Utilizing GPS to Track Crime Scene Investigators Within a Crime Scene and Monitoring Their Fatigue

Veronica D’Souza

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Brendan Chapman

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**Declaration**

I declare that this thesis does not contain any material submitted previously for the award of any other degree or diploma at any university or other tertiary institution. Furthermore, to the best of my knowledge, it does not contain any material previously published or written by another individual, except where due reference has been made in the text. Finally, I declare that all reported experimentations performed in this research were carried out by myself, except that any contribution by others, with whom I have worked is explicitly acknowledged.

Signed: Veronica D'Souza
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Literature Review

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Abstract
Crime scene investigators (CSI’s) can work long hours in less than ideal conditions which may increase the chances of fatigue being experienced. By understanding the mental acuity required for the job it can be understood to further analyse how physiological signs of stress and fatigue can affect the CSI’s work. In understanding fatigue, examination to monitor, measure and manage is needed. Physiological parameters including heart rate, blood pressure, and body temperature have been analysed to show some association with fatigue and stress (1-3). The examination of physiological parameters in association with fatigue and stress is applied to athletes and whether it can be applied in the crime scene setting. In crime scene investigation, there are specific procedures followed to ensure continuity and integrity from the crime scene to the courtroom. One important procedure is note taking of the crime scene, which includes an entry and exit log of personnel moving in and out of the scene (4). By introducing Global Positioning System (GPS) as a component to track individuals in a crime scene, this could potentially replace crime scene entry and exit logs if proven successful. GPS is a satellite navigation system developed by the US Department of Defence and Global Navigation Satellite System (GLONASS) developed by Russia, where both provide positioning, navigation and timing services (5). The experimental project is to establish if GPS devices can effectively track CSI’s in a crime scene environment, while measuring their physiological parameters to show signs of stress and fatigue.
Introduction
Crime Scene Investigators (CSI’s) play a vital role in society to provide support as the necessary link between the police investigation, the laboratory and the courts (6). In crime scene investigation, there are specific procedures followed to ensure continuity and integrity from the crime scene to the courtroom. One important procedure is note taking of the crime scene, which includes an entry and exit log of personnel moving in and out of the scene (4). It is imperative to complete scene documentation and record practices correctly to follow through to court (4). By introducing Global Positioning System (GPS) as a component to track individuals in a crime scene, this could ultimately replace crime scene entry and exit logs if proven successful. With less time and resources spent on written logs, more time can be spent on other important aspects at the crime scene such as exhibit selection and collection, and decrease the potential for bias logs where they may be deliberately altered from the truth for any reason, potentially time constraints. As part of their role, forensic investigators can work long hours examining crime scenes, anywhere from days to weeks, on high-profile homicide cases. Often there will be a single team working on a major crime scene to completion to ensure continuity of management. This is compounded for crime scenes in rural and remote locations, such as the Western Australian landscape. Along with working long hours, officers can work in conditions where they are outdoors in the hot Australian summer, wearing burdening Personal Protective Equipment (PPE) all day, including masks blocking off fresh air and limited rest. These conditions may lead to officers becoming fatigued, which can be problematic, as this can cause officers to work inefficiently and leave room for errors (7, 8). Poorly performed procedures are amongst common errors that may occur at the crime scene. These cannot be fixed or corrected later when relocated to the laboratory (6), which can
subsequently increase the risk of unjust outcomes (9). By attempting to monitor investigators’ fatigue, it may be possible to further understand how much the workload is affecting them physiologically and on their ability to perform tasks efficiently, with an aim to ultimately reduce errors from occurring. Discussed in this literature review are the following concepts;

- The key decision making and cognitive requirements of a crime scene investigator,
- Workload effects impacting health,
- Understanding fatigue/stress, and how it is monitored, measured and managed,
- Fatigue amongst athletics with comparison to a CSI’s,
- Tracking methods with focus on GPS and GLONASS, and
- The experimental design and project discussed.
Discussion

Crime Scene Investigation

Crime Scene Investigators (CSI’s) are required to examine, assess, interpret, record and collect physical evidence from a crime scene (6). Duties that are undertaken at the crime scene are; crime scene initial assessment, control of the scene where a log is created and continued of all personnel entering and leaving the scene, examination of the scene, interpretation of the evidence, recording of the scene, exhibit collection and case management (6). Competence by the CSI is crucial in a wide array of applications including crime scene photography, exhibit handling, crime scene examination, assessing, controlling and recording of the crime scene, processing the evidence and presenting findings in court(6). Appropriate training and education programs, proficiency tests, and an accreditation program are a regular requirement of CSI. These requirements contribute to public trust results obtained in investigations, and in turn, strengthens the forensic science discipline(6). It is suggested that forensic investigations within police occurs not only at the crime scene but in the laboratory, the briefing room and in the courtroom(6, 10). Julian et al. (9) strongly suggests how critical examining and processing the crime scene can be, as it is where the collection of forensic evidence begins. Furthermore, critical decision making and overall managing of the crime scene is equally important for forensic investigations.

A decrease in efficiency within a crime scene can increase the risk of unjust outcomes(9). A study by Julian et al. (9) identified issues that can arise at a crime scene and why such issues can occur, with focus on decision-making and management of crime scenes. The authors cite that for complex crime scenes, excellent management skills and strong leadership are needed for effective and efficient examination. Processing a crime scene
ultimately focuses on three underlying components; the integrity of the crime scene maintained, consistent chain of evidence supported, and the ensuring the integrity of the scientific and physical evidence gathered (9). It is current practice for CSI’s to be briefed before examination of the crime scene on the information available, however, Jamieson (11) has suggested an opposite approach that little or no briefing should occur so investigators should have little or no prior knowledge of the case other than the collection of the physical evidence (11). This detachment of knowing circumstances may support crime scene examiners to form opinions based on factual evidence, and to be more prepared to exhaust all possibilities and potentially some impossibilities (6).

CSI’s identify evidence at crime scenes to help inform police investigations (4). Two key areas where CSI expertise are actively utilised are trace identification and avoiding contamination. At a crime scene, investigators successfully differentiate any trace evidence and whether it is crime related to than become trace evidence for the case, with the assistance of their experience, knowledge, and interactions with victims and witnesses (4). Wyatt (4) researched closely with CSI to understand their work, focusing more on volume crime where most of the time only one CSI would attend the scene. In this case CSI’s have limited time at each scene and therefore need to make relatively quick decisions on what trace evidence must be collected at the scene, with a range of decisions and interactions involved in the crime scene practices (4). Additionally, all CSI emphasise their judgement and importance in the selection and production of forensic trace evidence, by attempting to make sense of the scene, determine potentially meaningful to non-meaningful traces of evidence, and producing such evidence to take away and contribute to the investigation (4). Wyatt (4) concludes the need for more attention to such complex processes performed by CSI’s at the crime scene. CSI’s have
strict contamination avoidance protocols which they are acutely aware of and document their obedience to such protocol conscious of the consequences of poor contamination. Minor mistakes in the processes of crime scene practices (evidence collection) are problematic for potential contamination, and the expertise of the investigator and the validity of such evidence is undermined with any mention in the courtroom (4).

Jamieson (11) utilizes an approach for crime scene examination where a scientific practice is applied reflecting the hypothetico-deductive method. This approach involves four phases (listed in order); observation/data collection, hypothesis, assessment and then recovery, with the first 3 phases repeated as a cycle continuously at the crime scene. Through observation, there can be numerous hypotheses, where during assessment these hypotheses can be narrowed down and accepted to explain the observed data. This method can reduce the introduction of bias by utilising all evidence types available to deduce the most likely course of events that resulted in the observed conditions. Therefore, this method assists in avoiding pre-conceived hypotheses and inhibits the accumulation of evidence for a particular hypothesis. Crispino (12) also discusses the hypothetico-deductive method applied to forensic science, and its relation to deduction, induction and abduction thinking processes. The deduction is where something should occur, induction indicates something is occurring, and abduction proposes something could be occurring. By applying this thinking to forensic science, we can better understand the scientific processes. By highlighting the deduction and decision-making processes essential for CSI’s, the mental acuity required for the job can be understood to further analyse how physiological signs of stress and fatigue can affect the CSI’s work.
Health

Workload effects
Shift work and long work hours disrupt the day/night and work/sleep patterns of ‘normal’ work hours, where work is done during the day with time left over in the evening time for rest and recreation. Similarly, more than 48 hours per week are classified as extended work hours (13). By working long hours there is less time for sleep and recovering from work, less time for non-work related and family activities, workplace demands and hazards exposure increased. These aspects could lead to several adverse effects including; stress, fatigue and sleep disturbances (14). The same impacts found in Caruso’s additional study (15).

