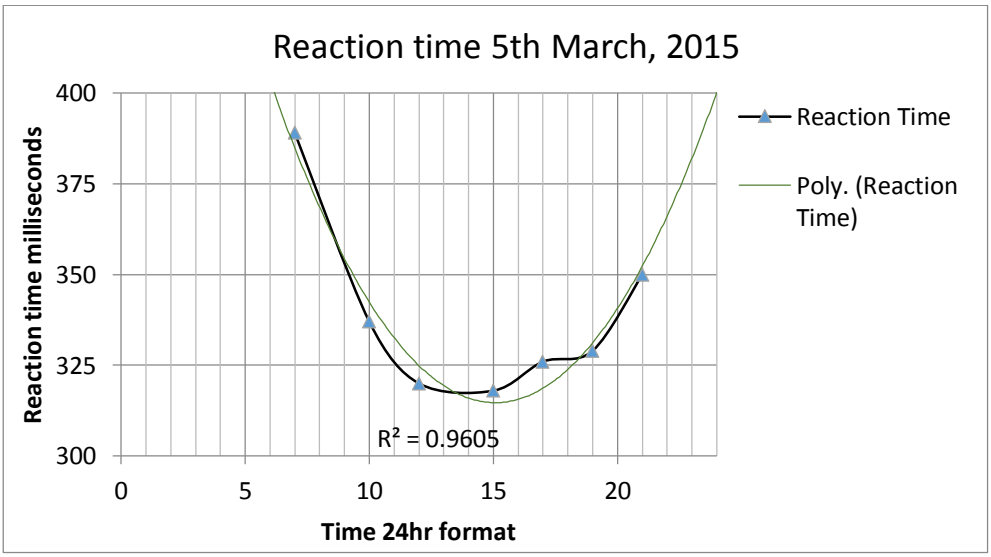
Sleep: 4hr 55min Awakenings: 7, Resting heart rate: 68bpm Total Calories: 4,615, Total Steps: 18,540					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	79	354	0.53
10.00	2345	2345	89	330	0.59
12.00	N/A	N/A	N/A	N/A	N/A
15.00	9032	11377	100	320	0.63
17.00	3286	14663	105	330	0.63
19.00	2694	17357	87	351	0.57
21.00	18157	18540	89	383	0.59

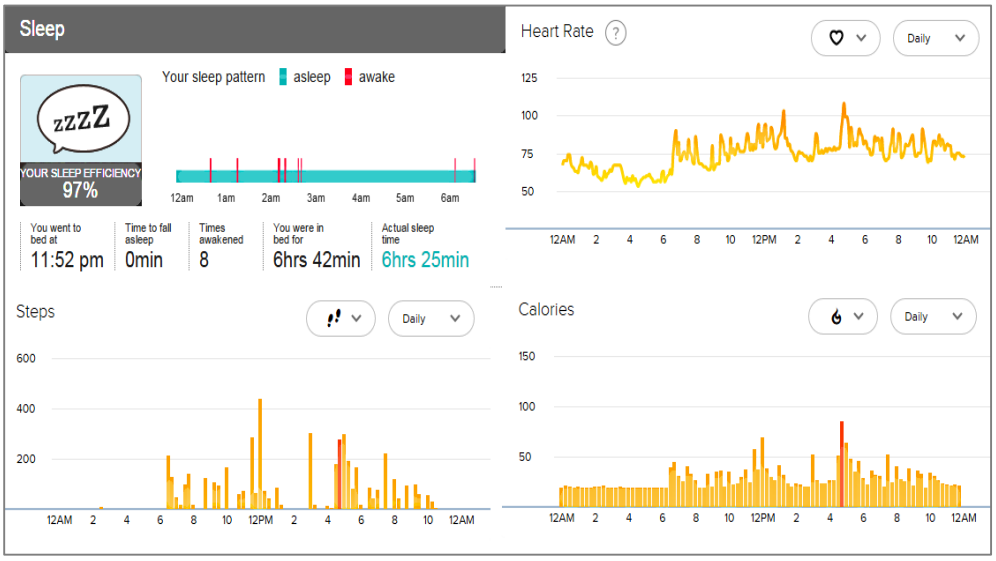



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
94%
Your sleep pattern
asleep
awake
1am
2am
3am
4am
5am
You went to bed at
12:20 am
Time to fall asleep
0min
Times awakened
7
You were in bed for
5hrs 25min
Actual sleep time
4hrs 55min
Steps
Daily
1,500
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Heart Rate
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 5th March

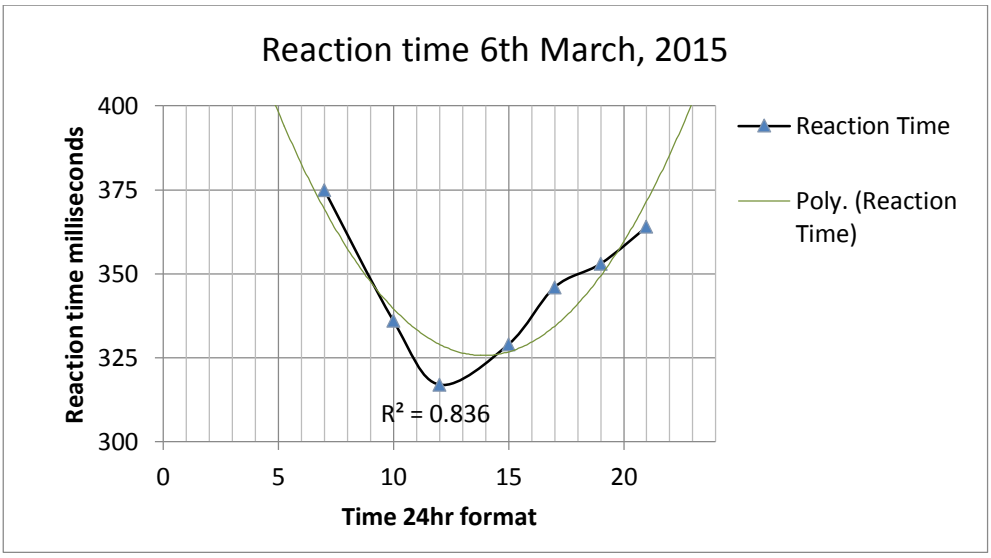
Sleep: 6hr 25min Awakenings: 8, Resting heart rate: 67bpm Total Calories: 2,812, Total Steps: 4,850					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	N/A	389	0.60
10.00	1115	1115	72	337	0.66
12.00	493	1608	84	320	0.60
15.00	958	2566	79	318	0.62
17.00	992	3558	77	326	0.57
19.00	487	4045	83	329	0.60
21.00	498	4543	78	350	0.59

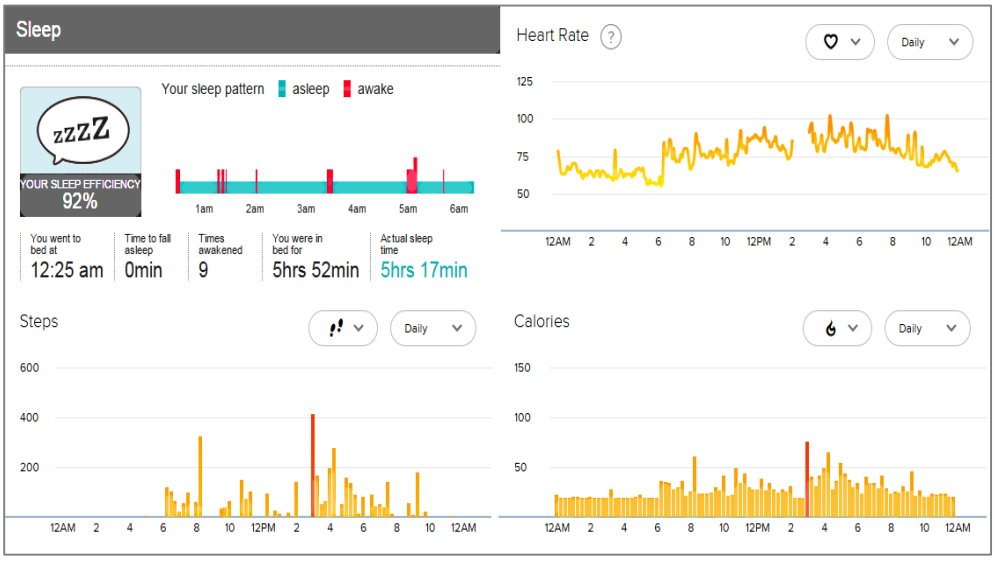



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
97%
Your sleep pattern
asleep
awake
12am 1am 2am 3am 4am 5am 6am
You went to bed at
11:52 pm
Time to fall asleep
0min
Times awakened
8
You were in bed for
6hrs 42min
Actual sleep time
6hrs 25min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
600
400
200
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 6th March

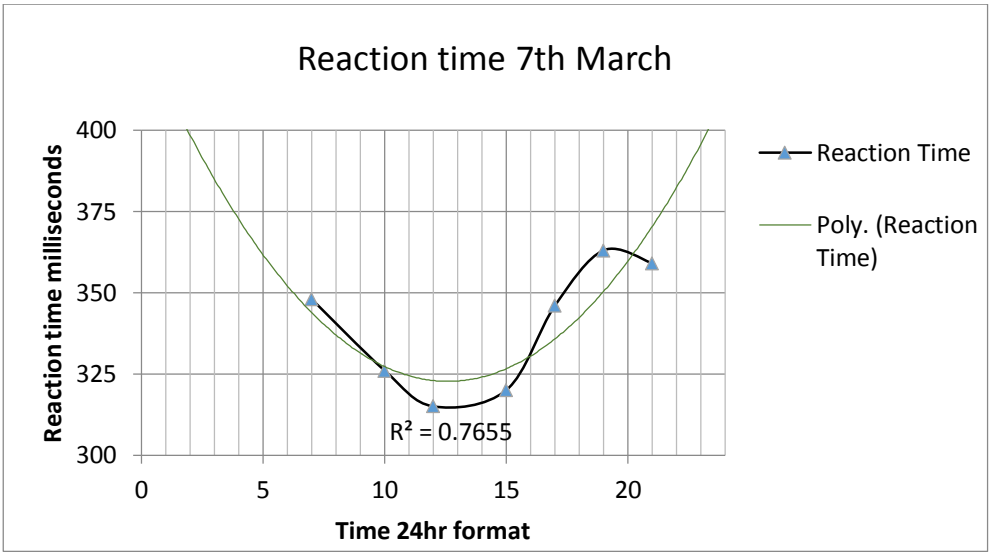
Sleep: 5hr 52min Awakenings: 9, Resting heart rate: 67bpm Total Calories: 2,784, Total Steps: 4,049					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	N/A	375	0.56
10.00	831	831	77	336	0.56
12.00	N/A	N/A	N/A	317	0.58
15.00	N/A	N/A	N/A	329	0.67
17.00	1996	2827	85	346	0.64
19.00	676	3503	98	353	0.65
21.00	293	3796	96	364	0.68

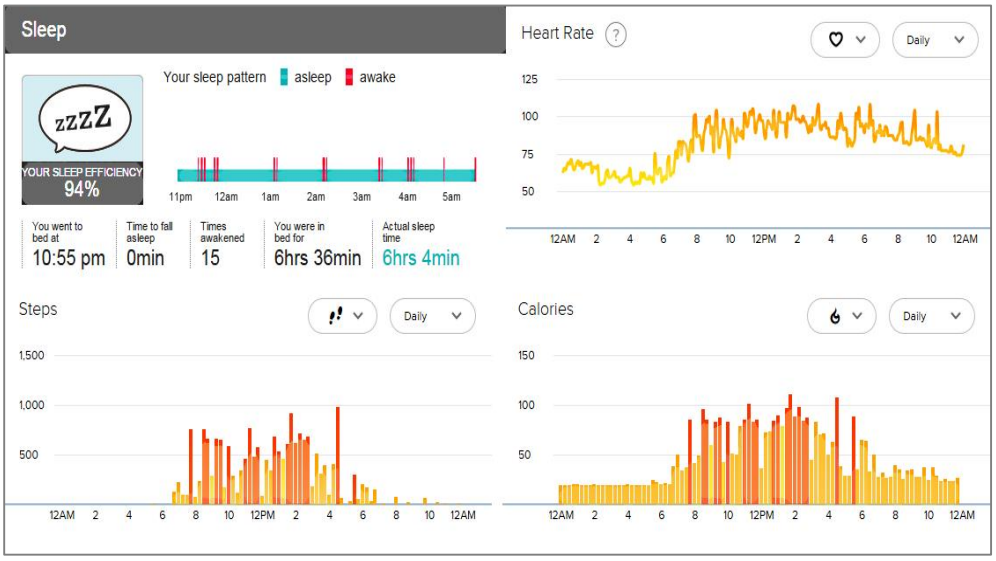



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
92%
Your sleep pattern
asleep
awake
1am
2am
3am
4am
5am
6am
You went to bed at
12:25 am
Time to fall asleep
0min
Times awakened
9
You were in bed for
5hrs 52min
Actual sleep time
5hrs 17min
Heart Rate
Daily
125
100
75
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Steps
Daily
600
400
200
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Calories
Daily
150
100
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM

