THE ANALYSIS OF THE STRAIN LEVEL AND THE PREDICTED HUMAN ERROR PROBABILITY FOR CRITICAL HOSPITAL TASKS.

BY

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THESIS

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ABSTRACT

South African hospitals, as a result of numerous factors, have the problem of an increasing workload for nursing staff, which in turn may affect patient treatment quality. This project aimed at addressing patient treatment quality specifically from the perspective of worker capabilities by investigating the strain level and predicted human error probability associated with specific patient-centered tasks in the South African health care sector. This was achieved through two independent yet interlinked studies which focused on seven patient-centred tasks. The tasks analysed were the tasks of setting up and changing intravenous medication, administering injection and pill medication, measuring blood glucose, temperature and heart rate and blood pressure. In the first study, work environment and task characteristics, task structure and execution were analysed. In addition to the task execution, the resulting strain levels, in the form of heart rate measures and subjective ratings of workload, were studied. The second study determined the error protocols and predictive error probability within the healthcare environment for the seven pre-defined tasks. The results for the first study established that different organizational and environment factors could affect task complexity and workload. The individual task components and information processing requirements for each task was also established. For the strain analysis, significant results for the tasks were determined for heart rate frequency and the heart rate variability measures, but some of these were contradictory. For the second study, specific error protocols and error reporting data were determined for the hospital where this research was conducted. Additionally the predictive error probability for the pre-defined tasks was determined. This combined approach and collective results indicate that strain and predictive error probability as a result of task workload can be determined in the field as well as being able to identify which factors have an effect on task strain and error probability. The value of this research lies in the foundation that the gathered information provides and the numerous potential applications of this data. These applications include providing recommendations aimed at improving nursing work environment with regards to workload, improving patient treatment as a result of a reduction in errors and the potential foundation these results provide for future research.

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CHAPTER I
INTRODUCTION

BACKGROUND TO THE STUDY

Nursing work is often characterised as physically (Lee-Treweek, 1997 as citied by Hignett, 2001) and psychologically straining (Janowitz *et al.*, 2006; Hignett, 2001). Specifically in South Africa, nursing stress and workload are exacerbated by economic, social and workplace factors, and nurses are often overburdened (Brysiewicz, 2002; Coovadia *et al*., 2009). As a result it is vitally important to understand nurses' working conditions and to attempt to improve them and heighten job satisfaction (Chirwa *et al*., 2009). Heavy nursing workloads not only influence the stress the nurse is exposed to but can also result in errors occurring (Janowitz *et al*., 2006). Errors or mistakes in this area are costly from a financial perspective for the healthcare system and may have severe consequences regarding patient health (Berguer, 1999; Carayon and Friesdorf, 2004; Janowitz *et al*., 2006). As a response to the above mentioned factors, ergonomic designs and interventions can play a crucial role in improving nursing workload and potentially reducing nursing error (Carayon and Gurses, 2008).

A systematic and holistic ergonomic approach is required in order to understand the workload risks and factors that can occur in the health care environment (Buckle *et al*., 2006). Ergonomics can assist in identifying which factors can lead to reduced work performance, which could result in unintended harm to patients (Buckle *et al*., 2006; Gurses and Carryon, 2009), and it can also assist with achieving an optimum worker performance with a low risk of error and injury (Berguer, 1999). Research in hospital ergonomics can result in potential benefits for not only improved working conditions but also improved patient safety (Buckle *et al*., 2006).

STATEMENT OF THE PROBLEM

South African hospitals have unique challenges and demands that are placed on the workers, which make the ergonomic requirements specific and in need of intensive further research; yet only limited research has been conducted on hospital ergonomics in South Africa. As a result of a diminishing nursing workforce (Vujicic *et al*., 2004), ergonomic research and interventions have become a necessity. This project aimed at addressing patient treatment quality from the perspective of worker capabilities. It did so by investigating the strain level and predicted human error probability associated with specific patient-centered tasks in the South African health care sector. The problem addressed in this research was that of identifying nursing workload stressors, by establishing the relationship between strain and task, and to assess the predicted human error probability for specific hospital tasks.