Sleep disturbances and fatigue are associated with poor work situations which can include; stress, shift work and physical work (16). Workers who are fatigued can make mistakes which can damage other people and the environment which can include vehicle crashes on the commute home, with the increased risk of driving while sleepy (15). Caruso (15) found several factors involved in work health and safety and working long hours including; less sleep, increased fatigue, unhealthy behaviours, a potential decrease in general health, reproduction and injuries. Additionally, such workers performed poorer on cognitive and executive function tests. The workers did not recognize the degree of their poor ability in planning and prioritizing tasks. US police officers can work a lot of overtime, causing tired officers unable to work as efficiently dealing with difficult people and situations. As a lot of CSI’s are police, poor judgment in their job could pose a risk to society. The risk of working long hours is influenced by the individual worker and their job demands and can be quite complex (15).
There are several aspects Harrington (13) considers to be affected by working extended hours including; circadian rhythms disruptions, sleeping and eating phase changes, lack of sleep, disruption of family and social life, reproductive effects, mental health including stress, anxiety and depression, fatigue and performance. Workplace efficiency can be caused by a combination of fatigue, sleep deficit and disruption of the circadian rhythm. Workers have often shown to complain of symptoms of fatigue, although these complaints are quite difficult to measure. Accidents have been looked at to have a connection; however, this is not supported well throughout the literature. Personality and age are factors to consider, as 20% of workers cannot tolerate shift work, only 10% enjoy it, and further research shows older workers can tolerate such work less than younger workers due to the inability to achieve what is needed as easily (13).

Time pressure from long work hours and increased levels of fatigue is attributed to overtime workers with a high workload. Resulting from these outcomes, workers will often rush through procedures or skip steps resulting in aseptic practices to performed defectively (17). However, measurements of fatigue relating to overtime are almost non-existent, with no direct relation of causality. Occurrence would occur when combined with other factors such as occupational, personal or organizational (17). There were no trends found with consistent results for fatigue in workers of extended work shifts. Although, extended work hours show to have some relation with stress, sleep disturbances, workplace efficiency and performance (13-17)

**Fatigue**  
Fatigue is often experienced in relation to situational factors or lifestyle, such as stress or lack of sleep, generally with an identifiable cause that can be resolved (18). When fatigue is experienced in each situation, the response is less than the predicted contractile
response than when fatigue is not experienced (19). Within the body, the peripheral and central mechanisms mediate the physical appearance of fatigue. Where peripheral fatigue is caused by a lack of response after central stimulation in the neuromuscular system, and central fatigue is an inability to transmit motor impulses to perform activities voluntary mediated through the central nervous system (18, 20).

Muscle fatigue can occur when the central nervous system is not able or willing to request the full capability of the muscles output required/expected to perform the task. Therefore, the muscles are incapable of responding in the same capacity than before the exercise which induced fatigue (19). It can be difficult to observe the presence and quantity of fatigue (19), and additionally, the monitoring and measuring in athletes (21). By following the activity performed you can observe when fatigue has occurred as the response is less than the reaction before the activity. When it is difficult to detect fatigue, looking at the $\text{Ca}^{2+}$ concentration and sensitivity levels in the blood can help identify the presence where both decreased. With this reduced $\text{Ca}^{2+}$ concentration, less $\text{Ca}^{2+}$ becomes bound to troponin, by either faster uptake of $\text{Ca}^{2+}$ or less $\text{Ca}^{2+}$ release leading to less developed force (19).

When any person does not meet their sleep requirements at night, they will exhibit some level of fatigue related impairment. Fatigued workers can lead to poor judgement and slow reaction time, where there are detectable symptoms, such as degraded mental performance (22). Fatigue can be influenced by numerous factors, with more specificity towards athletes, the type of stimulus where it is voluntary, type of contraption, the type of muscle, frequency, and intensity of the exercise, duration and environmental conditions (21). A single variable is unlikely to have a causal link to fatigue, such as
hydration, although there is no indication a lack of connection between the two. Evaluated in the psychological performance of soccer players, with a more probable scenario where dehydration acts a physiological stimulus which initiates conscious feelings of fatigue, example thirst (23). A reduction in cerebral blood flow and extracranial perfusion is related to fatigue which developed with hydration from prolonged exercise (24).

**Physiological Parameters**
In Meng *et al.* (25) physiological parameters including heart rate, blood pressure and respiration rate have been measured to determine any relationship to fatigue in labour employees. Results showed no difference in heart rate measured before and after fatigue. Alternatively, blood pressure and respiration rate showed a significant difference, with blood pressure increased after fatigue (1). Heart rate and blood pressure was measured in adolescents, both healthy and those who suffered with Chronic Fatigue Syndrome (CFS). Overall, blood pressure was equal between the two groups whereas heart rate was significantly higher among CFS individuals. Alternatively, while they slept, the heart rate and blood pressure were significantly higher for individuals with CFS (2). During exercise increased blood flow is needed for the contracting muscles and skin, which was expanded by Kenney *et al.* (3) who evaluated blood pressure and body temperature in healthy young subjects. Blood pressure did not critically fall and there was no increase in body temperature to compensate. They noted, to have an impact on blood pressure regulation additional stressors such as dehydration are needed to contribute (3).

**Sports**
The examination of physiological parameters in association with fatigue and stress is applied to athletes and whether it can be applied in the crime scene setting. Inevitably,
athletes will experience fatigue, with feelings of general tiredness and diminution in their physical performance. Experiences of fatigue can either be short-term with recovery time within hours or days which is ‘normal,’ or ‘abnormal’ fatigue that is long-term with prolonged recovery anywhere from a week or two, to potentially months or years from overtraining. When fatigued, performance and training are compromised requiring monitoring and management to optimize recovery as a vital part of athletic training (26). Additionally, athletes are consistently monitored for fatigue, where they have established each players’ optimal performance for time on the field and rest time. Fatigue has been monitored, amongst other measures, by measuring heart rate (27), body temperature relating to hydration (28), and blood pressure. The outcome of monitoring fatigue results in an improvement in performance to enable the balance of training and recovery time (27). Effectively optimizing recovery consists of sufficient nutrition, rest, and hydration (26) and may offer suggestions to the management of CSI’s. By analysing how athletes are monitored in their sport environment, we can further understand and compare this to a crime scene environment.

Monitoring Fatigue and Stress
Specifically, for athletes, although some aspects can apply to the wider community, monitoring tools for fatigue can include self-report questionnaires, training load assessment, performance tests and blood/saliva screening. A practical and reliable method used is psychological questionnaires as a subjective fatigue assessment with self-reports of athletes has shown effective in the short-term although insufficient support for long-term use (26). Relevant questionnaires can include; profile of mood states, and daily analysis of life demands for athletes’ questionnaire. Subjective training load assessments are critical and complex with three main approaches; observational with real-time
measurements, psychological monitoring heart rate, oxygen consumption and blood lactate concentration during training sessions, and a subjective estimate of their training load during or after non-steady-state exercise. This method is simple but effective. Performance tests are useful to confirm and establish recovery, more accurately, from an intensified training period. Blood/saliva screening can be helpful in monitoring health status to detect underperformance syndrome in athletes (26).

Measuring Fatigue
Cognitive testing and the quantification scale of fatigue impairment are approaches used by Dawson and Reid to assess fatigue related performance (29). Some standard tests for cognitive functions include memory, attention, reaction time and judgment tests, where they assess the cognitive domains of psychomotor processing, learning and working memory, and visual attention. Using the quantification scale, Hursh et al. (30) developed a model to use as a predictor of mental effectiveness/impairment based on sleep each night. Predictions of fatigue impairment are a basis for comparing results of the cognitive tests at the same point in time against the sleep model of the individual’s mental effectiveness level (22). Results from their experimentation showed the amount of sleep before the test affected alertness and efficiency levels where less sleep reduced these levels. Additionally, the time before the test when they were awake affects sharpness levels where the longer one is awake, the more the alertness and effectiveness levels will drop. These two aspects combined (cognitive tests and the sleep model) provide an adequate measure of mental effectiveness (22).

Managing Fatigue
Rest, sleep, nutrition and hydration are highly necessary for general fatigue management. Adequate rest is needed to enhance recovery where athletes should have each week at
least one passive rest day. Furthermore, rest reduces stress perception and lessens boredom. Sufficient sleep is also key as the quality of training, general well-being, mood state, and motivation negatively impacted by the consistent loss of sleep. Cognitive functions also can be impaired involving the ability to concentrate. As an athlete in general, proper nutrition is essential for superior performance and consistent training to avoid excessive fatigue, injury or illness. Intake of carbohydrates and proteins are suitable for muscle gain, maintain immune function and glycogen recovery. Hydration is particularly important in hot and humid environments, as sweat losses are high, water and salts need to be replaced following exercise as part of the recovery process. For short-term management, potentially there is physical therapy, cryotherapy, hydrotherapy and active recovery, although, there is no evidence to support the benefits, rather suggestions (26).