Physiological Information 7th March

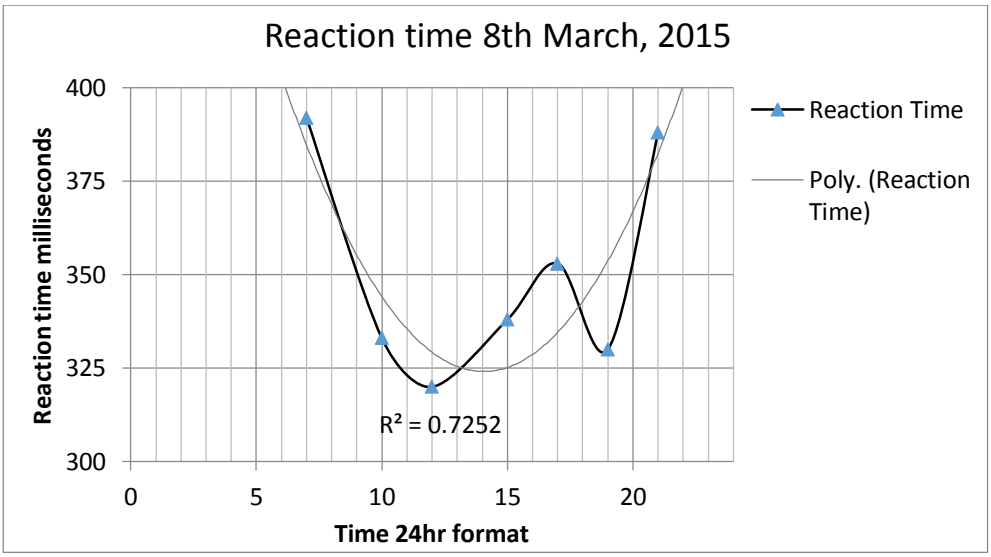
Sleep: 6hr 4min Awakenings: 15, Resting heart rate: 67bpm Total Calories: 4,492, Total Steps: 19,490					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	76	348	0.63
10.00	3579	3579	85	326	0.68
12.00	3655	7234	88	315	0.59
15.00	6782	14016	102	320	0.58
17.00	2910	16926	95	346	0.62
19.00	919	17845	86	363	0.67
21.00	223	18,068	106	359	0.61

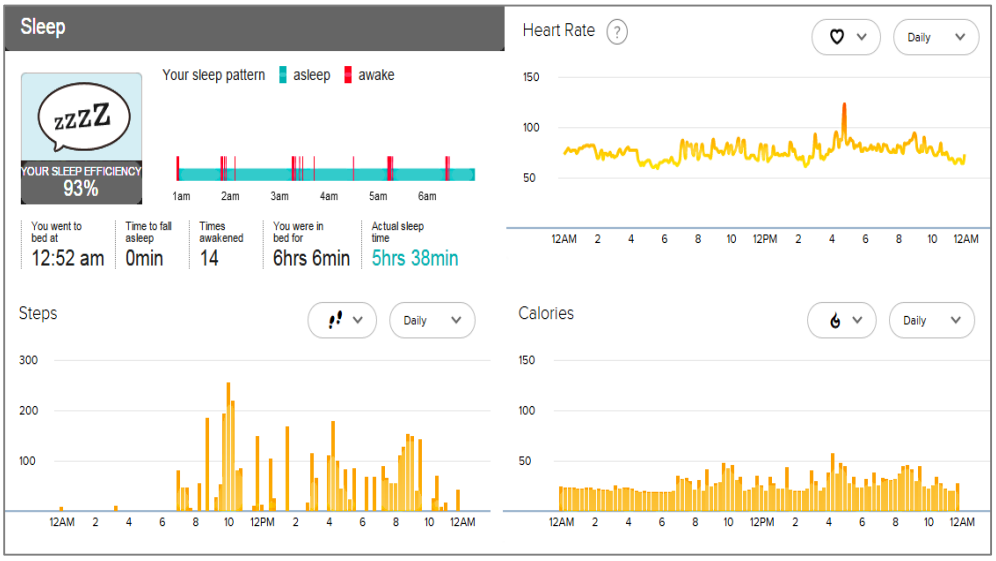



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
94%
Your sleep pattern
asleep
awake
11pm 12am 1am 2am 3am 4am 5am
You went to bed at
10:55 pm
Time to fall asleep
0min
Times awakened
15
You were in bed for
6hrs 36min
Actual sleep time
6hrs 4min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,500
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 8th March

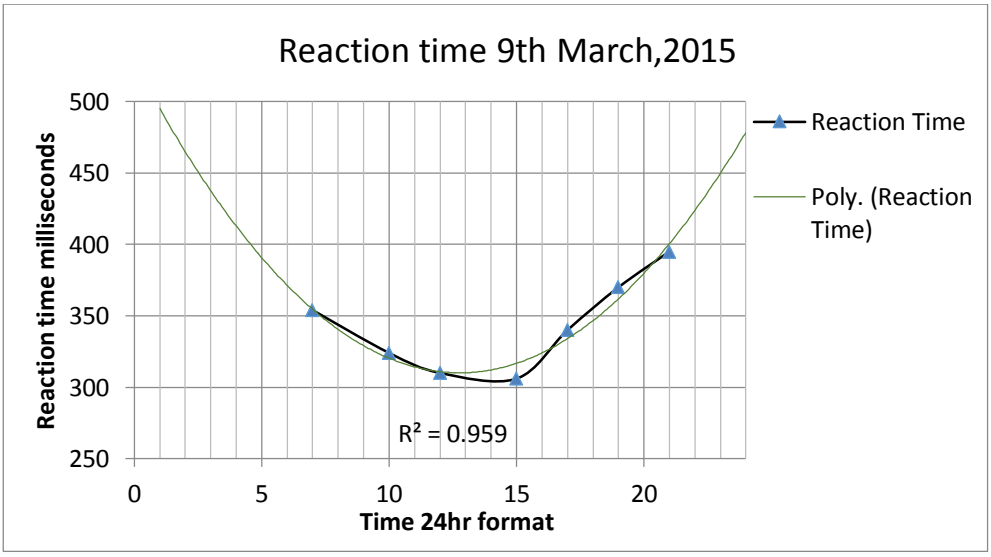
Sleep: 5hr 38min Awakenings: 14, Resting heart rate: 68bpm Total Calories: 2,736, Total Steps: 3,986					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	N/A	392	0.59
10.00	N/A	N/A	71	333	0.63
12.00	1373	1373	96	320	0.64
15.00	505	1878	80	338	0.62
17.00	579	2457	84	353	0.64
19.00	331	2788	91	330	0.62
21.00	559	3347	92	388	0.64

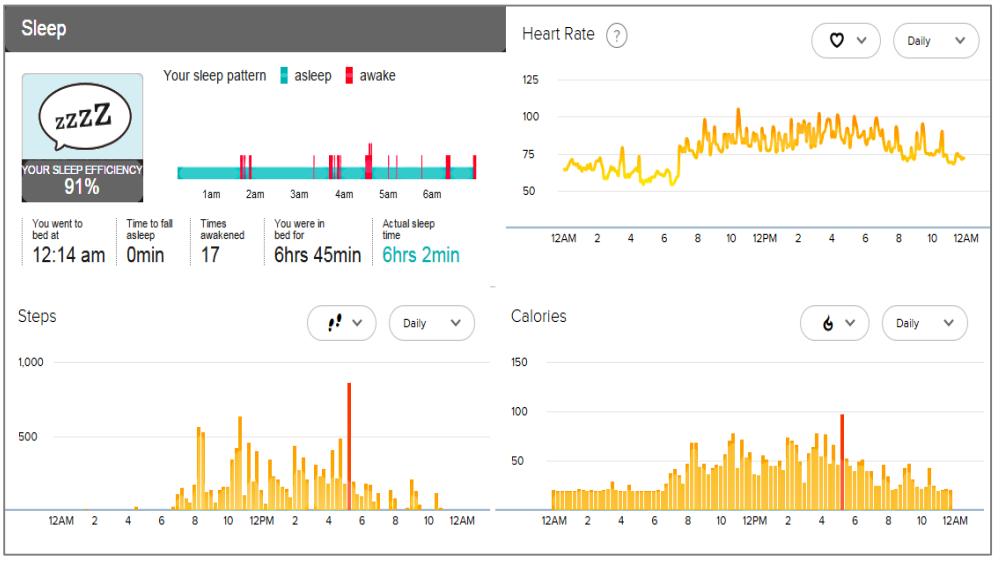



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
93%
Your sleep pattern
asleep
awake
1am
2am
3am
4am
5am
6am
You went to bed at
12:52 am
Time to fall asleep
0min
Times awakened
14
You were in bed for
6hrs 6min
Actual sleep time
5hrs 38min
Heart Rate
Daily
150
100
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Steps
Daily
300
200
100
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Calories
Daily
150
100
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM

Physiological Information 9th March

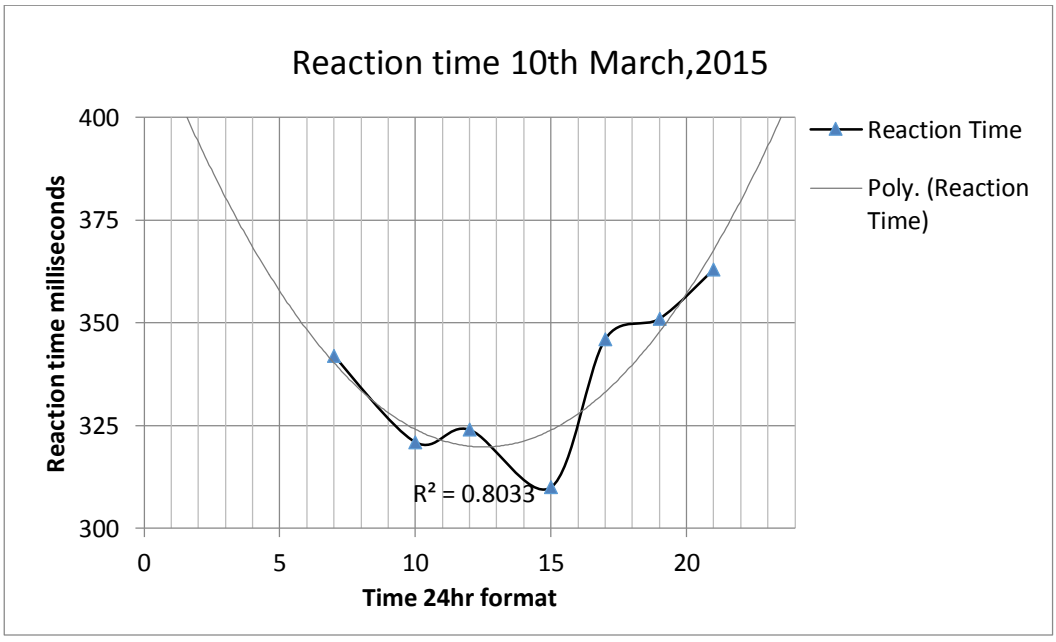
Sleep: 6hr 2min Awakenings: 17, Resting heart rate: 68bpm Total Calories: 3,705, Total Steps: 12,512					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	N/A	354	0.53
10.00	2297	2297	83	324	0.64
12.00	2791	5088	82	310	0.59
15.00	2562	7650	83	306	0.64
17.00	N/A	N/A	N/A	340	N/A
19.00	3350	11,000	N/A	370	0.64
21.00	994	11,994	80	395	0.61

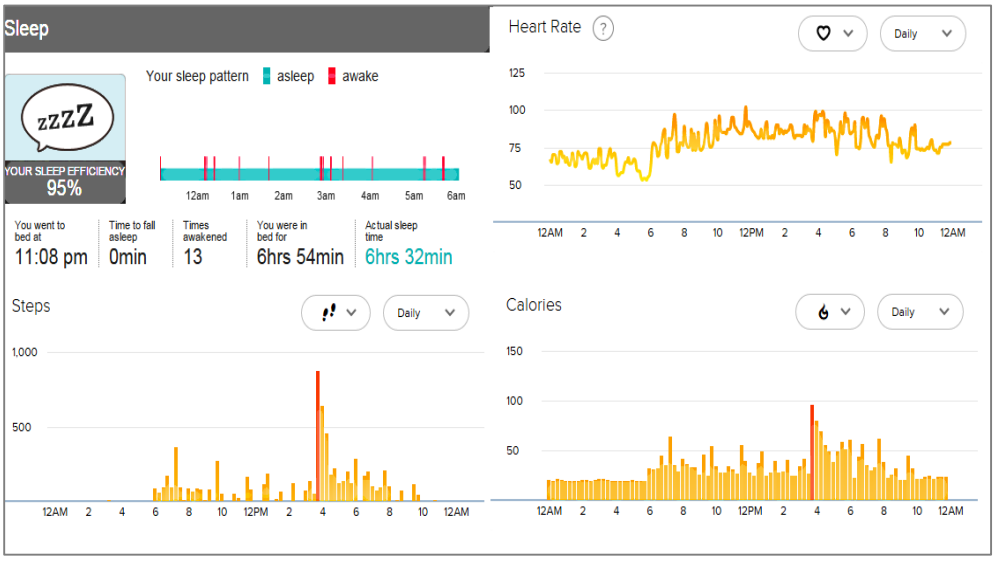



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
91%
Your sleep pattern
asleep
awake
1am
2am
3am
4am
5am
6am
You went to bed at
12:14 am
Time to fall asleep
0min
Times awakened
17
You were in bed for
6hrs 45min
Actual sleep time
6hrs 2min
Heart Rate
Daily
125
100
75
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Steps
Daily
1,000
500
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM
Calories
Daily
150
100
50
12AM
2
4
6
8
10
12PM
2
4
6
8
10
12AM

Physiological Information 10th March

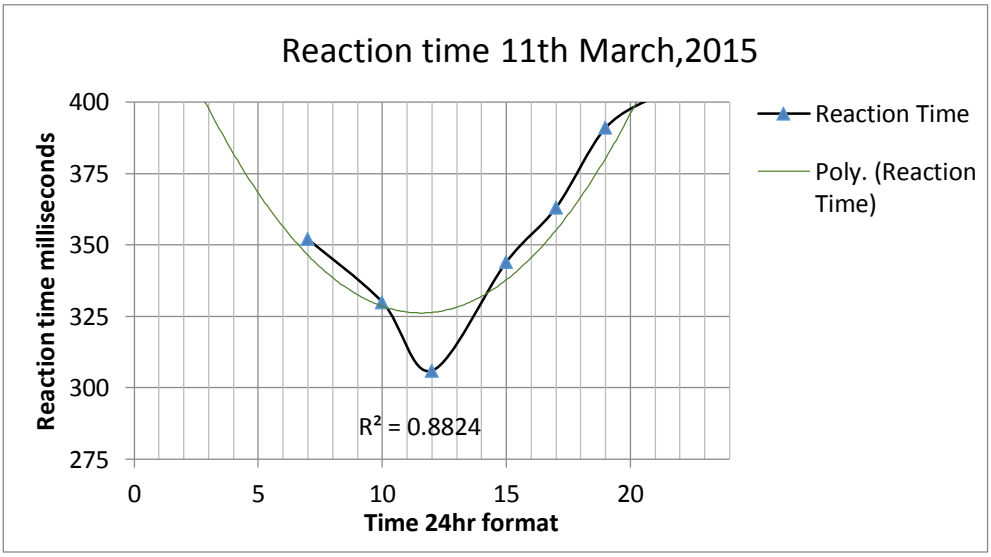
Sleep: 5hr 38min Awakenings: 14, Resting heart rate: 68bpm Total Calories: 2,736, Total Steps: 3,986					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	74	342	0.62
10.00	1656	1656	79	321	0.62
12.00	327	1983	86	324	0.64
15.00	639	2622	83	310	0.60
17.00	N/A	N/A	N/A	346	0.57
19.00	3847	6469	81	351	0.61
21.00	635	7104	90	363	0.62