The motivations for this enquiry were to better understand and establish which task and work environment characteristics affected the strain experienced by the nurse which could potentially affect the occurrence of errors. The relevance of this research was not only of intrinsic scientific interest and to supplement the knowledge on nursing workload, but also to identify potential hazards with the task or work environment that may, through design, be eliminated and so reduce the nursing stress and the probability of errors affecting patients. This research aimed to provide a foundation off which interventions may be developed for reducing nursing strain and optimising the efficiency of the daily hospital organisation; but the interventions themselves were outside the study's scope. The aim was achieved by investigating strain levels elicited by the tasks in conjunction with assessing the work environment and predicted human error probability.

RESEARCH HYPOTHESIS

The overall research hypothesis stated that the strain and the predicted human error probability of various hospital tasks could be determined in the field in conjunction with establishing probable contributing factors such as work organisation. The first section more specifically hypothesised that different hospital tasks, in conjunction with various contributing factors, elicit different strain levels as a result of workloads that are indirectly measurable. Furthermore, it was expected that several of the contributing strain factors could be identified, such as an increased nurse-patient ratio, which would increase the workload and would be reflected in an increased strain measure. The second section hypothesised that the predicted error probability of the analysed tasks could be determined.

RESEARCH CONCEPT

This research studied workload using psychophysiological measures based on the stress-strain concept by Luczak (1975, as cited in Luczak and Göbel, 2000) and the potential resulting error by adopting behavioural, subjective and physiological measures. The stress-strain concept (Luczak, 1975 as citied in Luczak and Göbel, 2000) is depicted in Figure 1, with the blocks in bold highlighting the focus areas of this research.

Workload, in the context of this research, was defined as the stress imposed by the task and work environment (Bridger, 2009). Numerous task stressors, which include task duration, task composition and environmental influences, were assessed in order to determine if they could be identified as contributing stress factors of the tasks observed. The direct effect of these stress factors cannot be directly measured, but accumulative strain experienced by the worker is accessible through numerous assessment techniques. The strain that an individual experiences can result in a training effect occurring, or it can result in fatigue (Bridger, 2009), which can lead to error or a reduction in working speed.

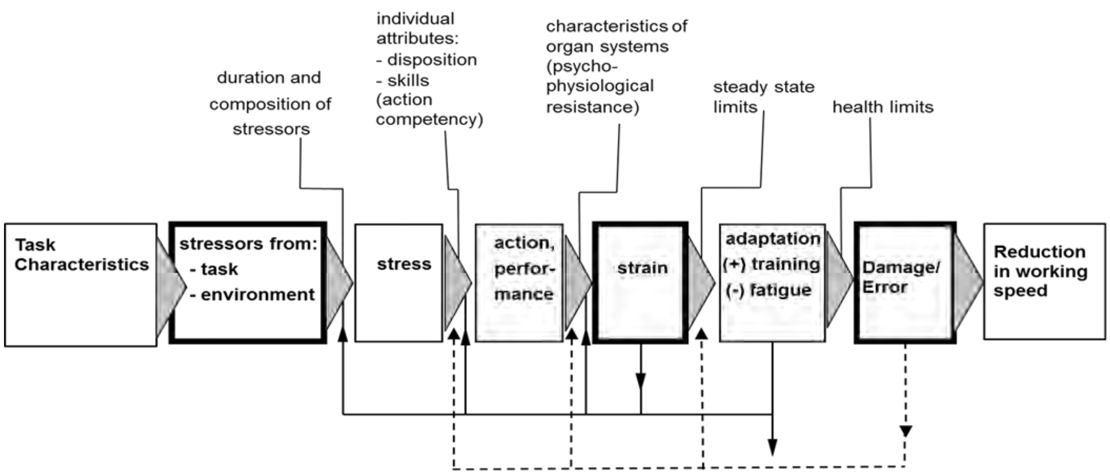


Figure 1: The extended stress and strain concept (Luczak, 1975 as cited in Luczak and Göbel, 2000).