Fatigue impairment is not just a safety concern in the workplace by in personal lives including the commute out and about and to and from work. According to Powell and Copping (22) sleep is the only natural cure for fatigue, and further studies show workers are not getting adequate sleep which affects their work performance. Each person requires their ideal sleep which varies between a person. Moreover, the quality of sleep is the same for most where there are minimal wake-up periods (22). As mentioned above, there are potential health risks to workers who work long hours with limited rest, where they may experience fatigue which decreases efficiency in their work ethic. Utilising activity trackers in combination with physiological parameters may potentially assist in the monitoring of CSI’s.
**Tracking**
As technology advances, there are many developments in devices with the ability to track a person, object, or navigate you to where you need to go. Devices that contain Global Positioning System (GPS) include built-in systems for your car, often built into the dashboard, or mobile units that can also be used in vehicles or for laptops. Smartphones which most people have on their person most of the time have GPS capabilities, digital cameras with listed coordinates, and small devices used to track suspect vehicles and monitor children (31). Geolocation is the estimation of the pinpoint position on earth of an object or individual which relies on wireless networks (32). Terrain variations have a higher impact affecting the accuracy of such technologies with GPS having a higher accuracy then geolocation technology software, such as using an IP address to determine location.

**GPS**
Global Positioning System (GPS) was originally developed as a tool for the military by the United States Department of Defence in 1978. In the 1980s it opened for civilian use with selective availability. However, became full availability for civilian use in 2000, substantially increasing accuracy (31). GPS transmits signals from 20,200 km above earth consisting of a collection of at least 24 satellites in six orbital planes equally spaced apart, and continuously orbiting the earth (5, 31, 32). The GPS constellation has been mentioned widely representing a slight increase of satellites over the years, with 28 satellites in 2001 (33), 31 in 2013 (34), 32 satellites by 2015 (35), and now in 2017 the Air force has 31 operational satellites over the past few years (5). These additional satellites above the core constellation of 24 are used when needed to maintain coverage if satellites are decommissioned or serviced (5). Ground stations support this satellite system by
monitoring the data sent by the satellites and then transmit back to the satellites with the corrective data. Two different radio signals are sent out as the satellite orbits the earth; L1 and L2. L2 is for government and military use, and L1 for civilian purposes in determining the location (31, 32). Three pieces of information are contained in these signals; almanac data, ephemeris data, and pseudorandom code. Almanac data includes the time and date of the transmission signal and the operational status at the transmission time. The precise location of the satellite and every other satellite in the system is the ephemeris data. Lastly, the pseudorandom code is the identification code of the satellite transmitting the data signal (31). All this data is converted into a signal is processed through GPS receivers providing a three-dimensional position of latitude, longitude, and altitude concerning the satellites with coordinates of the location (34). This can be further understood by dividing the process into three segments shown in Figure 1.

**Figure 1.** The three segments of navigational satellite systems; the space segment, the control segment and the user segment.
Accuracy
The accuracy and reliability of navigation systems are highly dependent on the amount of tracked satellites and the satellite geometry, which can be degraded in low satellite visibility areas (36). To properly operate, the GPS receivers need signals from at least four satellites of the 24 and clear views of the sky (32). As the system is based on using the clear line of sight, there can be some errors and inconsistencies when signals are required to pass through buildings, cars, and clouds which impairs the accuracy of the signal. A GPS receiver can take several minutes to fix the location without any prior knowledge of the GPS constellation’s state, which can be a considerable delay (32). Data accuracy can also be affected by limitations and errors of the satellites themselves, where data transmissions can be incorrect that causes the reported position to have minor inaccuracies. As the GPS receiver is using the location of these satellites to determine the position, the accuracy is dependent upon these receivers (31).

Strawn (31) identifies different levels representing the amount of fixed satellites that may impact accuracy. Where three satellites are tracked, it is a two-dimensional (2D) fix on orbiting satellites where the GPS receiver calculates the latitude and longitude of the receiver and the users’ position. Having four or more satellite signals is a three-dimensional (3D) fix that has the same capabilities of 2D with added altitude calculations. To correct for accuracy issues, a program was implemented to enhance GPS technology for aircraft to safely navigate using GPS and maintaining safe distances from other aircrafts. This system is the Wide Area Augmentation System (WAAS) that is available for all sectors to gain more accuracy capabilities. It works by sending corrective data through a serious of satellites and ground stations to account for errors consistent with inaccurate position reports, atmospheric delays and time drift to create a more accurate data stream.
to the aircraft. The precision of the data log can have a significant impact by knowing whether the data is in 2D, 3D or WAAS utilised by the receiver, and the location of the satellites used (31). Each satellite’s equipped with an atomic clock synchronized and highly accurate (34). Various sources of error can alter the signal between the satellite and receiver sourced from the receiver and satellite’s clock synchronization biases.

Modern day GPS devices achieve less than 15-meter accuracy with relatively new antennas, compared to an accuracy of 5 meters with a 3D fix. Many current mobile phones use Assisted Global Positioning System (AGPS) which improves the accuracy by relaying information to the phone and the computation of the GPS performed within the network. However, this can be pretentious as the phone needs to be in the service providers network area as it may take longer to identify the signal (31). Smartphones have low cost receivers for GPS which can exhibit significant errors in the location determination compared to higher quality devices with increased costs for increased accuracy (34).

**Assisted GPS**

Assisted GPS (AGPS) offers much greater accuracy, availability and coverage compared to stand alone GPS and network based geolocation, all at a reasonable cost. The concept of AGPS consists of an AGPS server with reference to a GPS receiver, and a wireless network infrastructure including a mobile switching centre and base stations, and the partial GPS receiver with a wireless handset. For users, indoors it is accurate within 50 meters and outdoors within 15 meters, and with a more sensitive order of magnitude than standalone GPS. Used for range measurements, a unique pseudorandom noise sequence is transmitted by each GPS satellite and communicates this prediction to the mobile. The phase of this pseudorandom noise sequence can be predicted by the AGPS server, and a
connection is maintained over the wireless link with the handset receiver. Ultimately, this can reduce the search space where the AGPS handset receiver can achieve the task in a fraction of the time needed for GPS (32).

**GLONASS**
Global Navigation Satellite System (GLONASS) is a Russian navigation satellite system operated by Ministry of Defence of the Russian Federation, which enables users anywhere on the Earth’s surface to obtain a 3D position, velocity vectors, and timing information. In 1993, GLONASS was declared operational, and consisted of 24 satellites in 1996, although, in 1999 only 15 satellites were vigorous (37). GLONASS consisted of 18 satellites in the constellation in 2007, with only 13 operating (38), 22 satellites in 2010 (39), and increased to 24 in the following years (35, 36). 20 satellites in the constellation were reported in 2007 by Alcay et al. (40), with a steady decrease from 1999 (40). Alternatively, from 2001 to 2011 Alcay and Yigit (36) suggest there has been a slight progression in the constellation of 24 satellites by 2017 (36). As the constellation increases, the GLONASS system becomes more independent with increased benefits to geodetic applications, including contributions in Precise Point Positioning (PPP) and network based positioning mode (36). In 2017, GLONASS has 24 operational satellites and 1 in flight test phase (41).

Comparable to GPS, GLONASS was developed originally for military timing and navigation needs and purposes, and in 1995 was put forth for military and civil users. The GLONASS system consists of three components; space segment, the control segment and user segment. The space segment consists of 8 evenly distributed satellites in each of three orbit planes, with a total 24 satellite constellation. From 99% of the Earth’s surface, at least five satellites can be seen simultaneously. The control segment component
comprises of the System Control Centre (SCC) in the Moscow region, and located widely over Russia are numerous Command Tracking Stations (CTS). The SCC acquires information from the CTS’s where they monitor and track the GLONASS satellites and pass on the satellite messages and ranging data. SCC processes this information to determine the status information for each satellite, navigation signals, and clock corrections. Lastly, an unlimited amount of GLONASS receivers makes up the user segment, with the signal components processed the same to GPS receivers. Within the ground base control complex, the GLONASS system time is constructed upon the central synchronizer, where it is compared twice a day along with the time scales of the satellites, with corrections uploaded to the satellites (37). These three segments can also be seen in Figure 1.

It has been noted to accommodate GLONASS, most of the data analysis software used must be updated. The broadcast GLONASS orbits will enable to the real time use of this system. IGEX98 was the first campaign initiated in 1998 for the observations of GLONASS satellites with international involvement providing a geographical distribution. This campaign consisted of 22 different countries representing 55 organisations. At specific sites receivers were installed for the tracking network to improve geographic coverage, with most stations to have an additional observing GPS receiver for dual purposes. With practical geographical distribution, the objectives will be met consisting of; combines the performance of GPS/GLONASS, positioning evaluation, precise orbit determination, and evaluation of software and receivers (42). The IGEX-98 experiment was also discussed by Habrich (37) with numerous objectives mentioned, and in early 1999, the network comprised of 52 stations with 13 single frequency and 39 dual frequency receivers.
GPS and GLONASS

GLONASS often combines with GPS due to the inadequate number of satellites in the constellation (40), and to utilise navigation, geodetic and timing applications (42). Combining GPS and GLONASS almost doubles the available satellites, while improving reliability and increasing the effectiveness of applications. The combination enhances the reliability of the resulting products and shorter observation sessions with the contribution of additional satellites. To combine these two systems, a unique time scale is required for all observations, and for the satellite and receiver positions, a unique reference frame is needed (37). GLONASS satellites transmit at a different frequency compared to the GPS constellation (43). By 2007, GPS had a satellite constellation of 29 that are active, and an active 13 for GLONASS satellites. Adding GLONASS to GPS was analysed through the EUREF Permanent Network (EPN) by using fixed orbits. The repeat abilities of the station coordinates are not significantly changed, and similarly with the coordinate differences. By combining both GPS and GLONASS there is minimal effort in the setup, and the positions obtained in the EPN are not tainted (38).