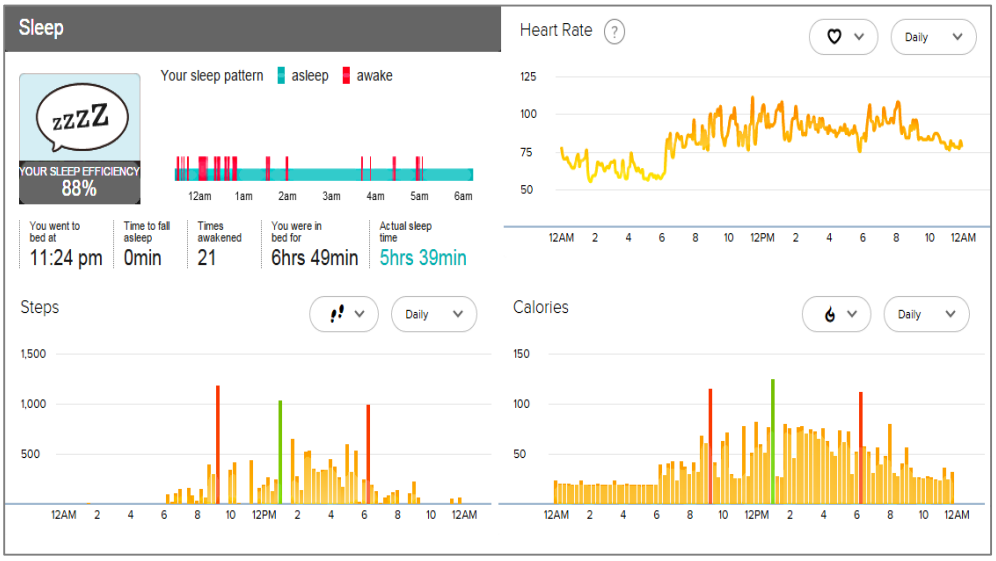



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
95%
Your sleep pattern
asleep
awake
12am 1am 2am 3am 4am 5am 6am
You went to bed at
11:08 pm
Time to fall asleep
0min
Times awakened
13
You were in bed for
6hrs 54min
Actual sleep time
6hrs 32min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 11th March

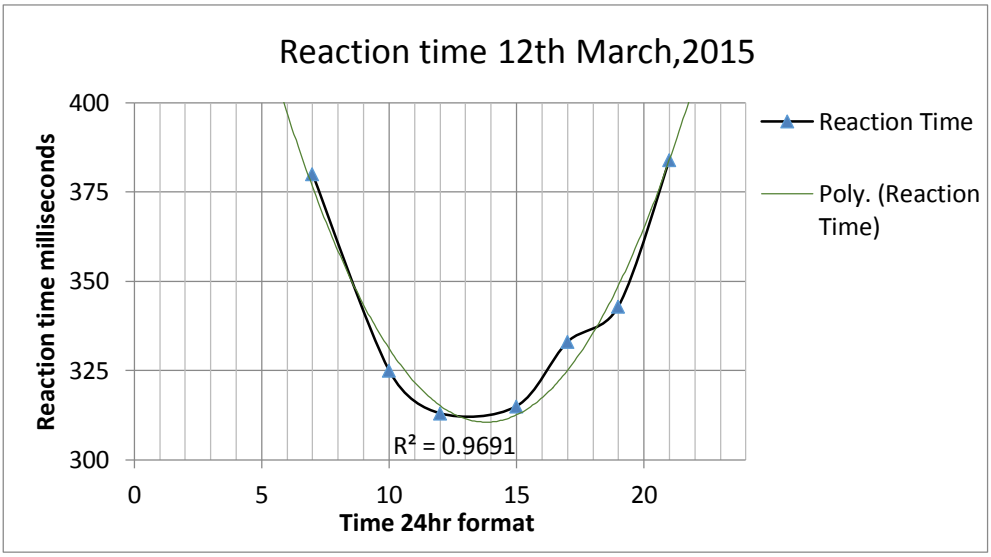
Sleep: 5hr 39min Awakenings: 21, Resting heart rate: 67bpm Total Calories: 4,142, Total Steps: 14,390					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	78	352	0.65
10.00	2725	2725	86	330	0.58
12.00	1224	3949	92	306	0.59
15.00	4195	8144	96	344	0.55
17.00	2471	10615	90	363	0.68
19.00	3198	13813	104	391	0.58
21.00	548	14361	88	402	0.65

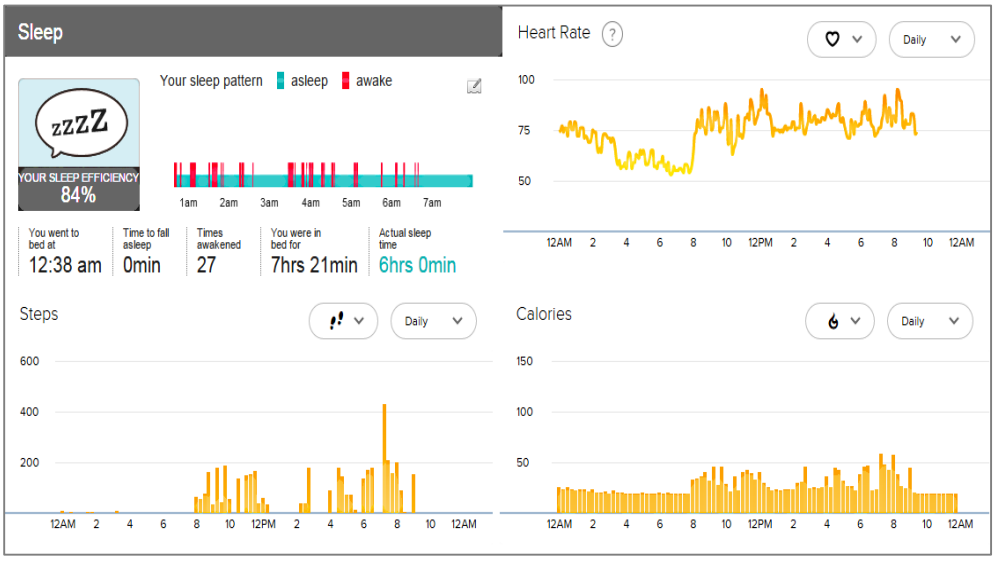



Sleep
zzzZ
YOUR SLEEP EFFICIENCY
88%
Your sleep pattern
asleep
awake
12am 1am 2am 3am 4am 5am 6am
You went to bed at
11:24 pm
Time to fall asleep
0min
Times awakened
21
You were in bed for
6hrs 49min
Actual sleep time
5hrs 39min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,500
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 12th March

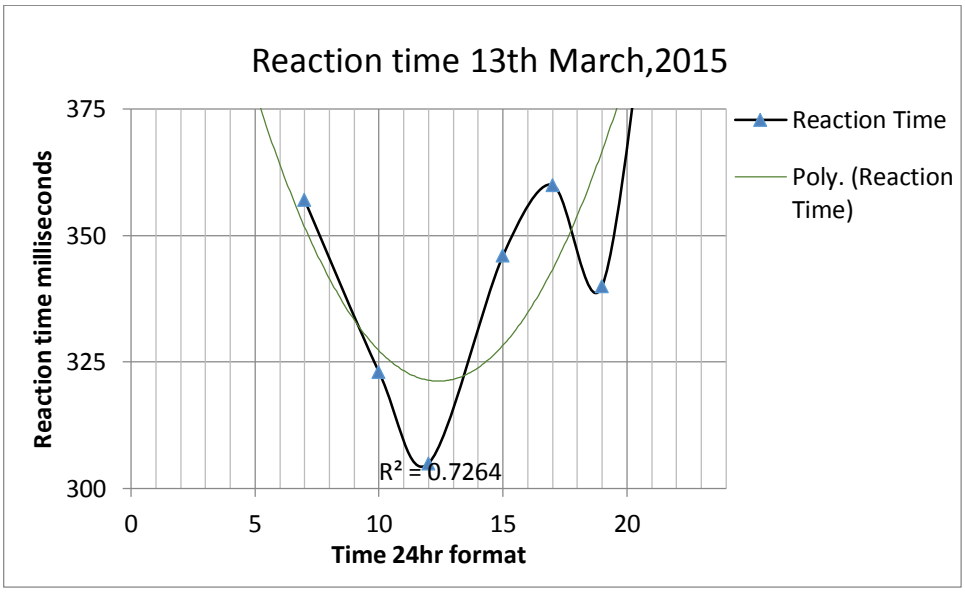
Sleep: 5hr 38min Awakenings: 14, Resting heart rate: 68bpm Total Calories: 2,736, Total Steps: 3,986					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	70	380	0.51
10.00	691	691	80	325	0.63
12.00	773	1464	87	313	0.65
15.00	302	1766	74	315	0.64
17.00	471	2237	79	333	0.73
19.00	915	3152	80	343	0.57
21.00	927	4079	86	384	0.65




Sleep
zzzZ
YOUR SLEEP EFFICIENCY
84%
Your sleep pattern
asleep
awake
1am 2am 3am 4am 5am 6am 7am
You went to bed at
12:38 am
Time to fall asleep
0min
Times awakened
27
You were in bed for
7hrs 21min
Actual sleep time
6hrs 0min
Heart Rate
Daily
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
600
400
200
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 13th March

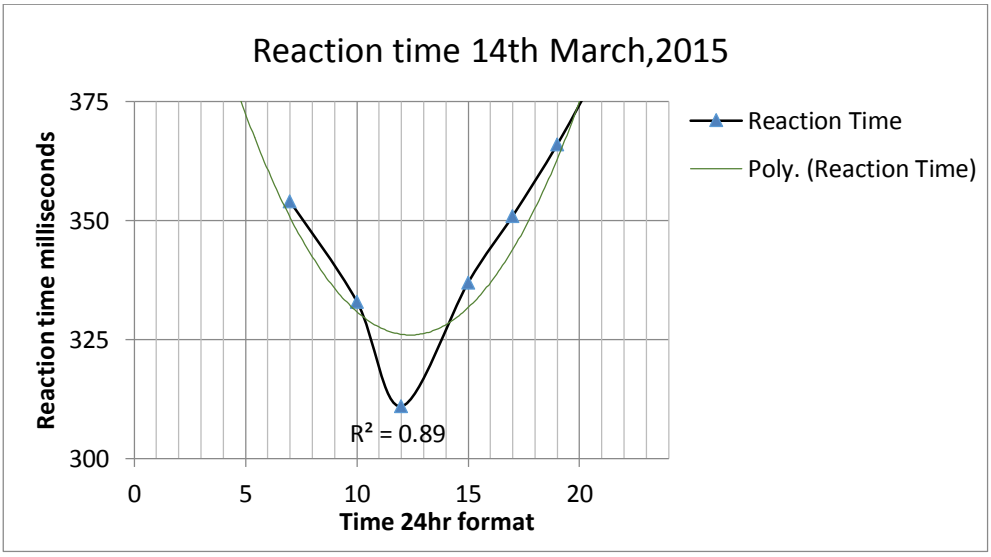
Sleep: Not Determined, Resting heart rate: 66bpm Total Calories: 3,037, Total Steps: 6,880					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	75	357	0.68
10.00	1061	1061	75	323	0.66
12.00	492	1553	83	305	0.66
15.00	2464	4017	92	346	0.75
17.00	673	4690	88	360	0.71
19.00	N/A	N/A	N/A	340	0.61
21.00	1023	5713	74	406	0.61

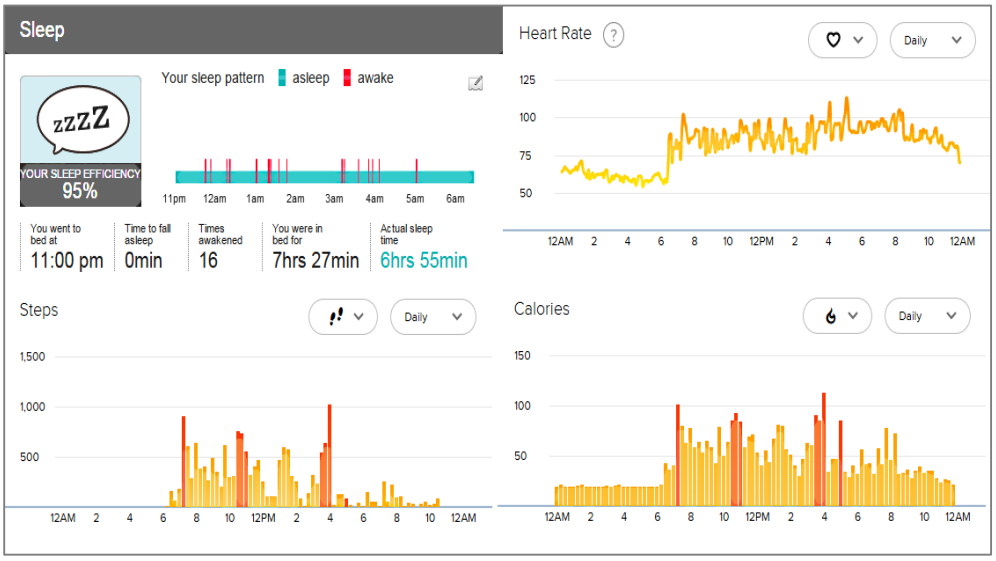


Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

Physiological Information 14th March

Sleep: 6hr 55min Awakenings: 15, Resting heart rate: 67bpm Total Calories: 4294, Total Steps: 17,244					
Time	Steps	Cumulative steps	Heart Rate	Reaction Time	Alertometer
07.00	N/A	N/A	81	354	0.59
10.00	5664	5664	74	333	0.66
12.00	4212	9786	86	311	0.68
15.00	2736	12612	85	337	0.59
17.00	3053	15665	105	351	0.65
19.00	412	16077	94	366	0.67
21.00	871	16948	98	383	0.66