This research comprised two independent yet interlinked sections which are depicted in Figure 2. To ensure that the overall objectives were met, methods were specifically selected with the overall research concept in mind. The first section focused on a comprehensive workload assessment comprising field-based work analysis to determine the strain level for various hospital tasks. Hierarchical task analysis was selected not only as it was a suitable tool for the workload assessment, but also as it served as the basis for the error risk analyses (Stanton and Young, 1999) performed in Section two. Psychophysiological measures were used in conjunction with the task analysis to determine the workload and strain experienced during the tasks observed. These measures were selected as they provide an indication of the physical and cognitive demands (Boucsein, 2001). The second section was aimed at determining the error protocol and error reporting systems within the hospital analysed in addition to determining the predicted human error probability for the task analysed in the first section.

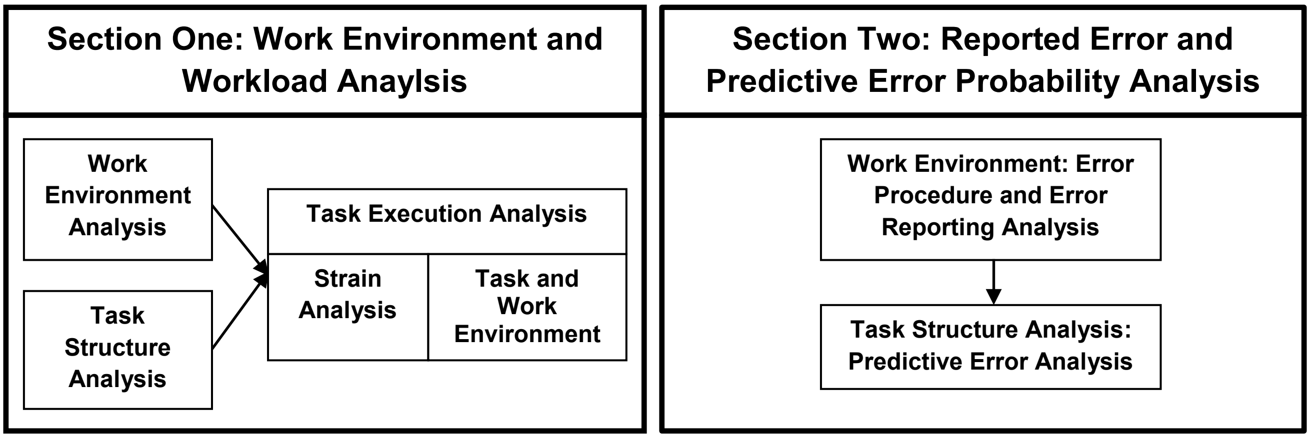


Figure 2: The structure of the methodology for the two interlinked sections which constituted this research.

Workload is an important contributing factor to the occurrence of errors but similarly to workload as error probability is also influenced by a similar host of factors and is context specific, this makes the study of error with regards to practical solutions very difficult (Bridger, 2009). This research investigated both the concept of workload and that of error in situ in the form of two studies.

SCIENTIFIC METHOD

Due to the complexity of this research's concept and objectives, both quantitative and qualitative approaches were selected and, by combining both approaches, the researcher aimed to use the qualitative data obtained to support and explain the quantitative data. This research concept comprised two field studies, with the first field study being both qualitative and quantitative in nature (described in Section one), and the second being an analytical and predictive analysis (described in Section two). Section one was inductive in nature, as it determined the strain parameters of various hospital tasks, and Section two was deductive as the task analyses used in Section one were utilised to establish the predictive human probability of the tasks. This research was designed to be both explanatory and predictive in nature as it aimed to explain the casual relationship of stress and strain, as well as providing information that might lead to error prediction techniques.