Multiple studies were evaluating the combination of GPS and GLONASS and if any improvements (36, 39, 40, 43, 44). The satellite geometry development by combining GPS and GLONASS improved the convergence time position and an improvement made on the position accuracy (44). GLONASS only, has lower precision than GPS and GLONASS combined. GPS and GLONASS can be used together, however, there has been found no significant difference between the GPS/GLONASS and GPS only results including accuracy (40). This potentially could be due to the lack of GLONASS constellation by 2012 and the satellite orbits less determined than the orbits of GPS (40). A combined GPS/GLONASS model evaluated against GPS only, is built on the ionosphere free observation
combinations. Position accuracy can be analysed by comparing the reference coordinates to the positioning results to give the positioning errors. There was no significant improvement in the position accuracy of GPS by adding GLONASS, particularly if there is already a sufficient amount of good geometry GPS satellites. Although by adding GLONASS satellites to GPS, the position convergence is significantly reduced. The GPS/GLONASS PPP has a slightly better accuracy than the processing solutions of GPS. When more satellites are available to GLONASS, the convergence time is expected to reduce further. The residual analysis showed, for GLONASS satellites there is a lack of code bias corrections, and less accurate clock and orbit correction data, representing the GLONASS residuals are double than GPS (39). Through understanding how navigational satellite systems work, we can further improve the understanding of the usefulness activity trackers can provide CSI’s at the crime scene.

Time and Frequency Transfer (TFT) comprises of observations of the code and carrier phase data from Global Navigation Satellite System (GNSS) which determines the synchronization errors connected to GNSS receivers of two remote clocks. Common View (CV) and PPP are two approaches used for TFT; where CV is the single differences between code and carrier phases, and PPP, the zero-difference observed of a single station is analysed to obtain the difference between the results. As an advantage, the CV approach uses the single differences to mitigate the errors on satellite orbits and clock. Although, depending on the amount of satellites in common visibility depends on the amount of observations. Regarding the frequency transfer, the variations were not reduced in the differences between the amongst the CV and the International GNSS Service (IGS) solutions with GLONASS contribution. When analysing short data batches, the CV and PP solution results are improved combing GPS and GLONASS constellations, as
there is not enough to calibrate the solution with GPS code data. Additionally, the short-term stability improved with additional GLONASS data. Therefore for TFT applications, it is worthwhile to utilize both GPS and GLONASS code and carrier phase data (43). High rate GPS used as a tool to unambiguously detect coseismic displacements and improved by filtering sidereal; concerning the constellations. Low frequency noise can contribute to tides, atmosphere refractions, and satellite orbits, and multipath to high rate GPS. Multipath dominates the low frequency noise caused by satellite signal reflections before they reach the antenna of the receiver; therefore, the station surroundings and satellite receiver geometry is administered. By integrating GLONASS, the noise can be significantly reduced of high rate GPS (43).

Elevation cut off angles refer to the different sky view conditions where 10° is open with no obstructions, 20° semi-open, 30° limited, and 40° very limited (36). For all sky view conditions, related results were comparing GPS and GPS/GLONASS system over 24-hour observation. Alternatively, for shorter observation periods of 4 hours, there was an improvement in accuracy for GPS/GLONASS solutions, particularly for very limited sky views at 40° (36).

Other Djuknic and Richton (32) suggest hybrid solutions for potential cost effectiveness and greater location accuracy. A multi GNSS model was evaluated by Li et al. (35) which is a four-system model including; GPS, GLONASS, BeiDou and Galileo. The aim is to achieve the best possible accuracy and consistency from each of the four systems’ observations to form a procedure with common parameter estimation. All together the four system GNSS consists of approximately 74 satellites and approximately 120 network tracking stations with three networks provided around the world; Multi GNSS Experiment, IGS, and BeiDou
Experimental Tracking Network. With the developing GNSS and each of the four systems themselves, expected more than 100 satellites will be available under this model in years to come. Around the globe multi GNSS monitoring stations have been positioned, with all supporting tracking of GPS followed by a majority of GLONASS, then Galileo and BeiDou. The accuracy and time latency determines the systems services capacity due to the performance of the precise positioning service with essential functions of the precise orbit determination and precise clock estimation. The GPS orbit accuracy is slightly better than that of the GLONASS due to the difficulty in ambiguity resolution of GLONASS. Furthermore, Galileo is worse than both as it only has a limited number of satellites and ground tracking stations as it is a newly developed system. GPS has the best clocks reportedly with higher clock accuracy than GLONASS. The results show accuracy can be achieved real-time at cm level of both satellite clocks and orbits. Additionally, when used together, the errors of clocks and orbits are compensated by each other. The addition of this four-system model reduces convergence time by 70% and improved positioning accuracy by approximately 25% compared with GPS alone. Precise position estimates highly achieved with multi GNSS at high elevation cut-offs up to and including 40° elevation cut off. To conclude, the multi GNSS substantially optimized at a site the spatial observation geometry, increased the amount of observed satellites, improved accuracy, reliability, convergence, and continuity of positioning, with increasing the capabilities to operate in constrained environments (35).

BeiDou and Galileo are two recently developed navigational satellite systems. The Galileo system is European with a constellation of 30 satellites in three orbital planes. China’s BeiDou covers the Asia-Pacific region since 2012 with the constellation consisting of 4 Medium Earth Orbit, 5 Inclined Geo-Synchronous Orbit, and 5 Geostationary Earth Orbit
satellites for positioning, navigation, and timing (PNT) services. Both are still developing and yet to complete their constellation, with GPS and GLONASS ongoing modernization (35).

Today, you can get GPS on your mobile phone which can track where it is via a dot on the map and assist in directions for your desired location. However, a dot on the map is insufficient to obtain the actual precise situation of the person according to Liao et al. (45) as this cannot show if an accident has occurred of the person tracking. They evaluated the use of GPS with an internet protocol (IP) camera to show the exact situation of a person more accurately than conventional GPS that has an accuracy of approximately less than a several meters. This process involves the individual carrying a mobile phone to transmit their GPS coordinates and IP cameras transmit the real-time image over wireless computer networks, which deployed in urban areas, in streets and communities. This method improves in the tracking of many people moving, and while moving, the collision of individuals by using moving object detection involving temporal differencing and background subtraction. The approach is enabled once the tracked person GPS coordinates enter the field of view of a camera, which begins the first phase of locating, then tracking and monitoring collision phases follow. Tracking efficiency is increased by limiting the moving object detection GPS coordinates to a small area and determines the next possible camera from the GPS coordinates to locate any target quickly, unable to be carried out by conventional GPS. There was a success with this approach with high accuracy and achievable in a practical environment (45). The limitation with this method is that it can only be applied where there are cameras in sight, whereas, if there are no cameras to utilise, this method is unusable.
Hedgecock et al. (34) introduce RegTrack (relative GPS tracking) attempting to provide centimetre scale accuracy for GPS, deriving the location information from multiple receivers. These GPS receivers shared satellite measurements between one another as a network which achieved high accuracy through several actions. The error sources were better modelled and corrected unique to the two-receiver localization case. A new observation model was created enabling the use of observations of an independent satellite from two receivers, and integrating this model producing 3D location vectors amongst any amount of remote receivers and a local node from a tracking algorithm (34).

RFID
A Radio-Frequency Identification (RFID) tag consists of a microchip that stores the serial number to identify the tag with an antenna attached. The microchip transmits the serial number enabled by the antenna to a reader, where it converts the radio waves into digital information viewed on a computer (46). The tag also consists of a form of encapsulation which maintains the integrity and protects the inside components (47). There are two types of tags available, passive tags are readable when sent from to reader to view the information, and active tags can communicate between the tag and the reader as they carry their own power supply with energy stored in an integrated battery (46, 47). Passive RFID is more standard as they do not require maintenance or batteries which can increase the cost and can be quite small. Additionally, tags can be either ‘read only’ or ‘read/writable’ as new data is transmitted (46, 47). RFID can have two design approaches for the power transfer between the tag and the reader, both transmitting and receiving data. Near field is transferred through magnetic induction and far field through electromagnetic wave capture (47). There have been several situations where RFID has been applied and effectively utilised in the forensic science discipline.
Baber *et al.* (48) evaluates the use of RFID tags on evidence bags to support contemporaneous evidence logging. With the introduction of digital versions to replace physical objects, might solve some problems though may also introduce new ones. They developed a prototype that digitised evidence labels and logs and compared to the current practice of writing out logs and evidence labels. The results showed contemporaneous notes can be collected, with more words utilised in the descriptions and took less time to complete compared to the paper labels and logs. Although, using this prototype is not sufficient in explaining the difference in overall performance (48).