Sleep
zzzZ
YOUR SLEEP EFFICIENCY
95%
Your sleep pattern
asleep
awake
11pm 12am 1am 2am 3am 4am 5am 6am
You went to bed at
11:00 pm
Time to fall asleep
0min
Times awakened
16
You were in bed for
7hrs 27min
Actual sleep time
6hrs 55min
Heart Rate
Daily
125
100
75
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Steps
Daily
1,500
1,000
500
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM
Calories
Daily
150
100
50
12AM 2 4 6 8 10 12PM 2 4 6 8 10 12AM

APPENDIX C – PHASE THREE REACTION TIME DATA

Crew 1 Paengaroa Simple Reaction Time

Monday 20th July

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	468	414	20716.2	143.9	7:10 AM
PF1	15	481	434	50733.1	225.2	7:05 AM
PF2	15	326	316	1547.9	39.3	7:13 AM
JB2	15	334	346	768.5	27.72	7:16 AM
JB1	15	399	399	14888.5	122.0	7:19 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	329	316	2920.1	54.0	11:53 AM
PF1	15	763	777	54415.7	233.3	11:56 AM
PF2	15	355	356	1704.2	41.3	11:51 AM
JB1	15	492	384	114404	338.2	12:00 PM
JB2	15	320	314	574.9	24.0	11:48 PM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	325	321	2256.2	47.5	3:44 PM
PF1	15	1048	1070	50292.1	224.3	3:41 PM
PF2	15	317	315	1940.0	44.0	3:34 PM
JB1	15	481	350	115812.8	340.3	3:38 PM
JB2	15	307	301	301.4	17.4	3:52 PM

Tuesday 21st July

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	333	319	2457.3	49.5	7:03 AM
PF1	15	388	367	4540.8	67.4	7:05 AM
PF2	15	311	315	568.0	23.8	7:08 AM
JB2	15	322	320	707.8	26.6	7:12 AM
JB1	15	359	336	12956.5	113.8	7:13 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev	start_time
CG1	15	359	338	4022.7	63.4	11:22 AM
PF2	15	320	310	1642.3	40.5	11:37 AM
PF1	15	473	424	64679.9	254.3	11:49 AM
JB1	15	369	358	9568.2	97.8	11:25 AM
JB2	15	338	330	2068.5	45.5	11:28 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	338	337	2657.8	51.6	3:39 PM
PF1	15	389	374	9142.9	95.6	3:48 PM
PF2	15	362	342	14465.5	120.3	3:36 PM
JB1	15	364	342	3587.9	59.9	3:33 PM
JB2	15	325	327	1103.1	33.2	3:45 PM

Wednesday 22nd July

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	355	334	3063.1	55.3	7:10 AM
PF1	15	371	336	6940.5	83.3	7:13 AM
PF2	15	358	331	12419.5	111.4	7:18 AM
JB2	15	328	328	827.3	28.8	7:16 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	390	352	12323.0	111.0	11:27 AM
PF1	15	398	368	9320.0	96.5	11:32 AM
PF2	15	337	299	16884.0	129.9	11:35 AM
JB2	15	325	303	2796.8	52.9	11:30 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	386	376	6971.4	83.5	3:38 PM
PF1	15	321	296	1960.1	44.3	3:46 PM
PF2	20	308	305	612.1	24.7	3:25 PM
JB2	15	330	323	2983.5	54.6	3:49 PM

Thursday 23rd July

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	378	361	7090.7	84.2	7:16 AM
PF1	15	387	372	3490.0	59.1	7:18 AM
PF2	15	286	281	1443.0	38.0	7:21 AM
JB1	15	331	283	17387.0	132.0	7:23 AM
JB2	20	325	316	4234.7	65.1	7:14 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	367	351	5967.4	77.2	11:05 AM
PF1	15	433	404	4028.1	63.4	12:09 PM
PF2	15	306	295	1387.1	37.2	12:12 PM
JB2	15	279	283	588.7	24.2	12:14 PM
JB1	15	339	331	2833.5	53.2	12:16 PM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	461	437	4624.8	68.0	3:38 PM
PF1	15	365	361	3236.1	56.9	3:27 PM
PF2	15	299	292	920.7	30.3	3:25 PM
JB1	15	389	285	75743.5	275.2	3:36 PM
JB2	15	311	305	1060.4	32.6	3:23 PM

Monday 24th August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	390	353	25915.4	161.0	6:58 AM
PF1	15	477	417	41524.8	203.8	7:05 AM
PF2	15	343	346	1955.8	44.2	7:02 AM
JB1	15	414	312	80350.3	283.5	7:10 AM
JB2	15	305	305	713.3	26.7	7:00 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	360	335	2422.1	49.2	11:24 AM
PF1	15	489	401	90691.9	301.2	11:36 AM
PF2	15	293	287	706.8	26.6	11:48 AM
JB1	15	342	335	2480.0	49.8	11:38 AM
JB2	15	295	294	555.0	23.6	11:45 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	392	386	1956.8	44.2	3:35 PM
PF1	15	386	374	7950.2	89.2	3:40 PM
PF2	15	327	318	3127.4	55.9	3:38 PM
JB1	15	316	285	8408.5	91.7	3:45 PM
JB2	15	350	310	8940.3	94.6	3:43 PM

Tuesday 25th August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	437	418	10063.1	100.3	6:59 AM
PF1	15	363	321	8786.8	93.7	7:03 AM
PF2	15	289	282	739.6	27.2	7:08 AM
JB1	15	328	339	1188.2	34.5	7:06 AM
JB2	15	311	313	622.3	24.9	7:01 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	366	359	2051.7	45.3	11:54 AM
PF1	15	439	425	18820.3	137.2	11:56 AM
PF2	15	310	298	3375.5	58.1	11:59 AM
JB1	15	325	316	2168.7	46.6	12:04 PM
JB2	15	328	309	3758.3	61.3	12:01 PM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	403	381	3496.2	59.1	3:34 PM
PF1	15	397	371	31482.4	177.4	3:28 PM
PF2	15	311	283	2587.1	50.9	3:38 PM
JB1	15	331	323	2008.8	44.8	3:46 PM

Wednesday 26th August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	465	477	5109.0	71.5	6:55 AM
PF1	15	376	354	4454.8	66.7	6:57 AM
JB1	15	357	333	3236.1	56.9	7:00 AM
JB2	15	323	312	2058.6	45.4	6:53 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
PF1	15	407	402	4336.8	65.9	11:04 AM
JB1	15	358	347	3481.8	59.0	11:01 AM
JB2	15	356	337	5113.1	71.5	12:04 PM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	435	428	5029.5	70.9	3:37:58 PM
PF1	15	384	327	32280.4	179.7	3:28:54 PM
JB2	15	362	317	10009.6	100.0	3:48:10 PM

Thursday 27th August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	387	386	2873.8	53.6	6:43:54 AM
PF1	15	349	347	1311.3	36.2	6:59:19 AM
PF2	15	299	295	1341.5	36.6	7:09:31 AM
JB2	15	328	308	3348.1	57.9	7:11:40 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
PF1	15	347	345	1111.3	33.3	11:25 AM
PF2	15	328	286	27169.6	164.8	11:48 AM
JB2	15	333	319	1303.6	36.1	11:50 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	420	390	11224.6	105.9	3:47 PM
PF1	15	471	415	36998.4	192.3	3:50 PM
PF2	15	313	287	4129.2	64.3	3:39 PM
JB2	15	348	325	3795.4	61.6	3:52 PM

Friday 28th August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	423	407	11573.9	107.6	6:38 AM
PF1	15	380	363	6087.2	78.0	6:41 AM
PF2	15	320	314	910.5	30.2	6:47 AM
JB2	15	367	355	3481.6	59.0	6:44 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1	15	365	372	5537.0	74.4	11:02 AM
PF1	15	342	331	3019.4	54.9	11:00 AM
PF2	15	323	308	3058.7	55.3	11:43 AM
JB2	15	388	352	8788.7	93.7	11:41 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
PF1	15	325	315	1245.4	35.3	3:31 PM
JB2	15	349	324	4958.2	70.4	3:35 PM
PF2	15	324	301	4436.5	66.6	3:42 PM
CG1	15	412	340	34578.1	186.0	3:48 PM

Crew 1 Paengaroa Choice Reaction Time

Monday 20th July

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	660	563	76580.7	276.7	7:11 AM
PF1	20	1042	1115	56278.7	237.2	7:06 AM
PF2	20	457	458	3250.9	57.0	7:14 AM
JB1	16	704	615	47997.1	219.1	7:20 AM
JB2	20	480	439	27339.6	165.3	7:16 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	19	645	587	30953.0	175.9	11:54 AM
PF1	20	1062	1068	45550.1	213.4	11:57 AM
PF2	20	418	415	824.5	28.7	11:51 AM
JB1	16	663	634	31298.9	176.9	12:01 PM
JB2	18	465	460	3644.0	60.4	11:49 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	677	638	18307.0	135.3	3:45 PM
PF1	20	1063	1040	34230.4	185.0	3:43 PM
PF2	19	398	384	2604.3	51.0	3:35 PM
JB1	18	695	649	47537.1	218.0	3:39 PM
JB2	20	427	415	3317.5	57.6	3:53 PM

Tuesday 21st July

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	619	561	22788.4	151.0	7:04 AM
PF1	19	775	660	83837.2	289.5	7:06 AM
PF2	19	420	390	18328.5	135.4	7:09 AM
JB2	19	448	434	7146.3	84.5	7:11 AM
JB1	19	583	573	8694.0	93.2	7:14 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	19	572	574	11360.6	106.6	11:23 AM
PF2	19	399	393	1348.7	36.7	11:38 AM
PF1	15	844	833	85071.1	291.7	11:49 AM
JB1	19	573	570	15661.9	125.1	11:26 AM
JB2	19	430	416	3005.1	54.8	11:29 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	535	535	8097.7	90.0	3:40 PM
PF1	18	1036	992	47219.3	217.3	3:48 PM
PF2	19	403	386	2502.8	50.0	3:37 PM
JB1	19	580	583	6935.5	83.3	3:34 PM
JB2	20	445	410	14003.8	118.3	3:46 PM

Wednesday 22nd July

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	565	544	11841.0	108.8	7:11 AM
PF1	14	795	790	49612.3	222.7	7:14 AM
PF2	18	434	418	7336.2	85.7	7:19 AM
JB2	20	475	457	7338.1	85.7	7:16 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20.0	535	533	4986.9	70.6	11:28 AM
PF1	18.0	862	848	60770.1	246.5	11:32 AM
PF2	19.0	425	421	3541.2	59.5	11:36 AM
JB2	20.0	408	385	5511.3	74.2	11:31 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	561	550	10007.5	100.0	3:39 PM
PF1	15	927	842	68583.8	261.9	3:47 PM
PF2	19	398	393	1993.5	44.6	3:26 PM
JB2	20	417	412	4368.4	66.1	3:50 PM

Thursday 23rd July

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	576	554	7756.6	88.1	3:39 PM
PF2	16	384	380	3679.2	60.7	3:26 PM
PF1	17	739	704	18594.8	136.4	3:27 PM
JB1	18	565	571	13433.0	115.9	3:37 PM
JB2	20	440	417	11555.4	107.5	3:24 PM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
PF1	18	830	807	18578.4	136.3	12:10 PM
PF2	20	420	393	5780.9	76.0	12:12 PM
JB2	19	393	372	3338.2	57.8	12:15 PM
JB1	19	585	593	10459.8	102.3	12:17 PM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	576	554	7756.6	88.1	3:39:26 PM
PF1	17	739	704	18594.8	136.4	3:27:57 PM
PF2	16	384	380	3679.2	60.7	3:26:08 PM
JB1	18	565	571	13433.0	115.9	3:37:14 PM
JB2	20	440	417	11555.4	107.5	3:24:00 PM

Monday 24th August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	516	500	6520.4	80.7	6:59 AM
PF1	16	738	733	16037.5	126.6	7:06 AM
PF2	18	403	399	1766.9	42.0	7:04 AM
JB1	18	555	568	13325.1	115.4	7:11 AM
JB2	18	418	397	8236.1	90.8	7:01 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	19	565	513	18389.4	135.6	11:25 AM
PF1	20	783	775	24704.5	157.2	11:37 AM
JB1	20	623	604	9416.1	97.0	11:39 AM
JB2	19	420	409	1649.2	40.6	11:46 AM
PF2	18	385	379	1443.9	38.0	11:49 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	630	584	43620.7	208.9	3:36 PM
PF1	19	773	738	20046.3	141.6	3:41 PM
PF2	19	419	377	13628.0	116.7	3:39 PM
JB2	19	444	438	2722.8	52.2	3:44 PM
JB1	19	668	645	19674.7	140.3	3:46 PM