DELIMITATIONS

For the work environment and task structure analysis in Section one, all questionnaires and interviews were performed at least twice in each ward observed. The task execution analysis, in Section one, was delimited to fourteen female nurses ranging in age from 27 to 64 years old. The sample consisted of South African nurses from Settlers Hospital in the Eastern Cape qualified as a registered nurse, staff nurse or a nursing assistant.

To limit the variability in the task execution analysis, this repeated measure design tested all subjects on two different weekdays, as the daily routine is different on weekends. Heart rate measures were recorded continuously throughout the shift in order to assess the strain of tasks performed. As a large portion of this research was qualitative and was recorded using observation techniques, only one researcher conducted the research and standardised the data from one external perspective only (Stanton *et al*., 2005). To overcome the disadvantage of the effect of a researcher's presence on the nurses' behaviour (Stanton *et al*., 2005; Stanton and Young, 1999), the nurses were well habituated prior to testing. Similarly, for the predictive error analysis in Section two, the systematic human error reduction and prediction approach was performed with the assistance of two senior nurses from each ward.

LIMITATIONS

As this research was conducted in the field, there was a lack of control over extraneous variables. Additionally pre-testing and non-task related behaviour could not be controlled. Despite the repeated design measure, these limitations might have negatively affected the statistical power of the results obtained, especially for the tasks that were not observed as frequently as the others, namely the tasks of administering and changing intravenous medication. This limitation could not be overcome as these tasks occurred naturally less frequently than the others did over the two month testing phase. Despite this, an advantage of this field research was that the tasks were analysed in the situations in which they occurred. As this study used psychophysiological variables in the field, this in itself resulted in a limitation as these variables have been predominantly used in laboratory studies (Boucsein and Backs, 2000). The researcher was aware of this limitation and wished to assess these variables applicability in the field as a result of the context of the field research, not many assessment techniques are suitable.

Another limitation was that no screening factors, such as a minimum experience level, were implemented for the nursing staff that participated in this study. In addition to this, only a small participant group from each nursing category (registered nurses, staff nurses, and nursing assistants) was recruited for this study and a small number of senior nurses assisted with the predicted error analysis. These limitations as a result of sampling strategy may have resulted in the wide spread of findings indicated by the standard deviation results. The sampling strategy employed was influenced by the availability and pool of potential participants, and as a result of this the subsequent limitations were beyond the control of the researcher.

SECTION ONE: WORK ENVIRONMENT AND WORKLOAD ANALYSIS

CHAPTER II

REVIEW OF RELATED LITERATURE

Workload is the result of an interaction of numerous factors related to the worker, the task and the environment (Hart and Staveland, 1988; Gaillard and Kramer, 2000). Resulting from this one needs to understand the underlying processes involved in work such as the required information processing as well as the effect stressors can have on the worker's experience strain (Boucsein, 2001). Workload, as well as all of these processes and reactions are dependent on the task and work environment the worker is exposed to and as a result, when analyzing workload the context wherein the task occurs needs to be thoroughly understood (Bridger, 2009).

WORKLOAD, STRESS AND STRAIN

Workload can be defined from two broad perspectives, namely: either from a human-centred perspective, as the psychological and physiological responses of the worker to the task requirements, or from a task-centred perspective, as the operational demands elicited by the task, such as the required duration and force necessary for task completion (Hart and Staveland, 1988). A combined definition of workload would be the task demands and costs incurred by a human operator to achieve a particular level of performance necessary to complete the task (Hart and Staveland, 1988). Workload can be defined from a physical, mental or combined physical-mental perspective (OGP, 2010).

The workload an individual experiences is the result of the interaction between the requirements of a task, the abilities of the worker and the circumstances under which the task is performed (Hart and Staveland, 1988; Gaillard and Kramer, 2000). Initial task demands are created by task objectives, duration, complexity, structure and available resources which can all be defined as the task-centred characteristics (Hart and Staveland, 1988). These demands are modified by a host of intrinsic and extrinsic factors that are unique to that specific task at that point in time (Sterud *et al*., 2008; Bridger, 2009). Some of these intrinsic factors include the worker's experience and current state, while extrinsic factors would include environmental factors, circadian influences, time pressure, task attributes and organisational factors such as co-worker support (OGP, 2010; Gaillard and Kramer, 2000; Sterud *et al*., 2008). These factors may contribute to sources of variability in the workload imposed by the task from one performance to the next (Hart and Staveland, 1988; Sterud *et al*., 2008), and may result in the unique strain that these factors produce in each individual (Matthews *et al*., 2000). How these factors moderate stressors, or the individual's perception of them, is still largely unknown (De Backer *et al*., 1999).