RFID chips have assisted in disaster victim identification (DVI) required to identify and tag dead bodies for them to process during storage and after such processes, essential for the consolidation of records, bodies, and findings (49). Currently, conventional tagging methods are not always reliable; where pen writing on the plastic body bag would not always last on the surface, tags inside the body bags become inaccessible once bodies are buried or go into cold storage. RFID microchips would be injected to lodge firmly inside cranial structures, and a chip reader used to identify the bodies allocated number. This procedure is reliable and the RFID chips readable in cold storage containers, and cuts down time searching and retrieving the tagged bodies in the cold environment of the container (49).

Nuzzolese *et al.* (46) introduce a denture marking system where a RFID tag inserted into dentures can later assist in forensic human identification. The many benefits associated with this method; the dentist does not require any specialised training to add the tag, it will not weaken the denture due to the small size of the tag, the cost is very low for each tag, and there is no need for removal of the tag when a reline or rebase is needed. This
tag will store the patients’ medical records, and information on the materials used to provide traceability. This method, however, limits the use to patients who have dentures, which on a bigger scale may not improve identification marginally. Although as there is minimal effort for this process, there is more to gain than lose.

Overworked CSI’s can experience fatigue which potentially decreases efficiency and increases the chance of unjust outcomes. There are many studies on fatigue in the workplace however very little specifically on CSI’s or forensic related. By measuring physiological parameters in concurrence with tracking individuals, we can provide more research in this area.

**Experimental Design**
Available GPS devices will be used to evaluate the accuracy of GPS and the ability to track a person both indoors and outdoors. A smartphone and two GPS watches will be used to track an individual and monitor the path it takes which plotted on a map. The GPS data will then be examined against where the person went compared to the path on the map. For the phone, an app will be used, with the phone held in hand or pocket, and the GPS watch will turn on an activity to track which can be viewed on the phone or uploaded to the computer.

To test the accuracy outdoors with each device a measured 20m square will be laid out, and each device is worn while walking on this marked path. The calculated path will be compared with the actual measurements from the GPS devices. Duplicates will be performed for each device, and different paces walked. This calculated path will be marked out in an open space (with no trees close) in the Whitby Falls location.
The next part will include GPS watches being worn and tracking a person in a mock scene environment at Whitby Falls Farm. Two students will be examining a 2-day mock crime scene where they will wear the GPS watch to monitor their movements. Later uploaded to view their movements on the map and compared with their entry and exit logs. I will also be monitoring the student’s fatigue where measurements will be taken of their blood pressure and heart rate. Their heart rate is consistently monitored throughout from the watch, and sleep monitored through the week of the watch worn. Blood pressure will be taken at the start and end of each day as well as regular intervals (hourly). Each participant will wear the watch over a week to monitor baseline measurements of heart rate and blood pressure measurements taken on several separate occasions. Participants will fill out a questionnaire at the end of each day for that day with questions on how they are feeling, water intake and stages of PPE worn. All this data will later be gathered and analysed. Analysis of the data to monitor fatigue together (heart rate, blood pressure and self-report questionnaire) will give some indication if such measurements can accurately monitor fatigue of the crime scene officer.

**Experimental Project**

**Aims**

From the research presented in this literature review, multiple devices are used for GPS purposes, and multiple global navigation satellite systems are available, which are strengthened when combined. Therefore, mobile phones with high availability and a GPS watch with both GPS and GLONASS are utilised with the aim to establish a cost-effective way to monitor and track crime scene investigators within a crime scene. There are studies presented in this literature review connecting fatigue to long work hours, although none specifically for crime scene investigators. Therefore, the aim of this project
is to utilise activity trackers to establish a cost-effective way of monitoring and tracking crime scene investigators within a crime scene. Additionally, accessing the ability to monitor and measure physiological signs to determine any correlation between heart rate, blood pressure, and self-report questionnaires.

**Objectives**
1. Evaluate the accuracy of each GPS device both indoors and outdoors. Outdoors, a calculated path will be set out and then compared with the measurements given from the GPS.
2. Evaluate the use of GPS devices/watches in a crime scene environment where it will track the movements of the forensic investigator while evaluating a mock crime scene.
3. Attempting to monitor fatigue of crime scene investigators in a mock crime scene measuring heart rate and blood pressure and self-report questionnaire.

**Hypotheses**
1. Mobile phone GPS will be less accurate than a GPS watch.
2. GPS tracking will be more accurate outdoors than indoors.
3. GPS watches can track personnel within a crime scene environment.
4. Combining heart rate and blood pressure measurements, and self-report questionnaire will show some indication of fatigue of a crime scene investigator in a crime scene environment.
Conclusion
In crime scene investigation, officers have a significant role to play in the justice system where integrity and continuity must be fulfilled to minimise errors and the impact they have on society. Where scene recording and documentation is an essential practice required in the field(6, 9). Several studies have evaluated the effects of extended work hours relating to fatigue, stress, sleep disturbances and workplace efficiency and performance(13-15, 17), amongst other factors. Fatigue can cause individuals to make mistakes, have more judgment and slow reaction time(15, 22), which is less than ideal if attributed by forensic investigators examining a crime scene. Not done before, performance management of athletes could be applied to a crime scene scenario where fatigue is monitored in forensic officers to ensure they are performing efficiently. In doing so, this can ensure officers are taking enough breaks to rehydrate to ensure they perform at their best. When officers are fatigued, this is where problems can arise, as their work is so critical, errors that occur can have huge consequences including false imprisonment from evidence mishandling(9).

By introducing global navigation systems, such as GPS as a component to track individuals in a crime scene, this could ultimately replace crime scene entry and exit logs. Utilising GPS can lead to more focus on other things within the crime scene as the focus is taken off required note taking. Additionally, results in fewer chances for a biased log, and forensic officers can be monitored more closely to ensure they are performing adequately. There has been research of RFID tracking evidence however not attempted to track an individual in a crime scene setting(48). With higher accuracy, requires potentially combined satellite systems(35), however, what accuracy required to potentially fulfil tracking of CSI is unknown. This unknown will be examined using several tracking devices
to evaluate the accuracy of each concerning monitoring of the crime scene officer in a crime scene environment.
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Part Two

Manuscript

Utilizing GPS to Track Crime Scene Investigators Within a Crime Scene and Monitoring Their Fatigue
Abstract
One important procedure in crime scene investigation is note taking of the crime scene, which includes an entry and exit log (1, 2). By introducing Global Positioning System (GPS) as a component to track individuals in a crime scene, this could potentially replace crime scene entry and exit logs if proven accurate enough. Crime scene investigators can work long hours in less than ideal conditions which may increase the chances of fatigue being experienced. This research was conducted with two tests; the GPS accuracy test, and tracking/monitoring in a mock crime scene environment. The Garmin Fenix 5™ activity tracker was worn by a participant to track their movements in a 2-day mock crime scene while measuring their physiological signs and seeing if there is a correlation between heart rate, blood pressure, and self-report questionnaires. The accuracy and precision of GPS/GLONASS devices (Fitbit Surge™, Garmin Fenix 5™ and Garmin Montana 650t™) were evaluated by walking at an arbitrarily determined slow and fast pace around a define and measured 20x20m square. The Garmin watch showed it could track a person in a mock crime scene environment. The physiological parameters (blood pressure and heart rate) used were unable to correlate with times of stress disclosed by the participant in the self-report survey. All the GPS devices used overestimated the true measurements of less than 2m. The Garmin watch utilizing GPS only and combined GPS and GLONASS, and the Garmin 650 at a fast walk pace resulted in the most accuracy and precision. More research is needed to additionally support the GPS tracking in a mock crime scene environment and consistent results to more effectively monitor fatigue through body packs with constant measurements taken.

Keywords: GPS (Global Positioning System), accuracy, fatigue, Crime Scene Investigators (CSI’s).
Introduction
Crime Scene Investigators (CSI’s) play a vital role in society to provide support as the necessary link between the police investigation, the laboratory and the courts (2). In crime scene investigation, there are specific procedures followed to ensure continuity and integrity from the crime scene to the courtroom. One important procedure is note taking of the crime scene, which includes an entry and exit log of personnel moving in and out of the scene (1, 2). It is imperative to complete scene documentation and record practices correctly to follow through to court (1). By introducing Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) as a component to track individuals in a crime scene, this could ultimately replace crime scene entry and exit logs if proven successful.

GPS is a satellite navigation system developed by the US Department of Defence that provides positioning, navigation and timing services (3). GPS transmits signals from 20,200 km above Earth consisting of a collection of at least 24 satellites in six orbital planes equally spaced apart, and continuously orbiting the earth (3-5). Data received is converted into a signal and processed through GPS receivers to provide a three-dimensional position of latitude, longitude, and altitude concerning the satellites with coordinates of the location (5, 6). Global Navigation Satellite System (GLONASS) the Russian satellite system operated by the Ministry of Defence of the Russian Federation, was developed after GPS operating equivalently consisting of eight evenly distributed satellites in each of three orbit planes, with a total 24 satellite constellation (7). Frequently, GPS and GLONASS are combined to utilise navigation, geodetic and timing applications improvements, as available satellites are doubled improving the reliability and effectiveness (7, 8). By utilising GPS/ GLONASS tracking devices, less time and
resources can be spent on written logs, and more time on other important aspects at the crime scene such as exhibit selection and collection. This can also decrease the potential for bias logs where they may be deliberately altered from the truth for any reason, potentially time constraints and aid in clarifying minor discrepancies between individual investigators notes.