Tuesday 25th August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	521	4712	26755.9	163.6	7:00 AM
PF1	17	841	761	55446.1	235.5	7:04 AM
PF2	18	388	383	1505.3	38.8	7:09 AM
JB1	19	625	620	5723.4	75.7	7:06 AM
JB2	20	407	413	2479.1	49.8	7:02 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	545	523	5289.8	72.7	11:55 AM
PF1	20	721	710	11104.9	105.4	11:57 AM
PF2	17	395	397	1658.2	40.7	11:59 AM
JB1	20	597	611	6342.9	79.6	12:05 PM
JB2	19	411	414	2728.5	52.2	12:02 PM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	544	521	10561.0	102.8	3:35:45 PM
PF1	19	807	772	46866.9	216.5	3:29:05 PM
PF2	18	425	398	18477.9	135.9	3:39:35 PM
JB1	18	559	560	6218.0	78.9	3:12:07 PM
JB2	20	389	379	2592.3	50.9	3:47:41 PM

Wednesday 26th August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	603	607	4235.8	65.1	6:56 AM
PF1	12	836	802	26360.6	162.4	6:59 AM
JB1	19	578	563	8458.0	92.0	7:02 AM
JB2	17	402	392	3143.7	56.1	6:54 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
PF1	20	841	811	29219.3	170.9	11:05 AM
JB1	20	577	533	15669.1	125.2	11:02 AM
JB2	18	433	426	6492.4	80.6	12:05 PM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	500	491	4933.9	70.2	3:38 PM
PF1	20	878	848	33500.8	183.0	3:29 PM
JB2	19	417	410	1636.2	40.4	3:49 PM

Thursday 27th August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	19	502	467	7527.7	86.8	6:44 AM
PF1	19	796	744	16368.1	127.9	7:00 AM
PF2	16	379	366	2777.7	52.7	7:10 AM
JB2	18	407	401	3764.2	61.4	7:12 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
PF1	19	684	671	16057.6	126.7	11:26 AM
PF2	18	386	369	4564.6	67.6	11:49 AM
JB2	18	407	406	1553.2	39.4	11:51 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	633	574	40152.1	200.4	3:47 PM
PF1	20	813	756	39261.8	198.1	3:51 PM
PF2	17	385	367	2968.9	54.5	3:40 PM
JB2	19	450	443	4232.8	65.1	3:53 PM

Friday 28th August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	515	500	5392.7	73.4	6:39 AM
PF1	18	749	694	22367.8	149.6	6:43 AM
PF2	18	438	404	21503.2	146.6	6:48 AM
JB2	19	448	425	5950.7	77.1	6:45 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	20	530	513	8357.3	91.4	11:03 AM
PF1	20	680	683	5877.5	76.7	11:01 AM
PF2	18	420	402	3348.9	57.9	11:44 AM
JB2	19	423	417	4997.7	70.7	11:42 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1	18	607	598	9745.7	98.7	3:49:28 PM
PF1	20	617	590	13172.3	114.8	3:32:21 PM
PF2	18	376	361	1773.4	42.1	3:43:57 PM
JB2	19	463	448	12504.1	111.8	3:36:49 PM

Crew 2 Taupo Simple Reaction Time

Monday 27th July

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	339	337	1699.4	41.2	7:45 AM
$PF1^{-T}$	15	296	299	766.3	27.7	7:46 AM
$PF2^{-T}$	15	372	320	18656.3	136.6	7:48 AM
$JB1^{-T}$	15	294	295	315.7	17.8	7:53 AM
$JB2^{-T}$	15	345	335	1065.4	32.6	7:50 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	331	327	1782.4	42.2	11:50 AM
$PF1^{-T}$	15	332	316	1914.5	43.8	11:44 AM
$PF2^{-T}$	15	359	364	3654.2	60.5	11:53 AM
$JB1^{-T}$	15	338	329	1843.1	42.9	11:59 AM
$JB2^{-T}$	15	327	314	2811.6	53.0	12:03 PM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	422	384	15214.6	123.3	3:21 PM
$PF2^{-T}$	15	314	302	2910.4	53.9	3:09 PM
$JB1^{-T}$	15	314	307	1126.6	33.6	3:16 PM
$JB2^{-T}$	15	485	480	22027.1	148.4	3:07 PM

Tuesday 28th July

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	480	397	57254.4	239.3	7:16 AM
$PF1^{-T}$	15	312	312	2607.4	51.1	7:21 AM
$PF2^{-T}$	15	340	319	2800.0	52.9	7:26 AM
$JB1^{-T}$	15	286	278	980.5	31.3	7:24 AM
$JB2^{-T}$	15	370	360	1294.3	36.0	7:18 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	402	367	11128.6	105.5	11:38 AM
$PF1^{-T}$	15	281	291	585.3	24.1	11:40 AM
$PF2^{-T}$	15	342	337	624.3	25.0	11:43 AM
$JB1^{-T}$	15	293	286	901.6	30.0	11:45 AM
$JB2^{-T}$	15	373	314	35596.0	188.7	11:47 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	354	334	3622.9	60.2	2:45 PM
$PF1^{-T}$	20	309	304	758.3	27.5	2:23 PM
$PF2^{-T}$	15	316	299	2892.2	53.8	2:26 PM
$JB1^{-T}$	15	277	276	268.3	16.4	2:47 PM
$JB2^{-T}$	15	399	378	5159.4	71.8	2:43 PM

Wednesday 29th July

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	399	396	2466.9	49.7	7:11 AM
$PF1^{-T}$	15	306	299	714.0	26.7	7:14 AM
$PF2^{-T}$	15	298	291	1063.6	32.6	7:16 AM
$JB1^{-T}$	15	302.	281	4134.5	64.3	7:18 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	346	307	7014.5	83.8	11:44 AM
$PF1^{-T}$	15	274	261	1396.6	37.4	11:37 AM
$PF2^{-T}$	15	270	263	939.8	30.7	11:39 AM
$JB1^{-T}$	15	268	273	1434.2	37.9	11:41 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
$CG1^{-T}$	15	337	327	2274.2	47.7	2:10 PM
$PF2^{-T}$	15	272	274	155.5	12.5	2:04 PM
$PF1^{-T}$	15	279	284	349.0	18.7	2:08 PM
$JB1^{-T}$	15	306	298	2003.6	44.8	1:54 PM

Crew 2 Taupo Choice Reaction Time

Monday 27th July

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	20	534	505	14193.5	119.1	7:42 AM
PF1-T	19	494	505	7653.9	87.5	7:47 AM
PF2-T	18	590	581	8153.2	90.3	7:49 AM
JB2-T	19	457	459	3454.4	58.8	7:51 AM
JB1-T	20	490	505	7828.5	88.5	7:54 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	18	496	505	8468.5	92.0	11:51 AM
PF1-T	19	490	445	22539.3	150.1	11:45 AM
PF2-T	20	505	492	6239.9	79.0	11:54 AM
JB1-T	19	517	485	11923.9	109.2	12:00 PM
JB2-T	20	455	438	5024.3	70.9	12:03 PM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	18	570	540	11548.6	107.5	3:22 PM
PF2-T	17	438	435	6220.4	78.9	3:11 PM
JB1-T	19	441	448	2324.4	48.2	3:17 PM
JB2-T	19	466	444	7048.0	84.0	3:08 PM

Tuesday 28th July

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	19	555	535	2819.1	53.1	7:17 AM
PF1-T	18	481	440	14604.5	120.9	7:22 AM
PF2-T	17	471	461	6078.8	78.0	7:27 AM
JB1-T	20	450	457	7449.2	86.3	7:25 AM
JB2-T	19	712	664	40896.2	202.2	7:20 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	20	469	434	11643.4	107.9	11:39 AM
PF1-T	19	421	406	6360.5	79.8	11:41 AM
PF2-T	19	407	392	3338.5	57.8	11:43 AM
JB1-T	17	440	434	4607.1	67.9	11:46 AM
JB2-T	20	719	649	58192.2	241.2	11:48 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	19	560	551	8045.7	89.7	2:46 PM
PF1-T	19	415	384	7109.8	84.3	2:25 PM
PF2-T	15	403	395	3795.3	61.6	2:27 PM
JB1-T	18	418	413	3256.0	57.1	2:48 PM
JB2-T	20	682	606	65317.4	255.6	2:44 PM

Wednesday 29th July

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	20	535	532	9711.5	98.5	7:12 AM
PF1-T	17	442	423	6415.2	80.1	7:15 AM
PF2-T	15	390	385	2410.9	49.1	7:17 AM
JB1-T	17	396	393	5548.1	74.5	7:19 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	17	553	566	17691.0	133.0	11:45 AM
PF1-T	20	399	391	3349.8	57.9	11:38 AM
PF2-T	15	413	350	56115.3	236.9	11:40 AM
JB1-T	14	393	396	3608.3	60.1	11:42 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-T	18	500	496	7541.9	86.8	2:11 PM
PF1-T	19	414	408	4172.4	64.6	2:09 PM
PF2-T	13	351	352	1665.6	40.8	2:04 PM
JB1-T	18	421	423	1890.9	43.5	1:56 PM

Crew 3 Taneatua Simple Reaction Time

Monday 10th August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	1259	1233	12050.3	109.8	7:08 AM
PF1-Tan	15	575	555	9778.4	98.9	7:12 AM
PF2-Tan	15	383	357	5754.0	75.9	7:15 AM
JB1-Tan	15	281	277	312.5	17.7	7:17 AM
JB2-Tan	15	1125	1134	34374.5	185.4	7:20 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	466	478	6188.3	78.7	10:59 AM
PF1-Tan	15	414	397	6038.2	77.7	10:57 AM
PF2-Tan	15	406	411	3024.4	55.0	11:45 AM
JB1-Tan	15	316	302	1267.1	35.6	11:09 AM
JB2-Tan	15	825	821	36969.3	192.2	11:12 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	410	388	5412.3	73.6	3:11 PM
PF1-Tan	15	395	403	1503.2	38.8	3:08 PM
PF2-Tan	15	362	354	2819.8	53.1	3:28 PM
JB1-Tan	15	281	268	1309.4	36.2	3:15 PM
JB2-Tan	15	423	382	13804.1	117.5	2:01 PM

Tuesday 11th August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	445	412	24583.0	156.8	6:48 AM
PF1-Tan	15	376	369	1680.2	41.0	6:50 AM
PF2-Tan	15	414	399	3846.0	62.0	6:52 AM
JB1-Tan	15	340	294	10434.5	102.1	6:54 AM
JB2-Tan	15	1003	955	35252.5	187.8	7:07 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	363	368	3441.2	58.7	10:56 AM
PF1-Tan	15	309	291	1097.8	33.1	10:58 AM
PF2-Tan	15	367	357	2807.0	53.0	11:00 AM
JB1-Tan	15	360	327	9260.8	96.2	11:02 AM
JB2-Tan	15	479	379	70994.2	266.4	11:05 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	393	348	15026.3	122.6	3:26 PM
PF1-Tan	15	393	379	2925.1	54.1	3:15 PM
PF2-Tan	15	371	375	2122.8	46.1	3:24 PM
JB1-Tan	15	278	283	765.8	27.7	3:28 PM
JB2-Tan	15	468	352	51112.1	226.1	1:42 PM

Wednesday 12th August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	400	372	7600.8	87.2	6:51 AM
PF1-Tan	15	384	352	4491.4	67.0	6:54 AM
PF2-Tan	15	378	381	2636.9	51.4	6:56 AM
JB1-Tan	15	312	286	6709.2	81.9	7:03 AM
JB2-Tan	15	920	903	14151.1	119.0	7:41 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	318	315	1294.1	36.0	11:02 AM
PF1-Tan	15	366	343	4033.7	63.5	11:09 AM
PF2-Tan	15	385	344	8605.1	92.8	11:07 AM
JB1-Tan	15	290	273	1696.5	41.2	11:00 AM
JB2-Tan	15	404	368	18905.9	137.5	11:05 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	371	325	13933.9	118.0	3:32 PM
PF1-Tan	15	400	389	5832.2	76.4	3:20 PM
PF2-Tan	15	338	336	4349.0	65.9	3:22 PM
JB1-Tan	15	272	268	471.5	21.7	3:26 PM
JB2-Tan	15	381	340	17385.0	131.9	1:52 PM

Monday 31st August

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	466	422	21549.0	146.8	7:14 AM
PF1-Tan	15	427	415	4114.2	64.1	7:19 AM
PF2-Tan	15	499	396	65088.1	255.1	7:21 AM
JB1-Tan	15	302	282	3027.6	55.0	7:24 AM
JB2-Tan	15	531	372	100747.5	317.4	7:17 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	405	322	48216.2	219.6	11:38 AM
PF1-Tan	15	410	386	5533.0	74.4	10:52 AM
PF2-Tan	15	416	402	9899.5	99.5	12:02 PM
JB1-Tan	15	291	277	3001.0	54.8	10:59 AM
JB2-Tan	15	368	348	3358.1	57.9	10:49 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	493	471	23029.6	151.8	2:57 PM
PF1-Tan	15	372	354	2229.5	47.2	3:00 PM
PF2-Tan	15	389	372	2661.7	51.6	3:25 PM
JB1-Tan	15	298	294	762.6	27.6	3:34 PM

Friday 4th September

Period: Start

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	349	329	7285.5	85.4	6:53 AM
PF1-Tan	15	402	385	4031.3	63.5	7:03 AM
PF2-Tan	15	376	368	2824.7	53.1	6:55 AM
JB1-Tan	15	313	303	2520.6	50.2	7:01 AM
JB2-Tan	15	418	358	56689.7	238.1	6:57 AM

Period: Break

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	333	322	2346.5	48.4	10:48 AM
PF1-Tan	15	380	371	3453.7	58.8	11:23 AM
PF2-Tan	15	585	393	130265.7	360.9	11:14 AM
JB1-Tan	15	301	287	1148.9	33.9	11:08 AM
JB2-Tan	15	341	311	10759.8	103.7	11:18 AM

Period: End

PID	Count *n*	Mean msec	Median msec	Variance	StdDev msec	start_time
CG1-Tan	15	332	323	1917.3	43.8	3:23 PM
PF1-Tan	15	461	420	26999.8	164.3	3:28 PM
PF2-Tan	15	409	386	12982.2	113.9	3:18 PM
JB1-Tan	15	305	292	1072.5	32.7	3:32 PM
JB2-Tan	15	422	362	34454.7	185.6	3:25 PM