The factors that affect workload may also influence the performance of the task (Kirschner, 2002). Workload is generally assumed to be related to performance in that low and moderate levels of workload are associated with an acceptable level of performance (Wilson and Eggemeier, 2001). Excessive workload may result in poor performance and operator stress (Gaillard and Kramer, 2000; Wilson and Eggemeier, 2001; Bridger, 2009) which have negative health implications (Cox and Griffiths, 2005). But underload may result in boredom and therefore distraction (Wilson and Eggemeier, 2001). Both of these may lead to inadequate performance, and human errors may result (OGP, 2010). Therefore workload is an important concept that is often required to be measured (OGP, 2010; Hart and Staveland, 1988) and the more complex the system, the more important the evaluation of workload becomes (Rubio *et al*., 2004). One means of defining complexity is that from a systems theory perspective. This defines complexity as being related to the number of elements and how the elements relate to each other within a given system (Leplat, 1988). Due to workload being a wide-ranging concept, it cannot be directly measured (Hart and Staveland, 1988) and both the qualitative and quantitative loads induced by work are important considerations, as they are closely related to stress and fatigue (Kumashiro, 2005). As the worker experiences workload as a result of numerous factors that have been modified, workload assessment techniques reflect modified workload (Hart and Staveland, 1988).

There are a number of approaches that can be used to attain an indication of workload, including the assessment of workload from the subjective, objective and psychophysiological perspectives (Baker, 1985; Kumashiro, 2005). Within these various perspectives numerous techniques are available, a result of the broad definition of workload, and some will be described in greater detail at a later point in this thesis. To better understand the concept of workload assessment, one needs to consider it from a psychological perspective in terms of the broader concept of stress-strain processes (Boucsein, 2001), within which workload, as a work-related stressor, can be classified.

THE STRESS-STRAIN CONCEPT

As with workload, there are numerous definitions for the term stress depending on the situational context (Ganster, 2008). The most pertinent ergonomic definition of stress is a set of environmental demands or events that causes strain experienced by the worker (Ganster, 2008). Stress can be physical or psychological in nature, both of which elicit similar responses, but the consequences of these responses differ (Bridger, 2009). Stressors can be either discrete events, which refer to traumatic occurrences at work, or non-discrete events which refer to conditions such as high workload, interruptions, and negative interpersonal interactions (Ganster, 2008). For the purposes of this research, henceforth stress will refer only to the results of non-discrete events.

Numerous factors can result in stress such as physical, psychosocial and organisational work factors (Bridger, 2009). These can cause transitory consequences such as increased blood pressure, decreased mood, increased anxiety or, if the exposure to intense stress is sustained, long-term health risks such as increased risk of sub-optimal health and cardiovascular disease (Bridger, 2009; Cox and Griffiths, 2005). If the worker experiences the more chronic negative effects of stress, then resulting negative organisational effects may occur such as high absenteeism, high staff turnover, poor morale, and reduced safety (Bridger, 2009; Cox and Griffiths, 2005). Not all types of stress, however, result in these negative consequences and numerous factors moderate the effect of stress on individuals (Bridger, 2009; Cox and Griffiths, 2005).