CSIs are required to examine, assess, interpret, record and collect physical evidence from a crime scene (2). As part of their role, forensic investigators can work long hours examining crime scenes, anywhere from days to weeks, on high-profile homicide cases. Along with working long hours, officers can work in conditions where they are outdoors in extreme heat or cold, wearing burdening Personal Protective Equipment (PPE) all day, including masks blocking off fresh air and access to limited rest sessions. These conditions may lead to officers becoming fatigued, which can be problematic, as this can cause officers to work inefficiently and leave room for errors (9, 10). The mental sharpness, decision making, management, and leadership skills essential for this role can be compromised which may lead to an increase risk of unjust outcomes (11).

Fatigue is often experienced in relation to situational factors or lifestyle, such as stress or lack of sleep, generally with an identifiable cause that can be resolved (12). When fatigue is experienced in each situation, the response is less than the predicted contractile response than when fatigue is not experienced (13). Within the body, the peripheral and central mechanisms mediate the physical appearance of fatigue. Where peripheral fatigue is caused by a lack of response after central stimulation in the neuromuscular system, and central fatigue is an inability to transmit motor impulses to perform activities voluntary mediated through the central nervous system (12, 14). Heart rate, blood
pressure, respiration rate, hydration and body temperature are many physiological parameters that have been analysed providing some association with fatigue (15-17). By attempting to monitor investigators’ fatigue, it may be possible to further understand how much the workload is affecting them physiologically and on their ability to perform tasks efficiently, with an aim to ultimately reduce errors from occurring and implement early warning mechanisms. Another issue is the officers driving after these sessions of long work hours while sleepy increases the risk to potential be involved in a track collision (18).

The aim of this project is to utilise these activity monitors to establish a cost-effective way of monitoring and tracking crime scene investigators within a crime scene. Additionally, accessing the ability to monitor and measure physiological signs to determine any correlation between heart rate, blood pressure, and self-report questionnaires.

Within this project there are several objectives;

- To determine the accuracy and precision of each GPS device by comparing GPS movements and measurements to a known 20x20m square.
- Evaluate the use of GPS devices/watches in a crime scene environment where it will track the movements of the forensic investigator while evaluating a mock crime scene.
- Attempting to monitor fatigue of crime scene investigators in a mock crime scene by measuring heart rate and blood pressure, and self-report questionnaires.
Materials and Methods

Square Test
In the same vicinity, Whitby Falls Farm a rural area with long grass, trees and bush land, a measured 20x20m square was laid out in an open field area. This was done using a peg for each of the four corners and string that would go around these pegs and make the sides of the square. A 50m tape measure was used to measure each side and diagonal between the points. With the square sectioned into two triangles, Pythagoras theorem was used to determine the third side of the triangle, which equalled the diagonal between two points (Figure 1). The third side of the triangle was measured across from each corner. The calculation used: \( \sqrt{(20^2 + 20^2)} = 28.28m \).

![Figure 1](image-url)

**Figure 1.** The 20x20m square sectioned into two triangles with third side of each triangle measured at 28.28m.

Once the square was laid out all three devices (Garmin Fenix 5™ watch, Garmin Montana 650t™, and Fitbit Surge™) were used with the GPS on to track movements while the investigator paced around the square. The watches were on the right wrist and the Montana held in the right hand, while they were walked just inside the edge of the marked square anticlockwise. Each device was walked around the inside of the square five times, the series of laps were a brisk/fast walking pace and another set was a slow walking pace (for each device). The Garmin watch was used on a separate day to the
Fitbit and Garmin 650 with the same method, with several different settings changed for each set of laps as the following:

- Fast walk, Setting 1 (ultratrac)
- Slow walk, Setting 1 (ultratrac)
- Fast walk, Setting 2 (GPS)
- Slow walk, Setting 2 (GPS)
- Fast walk, Setting 3 (GPS + GLONASS)
- Slow walk, Setting 3 (GPS + GLONASS)

2-Day Mock Crime Scene
There were two participants involved in this study who both conducted an examination of a mock crime scene over two days. Participants were consenting and signed consent form. This mock scene was part of a field trip for their own studies in the Murdoch University Master of Forensic Science (Professional Practice) and was not related to this project. It was conducted at Whitby Falls Farm. The weather experienced changed between sunny and cloudy throughout both days.

In the week leading up to the mock scene, participant 1 wore a Garmin Fenix 5™ to monitor the participants’ sleep and establish a base heart rate. For the two days of the mock scene both participants continued to wear a GPS watch which consistently monitored their heart rate and GPS movements. Participant 1 wore the same Garmin watch under the GPS only setting, and had a Garmin Montana 650t™ (standard GPS) in his pocket for day 1, and participant 2 wore a Fitbit Surge™. Participant 2 wore the GPS watch for 5 days after the mock scene to establish a base heart rate. The GPS tracking
was turned on at the start of the day, when they first arrived at their crime scene and turned off when the crime scene was closed each day. Participants’ were given self-report questionnaires at the start of day 1, which were to be filled out at the end of each day of the 2-day scene.

Over these two days participants’ blood pressure (BP) was measured using a sphygmomanometer; at the start of the day and approximately every hour during their examination. For day 1 their BP was also taken a few hours after the close of the scene that night once they were in a more relaxed environment. On day 2 their BP was taken prior to starting the crime scene and was taken approximately every hour until lunch time. The next two following weeks after the mock scene examination, for one day of each week participants’ BP was measured to identify base BP measurements.

Data Analysis
Square Test
The data from each device was uploaded the same as mentioned above for the 2-day mock scene. For the Garmin 650 and the Fitbit there were two files for each which represent the different walk paces, and the Garmin watch had six files; two walking paces for each of the three settings. All files were viewed and analysed in Garmin Basecamp and Google Earth. For each side of the square, for each lap, the distance was calculated by selecting all the points of the side and adding up the total meters in Garmin Basecamp. This was done for each side and lap of each square that was created, and measurements recorded in excel. The Garmin watch Ultratrac setting squares for each pace were excluded due to high inaccuracies and inability to complete a full table of measurements (Figure 6). In google maps, the squares tracked where shown against a drawn 20x20m representing the actual square (Figures 6&7).
The mean and standard deviation was calculated for each square and plotted into a bar graph. These measurements were compared to the actual measurements of 20m per side via a paired t-test, completed for each walking pace for each device. Two tailed level of significance at p < 0.05 with all degrees of freedom equal to 19. The %TEM (relative technical error of measurement) was calculated for each generated square using the technique described by Pederson and Gore (19) to test the intratester reliability. The intratester reliability tests the reliability of the repeat measures performed.

2-Day Mock Crime Scene
GPS Tracking

For all three GPS devices, available data was uploaded on to the computer; Garmin watch was uploaded to Garmin Connect, Fitbit uploaded to the Fitbit website, and the Garmin 650 GPS files were uploaded straight to the computer as GPX files. The Garmin watch contained both heart rate and GPS data, where the GPS data was exported as TCX files. The Fitbit data for the 2-day crime scene was unavailable due to errors with the fitbit server therefore this data could not be used and analysed. The TCX files from the Garmin watch were converted to GPX files, and GPX files from all devices were converted to KML files (to view in google earth) via this website: http://www.gpsvisualizer.com/. The GPS file from the Garmin 650 had other personal GPS data attached irrelevant to this study, therefore, could not be further analysed. The GPS files from the Garmin watch were uploaded into Garmin Basecamp, Google Earth and ArcGIS program to view and analyse. In Google Earth the tracks were viewed and observed to see the movements of the participant and the location at the Whitby falls farm. In ArcGIS the files from the Garmin watch were analysed by changing the style of the location options to show heat maps of location, and movements according to time of day (Figures 2&3).
A copy of the entry and exit log was provided from each of the participants of their written notes when entered and exited the crime scene. Analysing the GPS output in Garmin Basecamp and Google maps, estimated times were noted when the participant entered and exit the scene vicinity. This was done for participant 1 from the Garmin watch over both days, listed and compared.

**Physiological Parameters**

The blood pressure measurements were entered in excel with systolic and diastolic in separate columns against the time they were measured. Scatter graphs with straight lines and markers were created to show any trend over time in changing measurements. For each participant, there was a graph of day 1, day 2, and baseline measurements.