Crew 2 Taneatua Choice Reaction Time

Monday 10th August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	765	728	21577.7	146.9	7:10 AM
PF1-Tan	20	838	824	21085.2	145.2	7:13 AM
PF2-Tan	19	539	538	12254.6	110.7	7:16 AM
JB1-Tan	20	509	503	18235.8	135.0	7:18 AM
JB2-Tan	20	1292	1291	20024.9	141.5	7:21 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	758	707	29145.1	170.7	11:00 AM
PF1-Tan	20	583	594	13288.0	115.2	10:58 AM
PF2-Tan	20	610	580	13150.6	114.7	11:46 AM
JB1-Tan	20	480	453	14218.8	119.2	11:10 AM
JB2-Tan	20	986	952	32803.6	181.1	11:13 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	19	547	527	9978.1	99.9	3:12 PM
PF1-Tan	20	562	492	46006.9	214.5	3:10 PM
PF2-Tan	20	603	576	7069.8	84.1	3:29 PM
JB1-Tan	20	455	465	6339.9	79.6	3:16 PM
JB2-Tan	20	704	586	52324.8	228.7	2:02 PM

Tuesday 11th August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	19	622	599	17075.8	130.7	6:49 AM
PF2-Tan	19	559	575	4297.2	65.6	6:52 AM
JB1-Tan	20	475	486	5685.6	75.4	6:55 AM
JB2-Tan	20	1007	1022	33758.6	183.7	7:08 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	644	593	32505.4	1803	10:56 AM
PF1-Tan	19	526	471	13534.1	116.3	10:58 AM
PF2-Tan	20	558	537	12230.8	110.6	11:01 AM
JB1-Tan	20	438	421	5387.7	73.4	11:03 AM
JB2-Tan	20	804	679	101219.5	318.2	11:06 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	516	510	3651.0	60.4	3:27 PM
PF1-Tan	20	544	505	21434.5	146.4	3:16 PM
PF2-Tan	20	592	585	7524.9	86.7	3:25 PM
JB1-Tan	19	486	485	3545.2	59.5	3:29 PM
JB2-Tan	20	920	952	76357.3	276.3	1:43 PM

Wednesday 12th August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev mean	start_time
CG1-Tan	20	599	580	13231.8	115.0	6:52 AM
PF1-Tan	20	475	455	6817.0	82.6	6:55 AM
PF2-Tan	20	600	604	7212.5	84.9	6:57 AM
JB1-Tan	18	575	526	28510.5	168.9	7:03 AM
JB2-Tan	20	902	875	25337.3	159.2	7:42 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	560	537	19353.1	139.1	11:03 AM
PF1-Tan	20	542	515	16419.9	128.1	11:10 AM
PF2-Tan	20	532	515	6129.5	78.3	11:08 AM
JB1-Tan	20	451	425	5019.7	70.8	11:01 AM
JB2-Tan	20	671	654	35504.6	188.4	11:06 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	19	512	517	3669.0	60.6	3:33 PM
PF1-Tan	19	498	500	8420.4	91.8	3:21 PM
PF2-Tan	20	514	500	6115.1	78.2	3:23 PM
JB1-Tan	20	433	433	2051.5	45.2	3:26 PM
JB2-Tan	20	602	519	70115.3	264.8	1:54 PM

Monday 31st August

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	596	578	12026.3	109.7	7:15 AM
PF1-Tan	20	559	494	34067.2	184.6	7:20 AM
PF2-Tan	20	591	532	21725.3	147.4	7:22 AM
JB1-Tan	19	451	438	2534.9	50.3	7:25 AM
JB2-Tan	20	635	613	17132.5	130.9	7:18 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	469	481	5867.3	76.6	11:39 AM
PF1-Tan	20	514	501	8398.1	91.6	10:53 AM
PF2-Tan	20	604	590	6553.0	81.0	12:03 PM
JB1-Tan	20	444	436	5343.5	73.1	10:59 AM
JB2-Tan	20	636	541	48607.6	220.5	10:50 AM

Period: End

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	565	515	34081.0	184.6	2:58 PM
PF1-Tan	20	493	472	6317.5	79.5	3:01 PM
PF2-Tan	20	570	514	30725.5	175.2	3:25 PM
JB1-Tan	18	459	460	3940.2	62.8	3:35 PM

Friday 4th September

Period: Start

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	493	473	3690.9	60.8	6:54 AM
PF1-Tan	20	467	461	2923.4	54.1	7:04 AM
PF2-Tan	20	574	567	5041.1	71.0	6:56 AM
JB2-Tan	20	597	549	17786.3	133.4	6:58 AM
JB1-Tan	20	511	492	5111.6	71.5	7:01 AM

Period: Break

PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	488	474	7779.3	88.2	10:48 AM
PF1-Tan	20	415	412	1442.6	38.0	11:24 AM
PF2-Tan	20	626	586	23004.7	151.7	11:15 AM
JB1-Tan	20	474	461	8517.0	92.3	11:09 AM
JB2-Tan	20	563	520	31370.2	177.1	11:19 AM

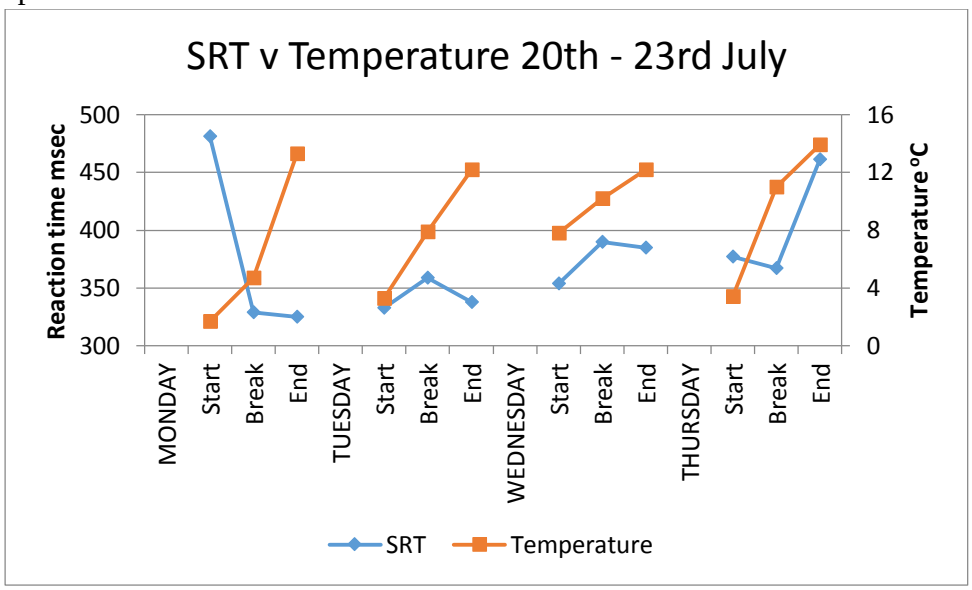
Period: End

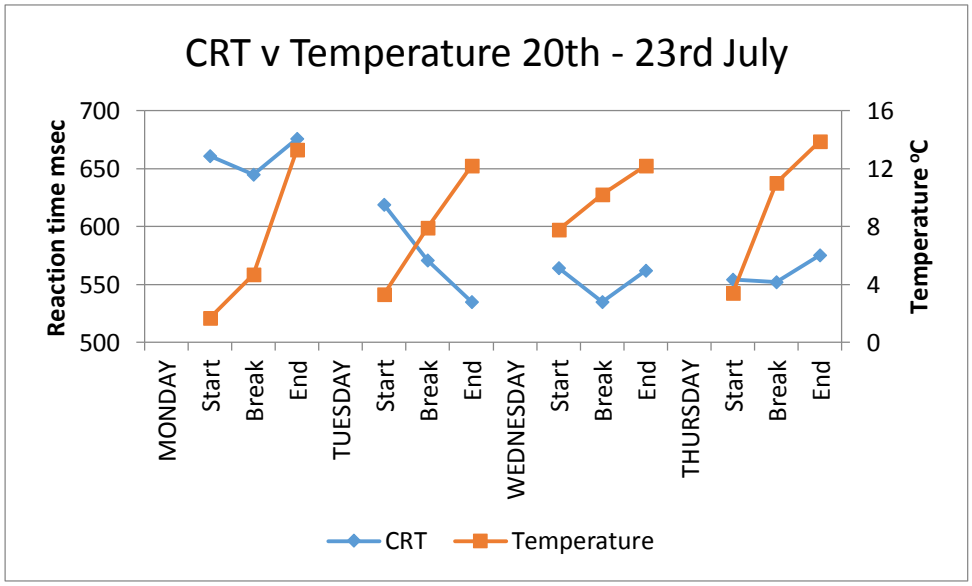
PID	Correct Count *n*	Correct Mean msec	Correct Median msec	Correct Variance	Correct StdDev msec	start_time
CG1-Tan	20	572	546	16334.8	127.8	3:24 PM
PF1-Tan	20	498	468	10121.8	100.6	3:28 PM
PF2-Tan	19	592	585	16470.3	128.3	3:19 PM
JB1-Tan	20	445	446	3147.3	56.1	3:33 PM
JB2-Tan	19	547	528	16440.6	128.2	3:26 PM