Different theoretical approaches are available to study stress, specifically work stress, and these include physiological, psychological and engineering approaches (Cox and Griffiths, 2005). The physiological approach views stress as a generalised and non-specific physiological response to negative stimuli, the psychological approach views stress as a cognitive state which reflects the individual's perception and adaptation to work demands, and the engineering approach views stress as the negative objective characteristics of situations resulting in the worker experiencing strain (Cox and Griffiths, 2005). Stress itself cannot be directly measured as it is difficult to conceptualise (De Backer *et al*., 1999), but the resulting strain can be measured to provide an indication of the stress level (Hurrell *et al*., 1998). Strain, unique to each individual, is the resulting short-term response to stressors (Boucsein, 2001) and can be measured in the form of psychological, affective or behavioural responses (Ganster, 2008).

Stress experienced in the work environment and the resulting job strain have been linked to numerous health risk factors (Van Egeren, 1992). They can have severe implications on the worker in that they may play a role in causing negative long-term effects (De Backer *et al*., 1999; Bridger, 2009). By addressing these stressors, not only is worker health improved but worker productivity may also increase (Ganster, 2008). Karasek (1979) proposed a model of job stress called the demand control model that predicts that biologically aversive strain will occur when the psychological demands of the job exceed the control resources over the task (Johnson and Hall, 1988). In addition to this, the model proposes that a combination of high demands and low control produces job strain (Johnson and Hall, 1988; Gaillard and Kramer, 2000), whereas jobs with high demand and high control produce little or no stress reactions and psychosomatic complaints (Karasek, 1979; Gaillard and Kramer, 2000).

As workload is a type of stressor, so similarly the factors that affect workload will affect the strain experienced (Lemaire and Mormède, 1995). One needs to consider not only the objective components of stressors but also the subjective interpretations of these stressors, as these have implications for the resulting strain experienced by the individual (Ganster, 2008; Hart and Staveland, 1988). Two individual factors which affect the experience of stress and workload are those of worker arousal, which refers to the state of the worker's mental activity, and worker experience (Matthews, 2001). Arousal provides an explanation for the effect of stressors on human performance, and suggests that both under- and over-arousal may cause potential problems in the work environment (Matthews, 2001). For worker experience, the more experienced the worker is, the less strain she will exhibit (Fairclough *et al*., 2005). Some task related factors that affect stressors, resulting in high intrinsic demands placed on the worker, include visual scanning tasks for multiple conditions, tasks that require written instructions to be read, decision making, calculation and remembering information (Embrey *et al*., 2006). Low workload conditions or low work-related stressors usually include discrete actuation of controls, continuous adjustment of controls, performance of well learned and highly routine activities, detection of simple audio alarms, and the orientation to sounds (Embrey *et al*., 2006).

While workload and stress are related, they can also be seen as involving two separate approaches which differ in theoretical and methodological background (Gaillard and Kramer, 2000). The workload approach focuses on the efficiency of performance in complex tasks, while the stress approach is predominantly focused on the work-health relationship and the psychosocial factors of the environment (Gaillard and Kramer, 2000). This research adopted a combined approach in that psychophysiological variables were assessed in conjunction with analysis of task execution, in order to better understand the workload imposed on the worker. All tasks rely on cognition and information processing to enable them to be carried out effectively (Shepherd, 2001). As a result of this, the majority of tasks elicit some level of mental workload. Mental workload refers to the worker's ability to meet the required information processing demands of the task (Wilson and Eggemeier, 2001), and human information processing models have been proven useful when analysing mental workload (Embrey *et al*., 2006).

HUMAN INFORMATION PROCESSING

For an individual to complete a task efficiently, a degree of information processing is required in order to respond to the stimuli and to coordinate the actions needed to perform the task (Carswell and Stephens, 2001; Shepherd, 2001). Numerous information processing models are available to understand the way human information processing occurs for goal-directed behaviour (Carswell and Stephens, 2001). Most of these models propose that the stimulus or task information is internalised and interpreted, and that an appropriate response is then selected (Carswell and Stephens, 2001; Shepherd and Stammers, 2005). These models propose that the information passes through a system of stages where, at each stage, the information is transformed and retained in different stores, such as the short-term sensory store, working memory and long-term memory (Carswell and Stephens, 2001). Depicted in Figure 3 is a combined general information processing model that features the different stages and information stores.