The heart rate (HR) measurements from the Garmin watch for the duration of each day (the two activities) were exported to Microsoft Excel. The average heart rate per hour from the start time was calculated and then plotted onto a graph. These HR results were added to the blood pressure graphs to create a combo scatter graph (excluding base measurements), resulting in four graphs (Figures 4&5). HR was unavailable for participant 2 for both days. Time markers were added to each of these graphs to show the start and end of examinations of the day, and lunch breaks according to each participants’ entry and exit log. Additionally, self-reported times where participants felt most stressed, decreased energy levels and tired from the self-report questionnaires were also added as time markers (Figures 4&5).
Results

2-Day Mock Crime Scene

GPS Tracking

The tracked movements of the Garmin watch over the 2-day mock crime scene were analysed in the ArcGIS program and generated heat maps of location shown in Figure 2.

Figure 2. The tracked movements from the Garmin watch of participant 1 shown through location heat maps; A) over day one and B) day two.
The low areas shown in blue represent the cold spots where there was less time spent during the day compared to the middle and high areas (hot spots) where more time was spent in those areas. On day one, there shows a relatively wide area in the low (blue) covering the map over the bushland area, and south of this is a small low area separate covering the end of the big building. The wider bushland area covered shows some red colouration (medium) within the blue, some to the right and more in the middle of the low area. In this middle area the red appears darker in a circle with yellow (high) within it (Figure 2A). Similarly, day two has two low areas shown in the same locations though smaller than in Figure 2A. The big low area in the bushland is shown with a medium area in a circle with the high area filling that circle. This medium to high circle is located within the low area to the upper left side (Figure 2B). Comparing the high areas from each day, they are in approximately the same place regarding the landscape of the image (Figure 2).

In the ArcGIS software, the GPS movements of participant 1 were analysed over the course of each day of the 2-day crime scene through a change in colour gradient showing the location changes over time shown below in figure 3.
Day 2

Figure 3. The tracked movements from the Garmin watch of the participant shown through time where the purple colouration progresses over the movements of the day. A&C) is overall image of the tracks, and B&D) closer view of the crime scene area.

As time progressed throughout each day, the white colour dots represent the movements at the start of the day, and gradually goes purple, to dark purple for the end of the day.

For day one, the white and grey/light purple areas representing the start of the day
appear around the outsides, behind, and in between the other points of the concentrated area in the bushland. The medium purple coloured areas (midday) are shown broad with some leading away from the main area heading up to an area which appears a bit more concentrated and then back to the main area (Figure 3A). The dark purple areas (end of day) are shown less broad and more concentrated within the middle of the main area with a light trail to the end of the building south of this area(Figure 3B). Day two showed the white behind the main area, and grey/light purple moving around the perimeter area of the bushland for the start of the day. Correspondingly, for the light to medium purple areas (approximately midday) to day one, it was shown to move to and from the main area with a bit more concentrated at the bottom point (Figure 3C). Medium to dark purple points are concentrated in the main area and then to, from and with a greater increase at the end of the building. The end of the day represented by the dark purple points are collectively in the centre of the main area on the image (Figure 3D). Overall for both days, the white to lighter colours appear broader over the location and the darker purple areas are more concentrated to the one bushland area (Figure 3).

*Entry and Exit log*

The GPS movements of the 2-day crime scene were examined through Garmin Basecamp and noted when the participant left the main crime scene area. These were listed and compared to the entry and exit log of the crime scene notes provided by the participant.
Table 1. Entry and exit logs from the participant’s notes and the GPS tracked movements for Participant 1 of the 2-day mock crime scene.

<table>
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<th>Day</th>
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The entry and exit log does not completely match the GPS movements noted. Although for day 1 the times mentioned in the notes relatively match up to those taken from the GPS, except for an entry at 1510 from the notes, which corresponds to the 1438 entry on the GPS. There is another occasion where the participant entered and exit the scene for 4 minutes which was not recorded in the log. On day 2 there is more discrepancies with two occasions the participant exits and entered the scene with no record in the notes. Furthermore, the times noted for exit and entry throughout the day (excluding first enter and last exit) were 1257 and 1332 did not match up to any entry and exit log shown from the GPS. The final exit times also varied with the mention in the notes of 1521 and the GPS turned off at 1706 representing the close of scene (Table 1).
Physiological Parameters

For each day of the 2-day mock scene the blood pressure and heart rate measurements recorded for participant 1 were graphed together. Additionally, time markers were added for the start and end of day examination, lunch break and any reports of feeling stressed, decreased energy levels and tired by the participant can be seen below in Figure 4.

**Figure 4.** Systolic and diastolic blood pressure and heart rate measurements for participant 1 for the 2-day mock crime scene, with added time markers of the start and end of the day, lunch break, and results from the self-report questionnaires of most
For participant 1 on day one their systolic and diastolic blood pressure (BP) measurements maintain consistency with each other over the course of the day. Excluding the first measurements from 1105 to 1212 where systolic increases slightly, and diastolic very slightly decreases. From the start of the day both increase, with BP slightly and HR quite rapidly, to peak before lunch with BP at 1315 of 155/115mmHg, and HR 103bpm at 1306. Over the lunch break both HR and BP show a slight decrease, with the participant felling the most stressed right before the end of lunch break at 1500. After lunch BP shows a slight increase till the end of the day, and HR decreases till 1606 and then increased (Figure 4A). Participant 1 started day two at approximately 0900 with a relatively high HR of 91bpm, though quickly dropped down to 82bpm at 1013 and stayed consistent for the next hour. Systolic and diastolic BP were relatively consistent with each other and throughout the day where both peaked at approximately 1100 with 145/90mmHg and then continued to decrease. The participant had decreased energy with a headache at 1030, and felt tired at 1100 for approximately half an hour corresponding to the slight peak in BP. HR decreased before lunch, then increased from the middle of lunch to peak to 83bpm at 1413, and continually decreased past the end of examination. Further feelings of most stressed by the participant were between 1500 and 1700 (Figure 4A).

For each day of the 2-day mock scene the blood measurements recorded for participant 2 were graphed. Time markers were added for the start and end of day examination, lunch break and any reports of feeling stressed, decreased energy levels and tired by the participant can be seen below in Figure 5.
Figure 5. Systolic and diastolic blood pressure measurements of participant 2 for the 2-day mock crime scene, with added time markers of the start and end of the day, lunch break, and results from the self-report questionnaires of most stressed, decreased energy levels and tired feelings. A) day 1 and B) day 2.

Systolic BP on day one for participant 2 was relatively consistent and diastolic BP was relatively inconsistent throughout the day. The start of the day till lunch time, systolic stayed consistent with a very slight decrease before lunch, and diastolic increased to 1200
and then decreased before lunch, around the time the participant had decreased energy levels at approximately 1300. From 1412 in the middle of lunch break, both systolic and diastolic BP slightly decreased till approximately 1520 where the participant felt most stressed. Systolic had a slight increase till 1622 and then slightly decreased till the end of day, with diastolic slightly increasing to the end of day (Figure 5A). Participant 2’s BP increased from the initial reading at 0849 to peak at 1000 just after the start of the scene for day two with 135/105mmHg. After this, BP decreased by lunch with systolic and diastolic remaining consistent with each other across the first half of the day. The participant felt most stressed towards the end of the day from approximately 1330 to 1400 (Figure 5B).

**Square test**
The movements around the 20x20m square were uploaded into google maps for each walking pace from the Garmin watch to visually see the tracked results. A black square was drawn as an overlay shape in google maps with each side measured to 20m, to show the actual 20x20m square that was measured out to visually see the differences shown below in Figure 6.
Figure 6. All tracked movements around the square using the Garmin watch three settings; Ultratrac, GPS only and GPS and GLONASS at a slow and fast walk, and the actual 20x20m square.

The Ultratrac and GPS only slow walk are similar visually with several lines across the centre of the square and past the outside, with each lap a different shape. The Ultratrac fast walk shows a relatively square shape with several lines representing the laps together however other lines have appeared far from the square to make slim triangles. GPS and GLONASS, and GPS only for the fast walk appear in a relatively square shape with each lap very similar in terms of location (close together). Although one or two laps appear as a bigger square, more so for the GPS and GLONASS slow walk, where there are also a few laps going across half of the square (Figure 6).

Similarly, to Figure 6, the movements shown of the Fitbit and Garmin 650. A black square was drawn to show the actual 20x20m square that was measured out to visually see the differences between the tracked results shown below in Figure 7.
Figure 7. All tracked movements around the square using the Fitbit Blaze and the Garmin Montana 650t at a slow and fast walk.

The Garmin 650 fast walk appears in a square shape similarly for each lap. The slow walk for the Fitbit and the Garmin 650 appear in a square shape however with the square appearing bigger compared to the actual square, and the laps less close together compared to the fast walk of the Garmin 650. The Fitbit fast walk is located slightly North-West of the actual square and appears in a relatively square shape, although, several laps it further extends the sides of the square shape (Figure 7).

The mean and standard deviation (SD) measurements were calculated for each of the squares created from all GPS Devices at each walking pace can be seen in Figure 8 below.
Figure 8. The mean measurements and standard deviation error of each lap of the track around the square for each GPS device for the slow and fast walking paces.