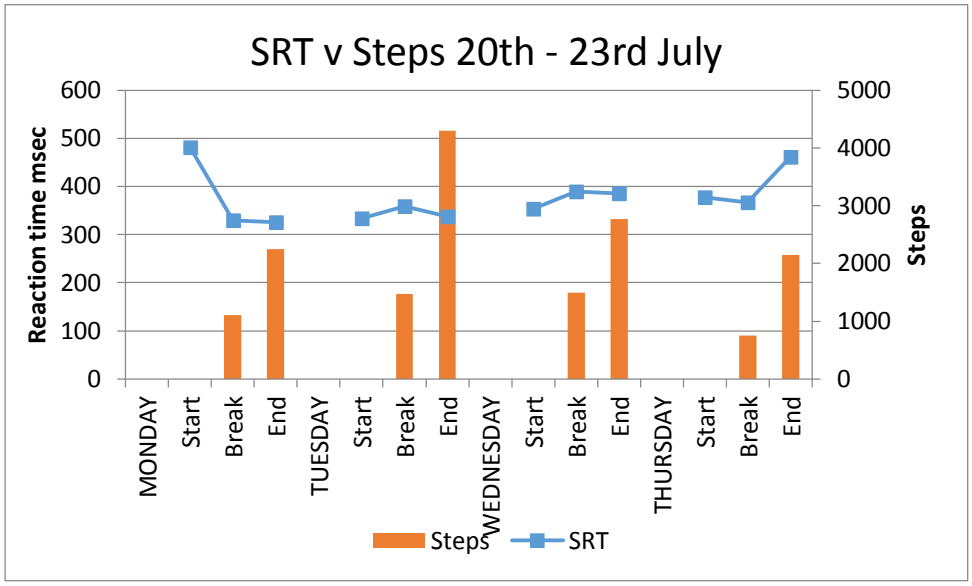
APPENDIX D – PHASE THREE PHYSILOGICAL AND REACTION TIME DATA EXAMPLE

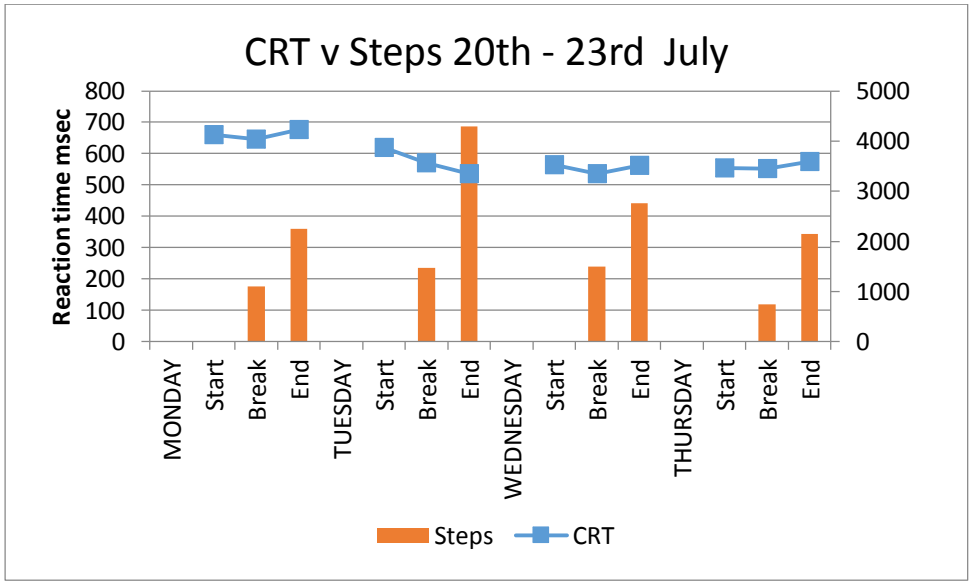
Crew 1 Paengaroa, visit 1

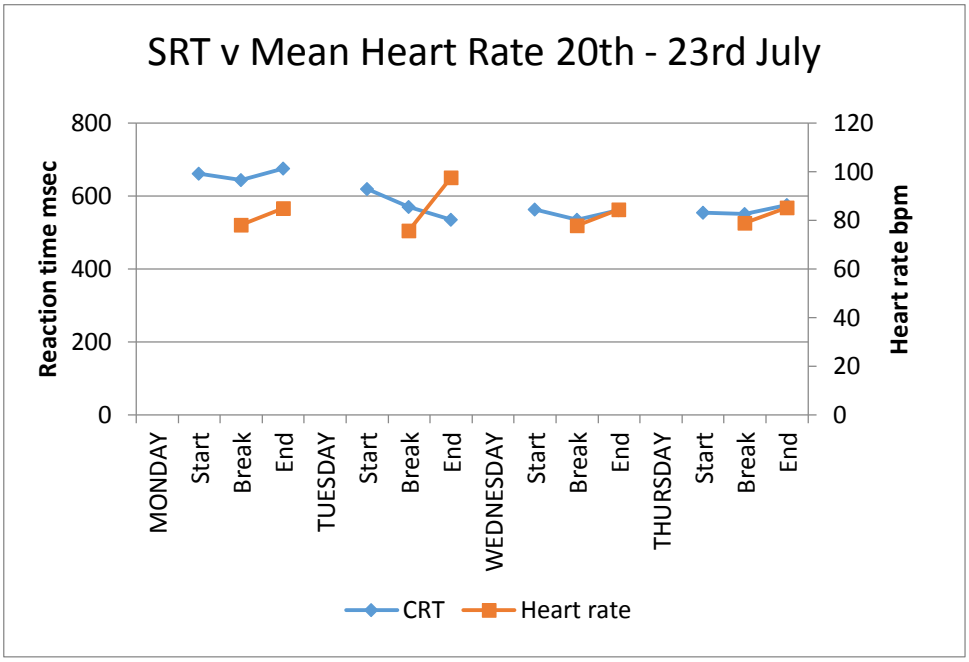
Participant CG1

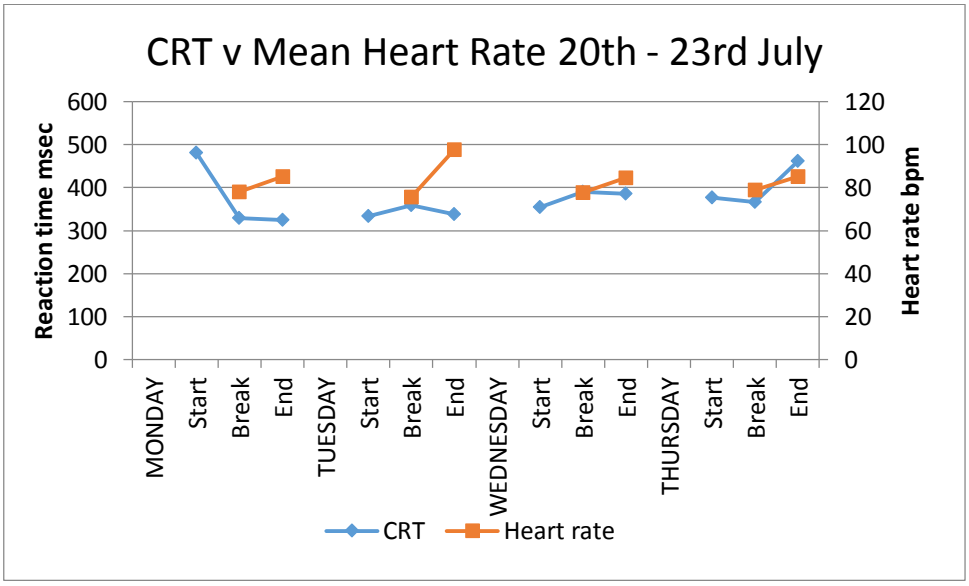


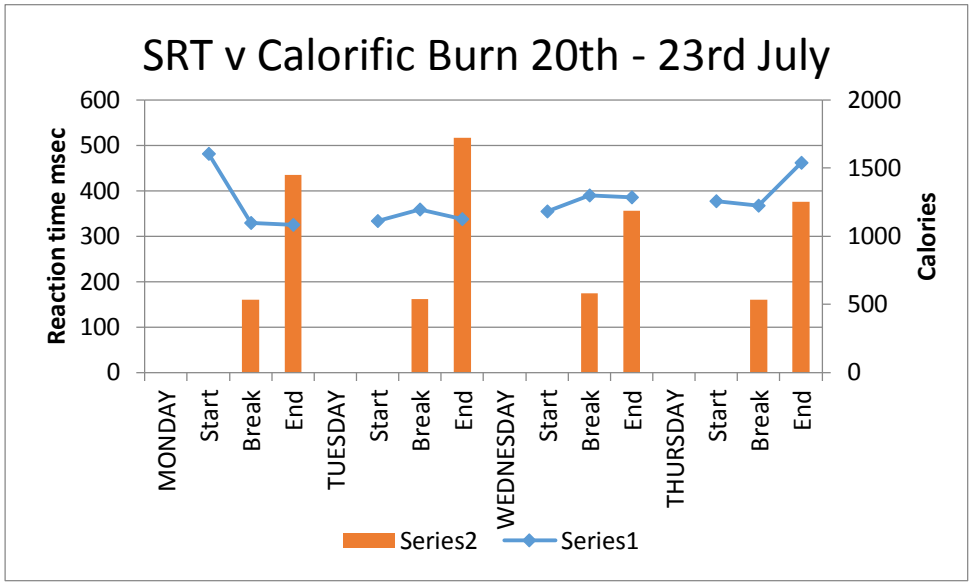


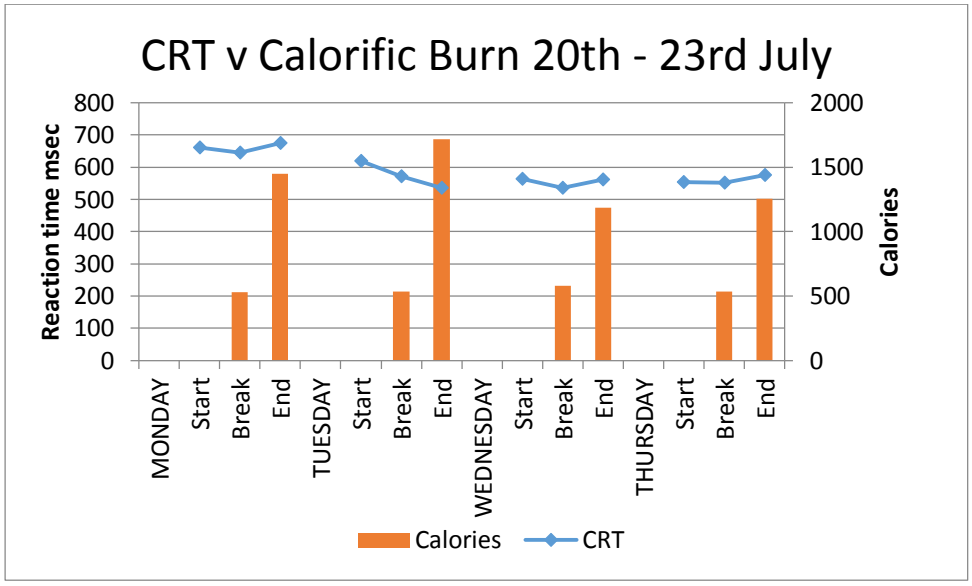

SRT v Steps 20th - 23rd July
Reaction time msec
Steps
600
500
400
300
200
100
0
5000
4000
3000
2000
1000
0
MONDAY
Start
Break
End
TUESDAY
Start
Break
End
WEDNESDAY
Start
Break
End
THURSDAY
Start
Break
End
Steps
SRT

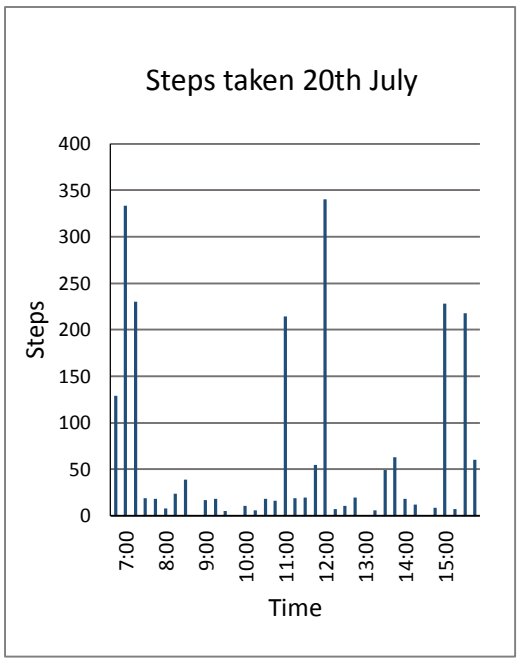

CRT v Steps 20th - 23rd July
Reaction time msec
800
700
600
500
400
300
200
100
0
5000
4000
3000
2000
1000
0
MONDAY
Start
Break
End
TUESDAY
Start
Break
End
WEDNESDAY
Start
Break
End
THURSDAY
Start
Break
End
Steps
CRT

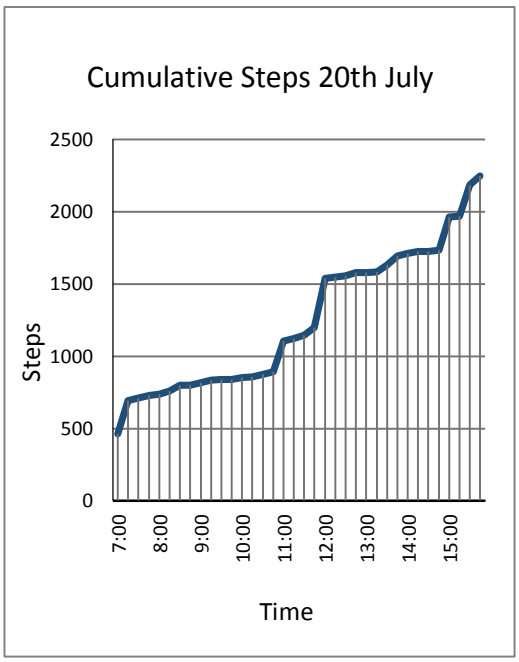

SRT v Mean Heart Rate 20th - 23rd July
Reaction time msec
Heart rate bpm
800
600
400
200
0
120
100
80
60
40
20
0
MONDAY
Start
Break
End
TUESDAY
Start
Break
End
WEDNESDAY
Start
Break
End
THURSDAY
Start
Break
End
CRT
Heart rate

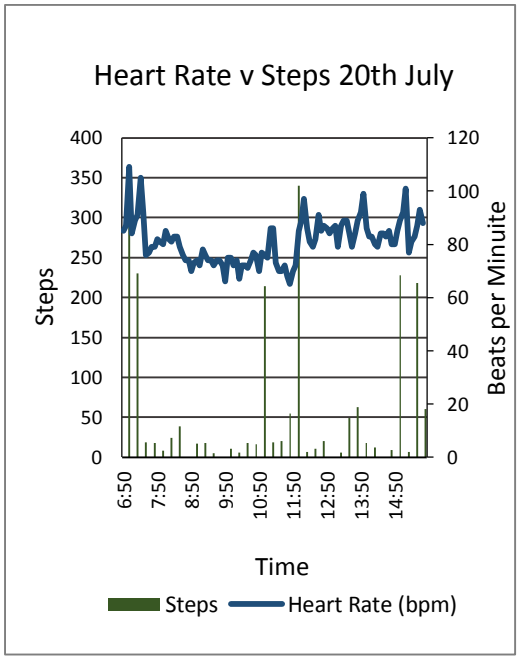

CRT v Mean Heart Rate 20th - 23rd July
Reaction time msec
Heart rate bpm
600
500
400
300
200
100
0
120
100
80
60
40
20
0
MONDAY
Start
Break
End
TUESDAY
Start
Break
End
WEDNESDAY
Start
Break
End
THURSDAY
Start
Break
End
CRT
Heart rate

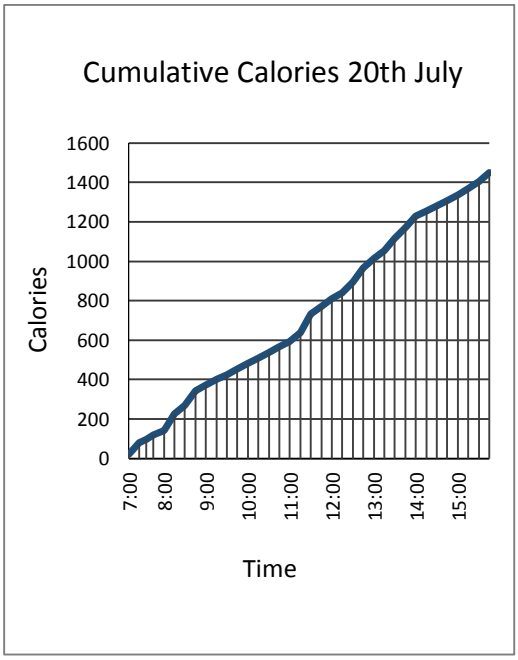

SRT v Calorific Burn 20th - 23rd July
Reaction time msec
Calories
600
500
400
300
200
100
0
2000
1500
1000
500
0
MONDAY
Start
Break
End
TUESDAY
Start
Break
End
WEDNESDAY
Start
Break
End
THURSDAY
Start
Break
End
Series2
Series1

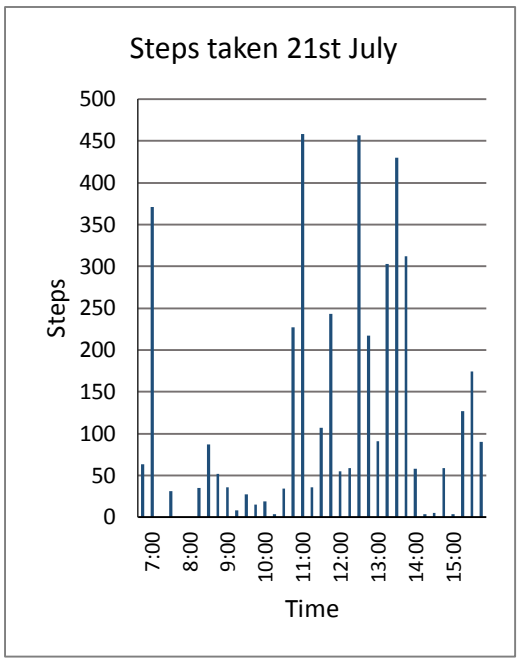

CRT v Calorific Burn 20th - 23rd July
Reaction time msec
Calories
800
700
600
500
400
300
200
100
0
2000
1500
1000
500
0
MONDAY
Start
Break
End
TUESDAY
Start
Break
End
WEDNESDAY
Start
Break
End
THURSDAY
Start
Break
End
Calories
CRT