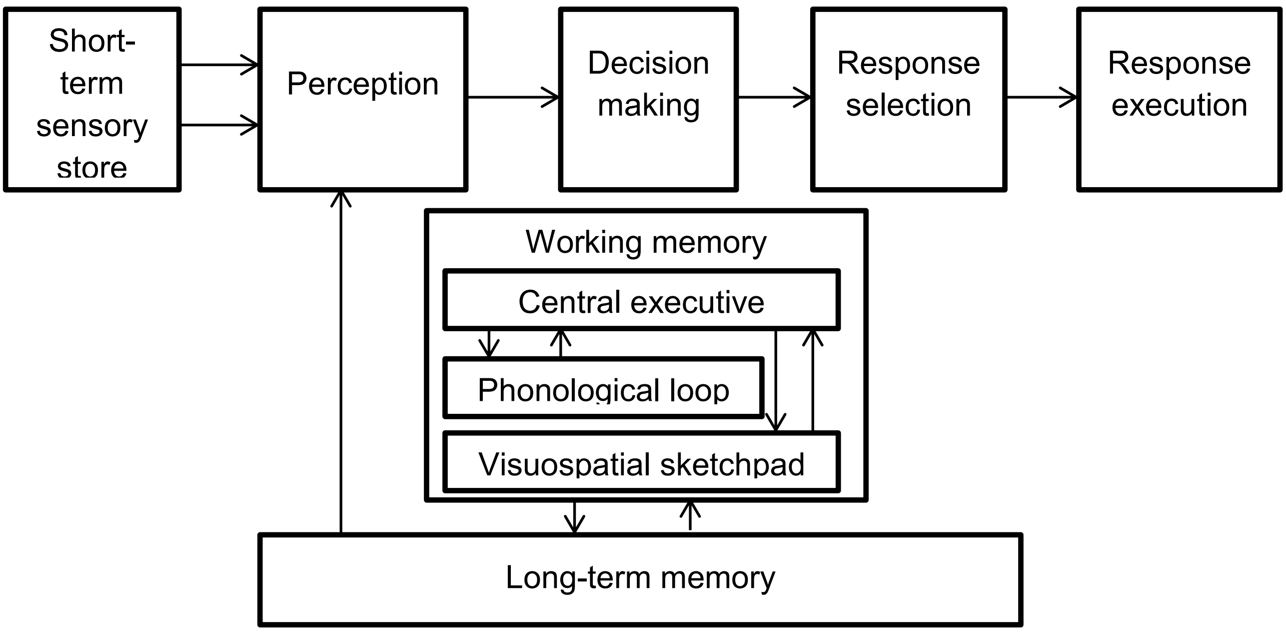


Figure 3: An information processing model based on the work of Atkinson and Shiffrin (1968), Baddeley (1997) and Wickens (1992) (Carswell and Stephens, 2001).

The incoming stimulus is initially stored in the sensory register, which stores a large amount of sensory information, but only for less than one second. If attention is not devoted to this information, it rapidly deteriorates and is forgotten (Carswell and Stephens, 2001). The information, if attended to, is then processed by perception, progressively using higher centres of the nervous system (Wickens, 1985), and is analysed to form separate objects that can be identified (Carswell and Stephens, 2001). This processing stage is affected by the complexity of the task, as it will influence the attention required (Wickens, 1985) as well as higher order processes such as beliefs and motives (Carswell and Stephens, 2001).

The information is then further processed by the working memory, alternatively called the short-term memory, which integrates internal information with the perceived information to allow the operator to make a decision and select a response (Carswell and Stephens, 2001; Bridger 2009). A degree of processing occurs with and without attention (Proctor and Read, 2001) and, as the information perceived can be temporarily preserved, attention may be diverted elsewhere during this process (Wickens, 1985). Despite this, the information is only stored for a short period of time (Carswell and Stephens, 2001; Bridger, 2009). The limitations to the working memory are usually considered as a limiting factor of the information processing chain (Carswell and Stephens, 2001).