All square measurements were above 20m with the Garmin GPS and GLONASS fast walk showing the lowest measurement at 20.55m (SD: 2.14m) with the Fitbit following with slow 20.70m (SD: 0.98m) and fast walk 20.90m (SD: 1.25m). There were minor differences between the slow and fast walking paces for each device with a maximum difference of 0.70m shown for the Garmin 650. The Garmin 650 showed the highest mean measurement for the slow walk of 21.85m (SD: 2.39m) and the second highest for fast walk at 21.15m (SD: 2.01m). For the Fitbit and Garmin watch GPS only, the slow walk measurements were less than the fast walk, which was the opposite for the Garmin 650 and the Garmin watch GPS and GLONASS. For the Garmin watch, the slow walk showed the same mean measurements for both settings of 21.20m with highest SDs of 7.58m for GPS only and 5.79m for GPS and GLONASS. (Figure 8).
There is a significant difference evaluated between the GPS measurements and the actual measurements of the square for the Fitbit slow walk ($t = 3.20$, $p$ value $< 0.005$) and fast walk ($t = 3.21$, $p$ value $< 0.004$), the Garmin 650 slow walk ($t = 3.46$, $p$ value $< 0.003$) and fast walk ($t = 2.56$, $p$ value $< 0.02$), and Garmin watch GPS only fast walk ($t = 2.23$, $p$ value $< 0.04$). Alternatively, the difference was not significant for the Garmin watch GPS and GLONASS fast ($t = 1.15$, $p$ value $< 0.26$), and slow ($t = 0.93$, $p$ value $< 0.36$), and GPS only slow walk ($t = 0.71$, $p$ value $< 0.49$). Most of the squares had slight variation in the data set, however, for GPS only and GPS and GLONASS settings on slow walk there was high variation with 57.5m for GPS only and 33.5m for GPS and GLONASS.

For the Fitbit the five repeats of laps made around the square demonstrated a relative TEM of 5.01% for the slow walk and 6.24% for fast walk. The Garmin 650 demonstrated a higher relative TEM of 8.83% for slow and 8.88% for fast walk. For the fast walks performed by the Garmin watch they established a TEM of 5.08 for GPS only and 7.01% for GPS and GLONASS. For the slow walks at these settings the TEM resulted much higher of 33.14% for GPS only and 27.10% for GPS and GLONASS.

**Discussion**
The used GPS devices can relatively demonstrate a tracked square where the faster walking pace had improved accuracy, precision, and reliability.

**Square test**
Both Figure 6 and 7 visually show the variation of each square tracked against the actual square. For the different settings of the Garmin watch; Ultratrac could not effectively demonstrate the path of a square. GPS and GLONASS, and GPS only were similar in effectiveness. Overall the fast walking pace appears to show more accuracy than the slow
walk for the Garmin watch settings. This could potentially be due to the GPS network thinking that the participant has stopped in the slow pace and assumes a stationary position, compared to fast paced where the position is moving more consistently with the location detected more frequently. Although, this was not the case for the Fitbit and Garmin 650, as the Fitbit slow walk showed more accuracy, and both paces were similar for the Garmin 650 with the fast walk slightly more accurate. The slow walk for both the GPS only and GPS and GLONASS resulted in high variation between each mean measurement, and relative to the mean which is further supported in Figure 6, more strongly for the GPS only setting. The Fitbit statistical results show high accuracy; however, this is seen contradictory viewing the tracked movements in google maps against the actual square. By visually viewing the tracked movements of the square highlights the errors inaccuracies of the GPS technologies.

The GPS only and GPS and GLONASS for the fast walk, and the Garmin 650 both fast and slow walk visually appear to have the most accuracy and precision in replicating the actual square. The GPS only compared to the GPS and GLONASS combined had minor impact in this study, contradictory to other studies where they found an improvement by adding GLONASS (20), although Alcay et al. findings are consistent with these results of no major difference between the two (21). All measurements were an overestimation of the square with the most difference only less than 2m compared to the actual measurement (Figure 8). These results agree with the work of Gray et al. (22) where they concluded an overestimation found of approximately 4m. Although, they further discussed how walking pace had a greater error and with increase intensity movements which did not correspond to majority of the results observed in this study, as the faster walking pace had less error, excluding the Fitbit.
The reliability measures of most squares with TEM of 5.01-8.88% show they can be confidently used to track a person. However, the slow walk pace for GPS only (TEM = 33.14%) and GPS and GLONASS (TEM = 27.10%) there is less confidence to have the ability to track a person, although still possible.

There were significant differences between the actual measurements compared to the tracked square using GPS for all except the Garmin watch; GPS and GLONASS fast and slow walk, and GPS only slow walk. This significant difference however is relatively small, though does highlight systematic errors in GPS systems. The statistics performed were based on the mean measurements of each side of the square which is not a true representation of the accuracy and precision as some statistic results are contradictory to the visual results shown (Figure 6&7). To further expand on this study, perhaps other statistical methods should be considered to determine a true representation of the data which can be seen visually. Each side created from the tracking device of the square can be measured against the actual square, where the difference can be measured from several points along each side. This could not accurately be performed in this study as the five laps performed were too high repetition to be able to clearly differentiate each lap. For future studies, less than five laps, approximately 2-3 laps would be more appropriate for this method. Overall the fast walk pace performed by the Garmin watch GPS only and GPS and GLONASS, and the Garmin 650 showed the most accuracy, precision and reliability.

Relating the square test to the tracked movements of the 2-day mock crime scene, shows potentially problematic as in a crime scene environment the walking pace would be decreased close to replicating the slow walk pace. As the accuracy and precision is
decreased in a slow walking pace this can represent the tracks from participant 1 are potentially at a lower accuracy. Although, overall the overestimation is less than 2m which is relatively high accuracy still effectively able to track a person, in this case a crime scene investigator in a mock crime scene environment.

2-Day Mock Crime Scene
GPS Tracking

The tracked movements from participant 1 wearing the Garmin watch for the 2-day mock scene are successfully shown through heat maps over location (Figure 2) and time (Figure 3). The heat maps indicate the area of the wider crime scene area as the general low areas cold spots, and the high area hot spots on the map represent the location of the condensed crime scene including the body and team setup location (Figure 2). The participant moving between these two points consistently throughout each day explain the high areas on the map. As Figure 2 shows the participant’s movements starting broader corresponds to their borders of the crime scene, as the day went on their cordon would move accordingly and decrease in size. The main concentrated areas over each day (Figure 3) are located over the same area as the high areas for the heat map location in figure 2, representing the condensed crime scene.

The GPS has provided support that it can be used as an entry and exit log and provided more information than the notes recorded for the entry and exit log. Although, the GPS was unable to determine if the participant had left the inner cordon of the crime scene to just outside to continue examination, which may have been a possibility for the inconsistencies shown in Table 1. With the addition of a dedicated access egress point, this may be better determined. Using a GPS device can offer further analysis of the
tracked movements of the crime scene an entry and exit log would not be able to provide. It is also worth noting the GPS device can show any discrepancies within the written entry and exit log. These methods prove effective used in conjunction with each other to more effectively evaluate the movements of the crime scene investigator.

Physiological Parameters

There are some trends shown between heart rate and blood pressure although no conclusive results. Mostly there is no relationship shown with feelings from the self-report questionnaire to the HR and BP measurements except shown in Figure 4B. There are instances shown where there is increased blood pressure and/or heart rate at times during the day however no feelings reported in the questionnaire. Although, there is evidence to support heart rate variability can be a measure of stress (23, 24). Potentially the participants may have forgotten or did not note down other times of feeling stressed. In Figure 4B there is a trend between all three variables before midday, although less correlation shown towards the end of the day when the participant felt most stressed. The heart rate was decreasing and no measurements of BP were recorded at this time.

Meng et al. (15) found blood pressure can elevate after fatigue potentially corresponding with results shown in Figure 5A where blood pressure has slightly increased after feelings of stress by the participant. Although, the results regarding heart rate disagree with their findings as there were fluctuations shown in participant 1. Perhaps the hourly heart rate calculated did not adequately capture the heart rate consistently over the day and any peaks seen. This may need to be examined in further research.

There is incomplete data to effectively support the relationship between physiological measures including heart rate and blood pressure, and self-report questionnaires of
feelings of potential fatigue. Therefore, more research is needed to effectively evaluate whether these aspects could detect and monitor fatigue. There are technologies that can monitor physiological parameters such as blood pressure, heart rate and body temperature through wearables that can be taken consistently throughout the day. To further expand this study a mock crime scene in the heat all day should be considered as this may have an increased effect on the participant’s physiological parameters.

Conclusion
Using a GPS device to track crime scene investigators within a crime scene is possible, although, more replication to further support this is needed to be able to ultimately replace entry and exit logs. Unfortunately, there is not enough evidence to support the ability to monitor and detect fatigue in a crime scene investigator in a mock scene environment. Most GPS devices and settings within them could effectively track a 20x20m square with an overestimation of less than 2m. The fast-walked movements were shown more accurate, precise and reliable with more emphasis on the Garmin 650, Garmin watch settings; GPS only and GPS and GLONASS.
References
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