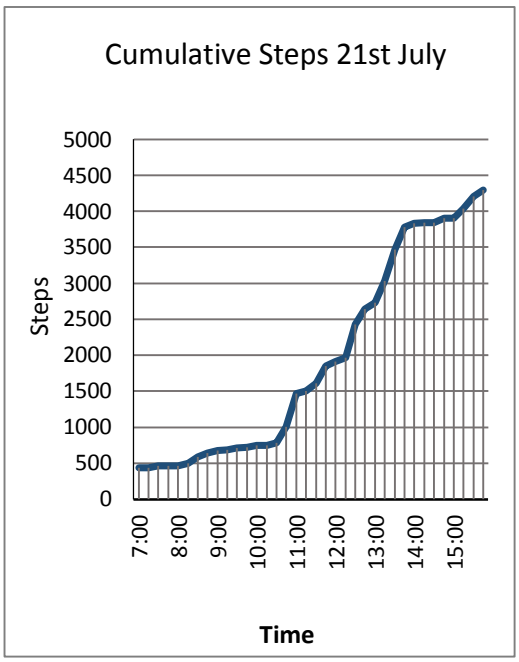

Steps taken 20th July
Steps
400
350
300
250
200
150
100
50
0
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time

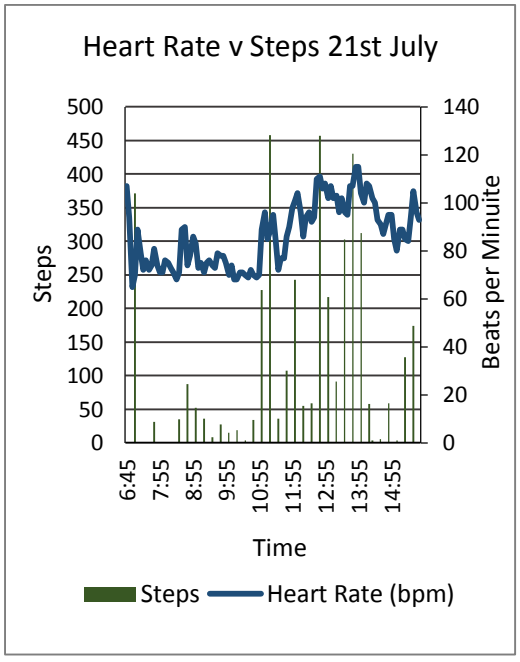

Cumulative Steps 20th July
Steps
2500
2000
1500
1000
500
0
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time

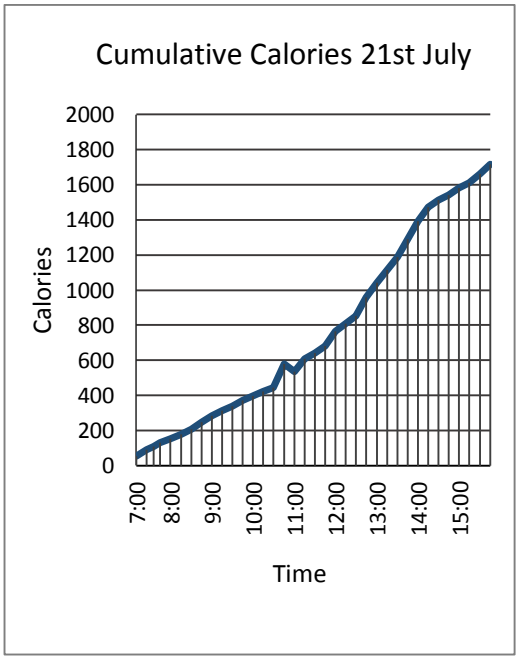

Heart Rate v Steps 20th July
Steps
400
350
300
250
200
150
100
50
0
Beats per Minuite
120
100
80
60
40
20
0
6:50
7:50
8:50
9:50
10:50
11:50
12:50
13:50
14:50
Time
Steps
Heart Rate (bpm)

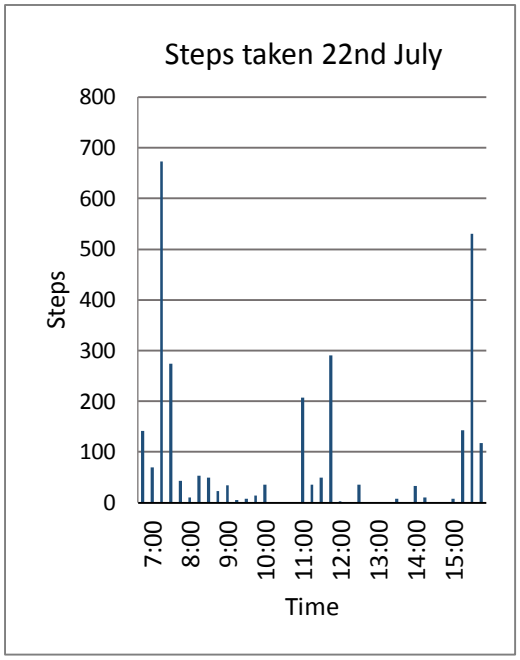

Cumulative Calories 20th July
Calories
1600
1400
1200
1000
800
600
400
200
0
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time

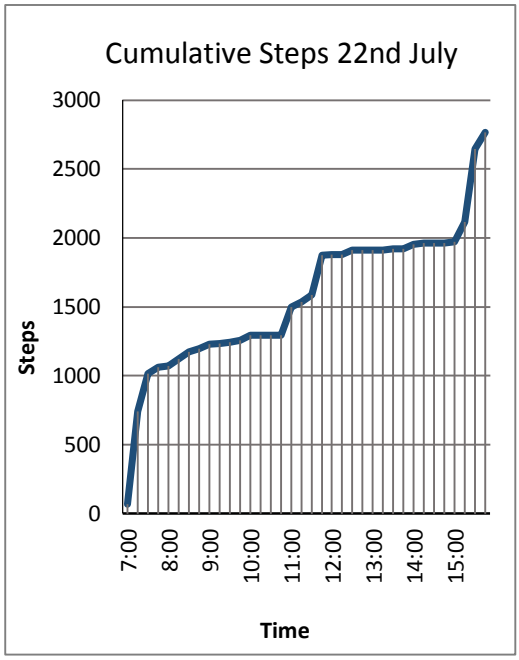

Steps taken 21st July
Steps
500
450
400
350
300
250
200
150
100
50
0
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time

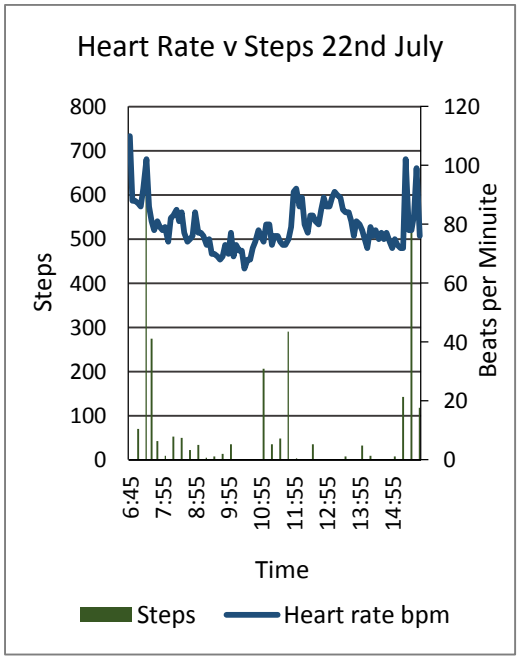

Cumulative Steps 21st July
Steps
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time

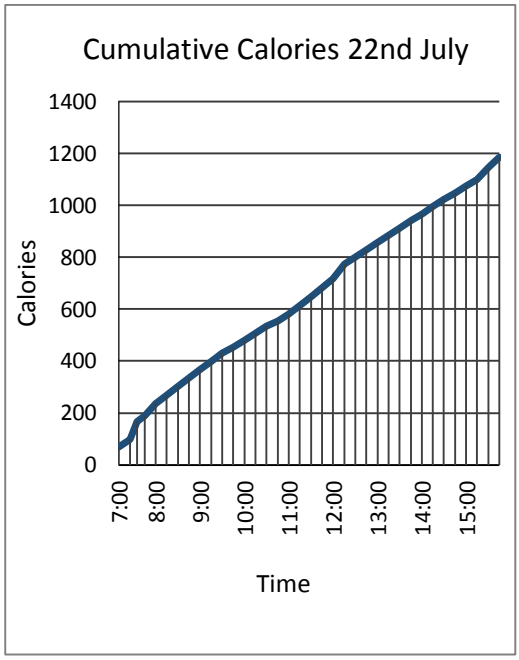

Heart Rate v Steps 21st July
Steps
Beats per Minuite
500
450
400
350
300
250
200
150
100
50
0
140
120
100
80
60
40
20
0
6:45
7:55
8:55
9:55
10:55
11:55
12:55
13:55
14:55
Time
Steps
Heart Rate (bpm)

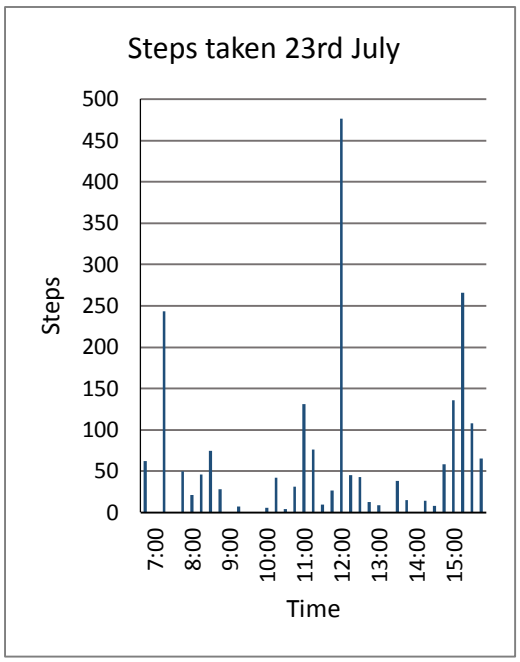

Cumulative Calories 21st July
Calories
2000
1800
1600
1400
1200
1000
800
600
400
200
0
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time

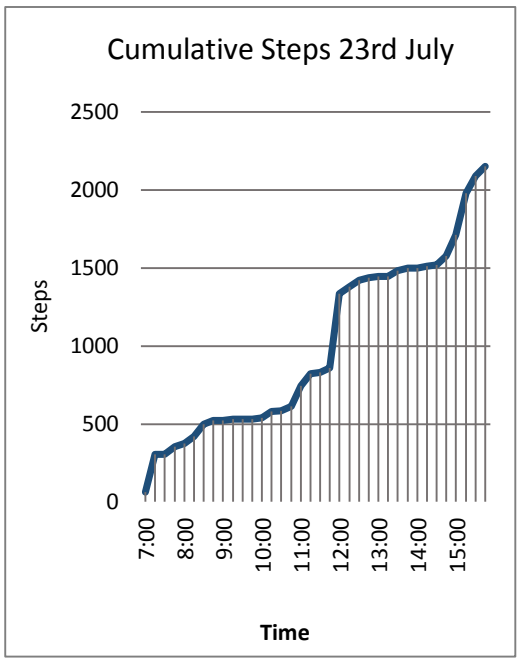

Steps taken 22nd July
800
700
600
500
400
300
200
100
0
Steps
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time

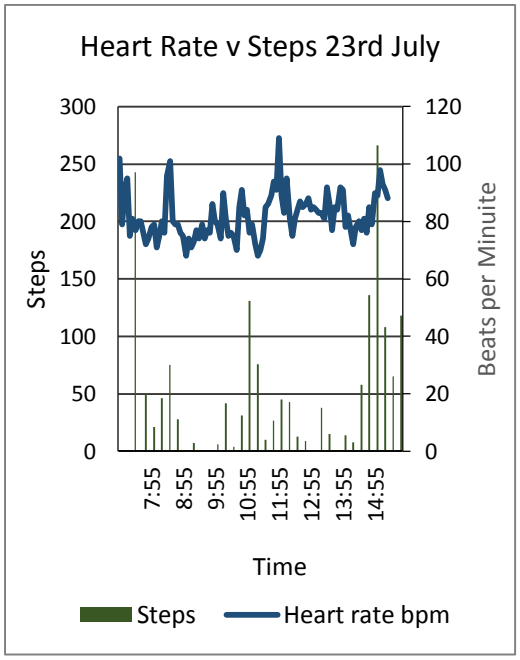

Cumulative Steps 22nd July
3000
2500
2000
1500
1000
500
0
Steps
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time

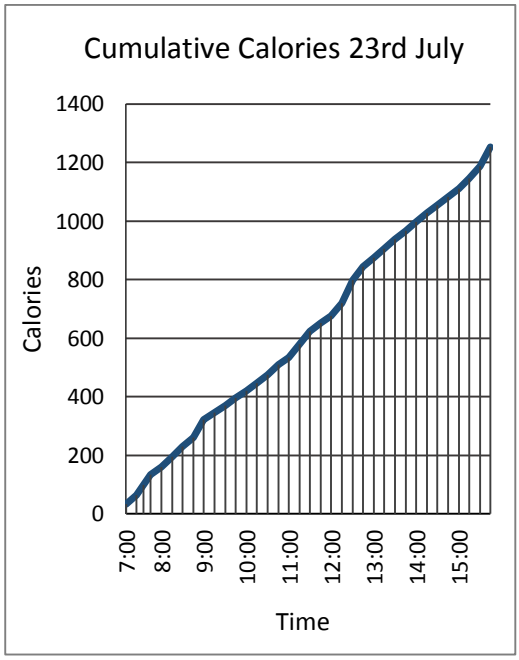

Heart Rate v Steps 22nd July
800
700
600
500
400
300
200
100
0
Steps
120
100
80
60
40
20
0
Beats per Minuite
6:45
7:55
8:55
9:55
10:55
11:55
12:55
13:55
14:55
Time
Steps
Heart rate bpm


Cumulative Calories 22nd July
1400
1200
1000
800
600
400
200
0
Calories
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Time









***Note*:** A full set of results are available from christopher.griffiths@xtra.co.nz