From there the information is then transferred to the long-term memory, where it is stored at a semantic level linked to various structures, including words and rules (Bridger, 2009), in order to be recalled at a later point in time (Wickens, 1985; Carswell and Stephens, 2001). The long-term memory store has little or no capacity constraints, but failures can occur as a result of the information not being initially successfully encoded, or as a result of retrieval problems, including interference from irrelevant information and lack of associations with easily retrieved memory cues (Carswell and Stephens, 2001). Once a decision has been made using the consolidated information, the operator then proceeds to execute the selected response (Carswell and Stephens, 2001).

Information processing is affected by numerous factors which, in turn, will affect the overall cognitive performance and workload of that task, including the number and types of stages of information processing required for a task (Carswell and Stephens, 2001). An additional factor that may affect the information processing chain is the performing of multiple tasks concurrently (Proctor and Read, 2001). When the worker is required to divide her/his attention for one or more tasks, concurrent processing of multiple sources of information is required and bottlenecks may result (Proctor and Read, 2001; Bridger, 2009).

With the use of information processing models, in addition to workload assessment techniques, workload can be comprehensively assessed and understood in order to assist the worker. Techniques need to be selected with regard to whether a workload or a stress approach has been adopted (Gaillard and Kramer, 2000). In addition to the measurements selected, conclusive background information regarding the task in relation to organisation and environmental factors needs to be obtained in order to comprehend the context wherein the workload is created (OGP, 2010).

ANALYSING WORKLOAD

Due to the complexity of workload, there are numerous approaches to assessing this concept, for example from the subjective, objective and psychophysiological aspects (Kumashiro, 2005). Within these different aspects are a number of possible methods. The selection of methods and measures is dependent on which different aspects relating to workload are to be the focus of the research, and in which work environments the analysis is to occur. The environment in which the analysis is to occur provides the researcher with limitations to the methods and measures available (Shepherd, 2001). This research took place within a hospital environment and, as a result, was limited to the use of ambulatory psychophysiological measures, while being as unobtrusive as possible. The method best suited for this research was a task analysis used in conjunction with subjective ratings and psychophysiological measures.

TASK ANALYSIS

Task analysis is an approach that uses various tools to collect information in order to describe and decompose a task into elementary components with the aim of analysing the necessary human performance requirements (Shepherd and Stammers, 2005; Annett and Stanton, 2000; Weinger and Slagle, 2002). This approach provides a system-specific context of the task requirements regarding necessary skills and knowledge of the worker, in addition to any performance and behaviour influencing factors (Phipps *et al*., 2008; Shepherd and Stammers, 2005), and as a result it promotes human-centred design (Bridger, 2009; Phipps *et al*., 2008). As this tool provides large quantities of qualitative data (Bridger, 2009), it can be used to analyse complex work systems, identify weaknesses in order to improve productivity and reduce errors (Shepherd, 2001), identify potential bottlenecks within the system (Carstens, 2006), and improve worker safety, well-being and satisfaction (Phipps *et al*., 2008; Shepherd and Stammers, 2005). In addition to these, task analysis can also be used to determine workload and potential influencing factors (Shepherd, 2001; Ainsworth, 2001).

Task analysis, through the use of tools such as observation, questionnaires, interviews and work samples (Burke, 2005; Shepherd and Stammers, 2005; Ainsworth, 2001), requires the consideration of the constituents of the task, interactions between individuals performing the task, constraints and the environment in which the task occurs (Watts and Monk, 2000). There are two main stages in a task analysis namely the stage of task description and, leading from this, the second stage which is a more detailed analysis of the task (Shepherd and Stammers, 2005; Ainsworth, 2001). The task description stage requires defining the worker requirements in operational terms to complete the task (Burke, 2005; Shepherd and Stammers, 2005), while the task analysis stage analyses the behavioural structure of the task by assessing the different activities required to complete the task (Shepherd and Stammers, 2005; Ainsworth, 2001). In order to better understand the human requirements of the task, the different task components are considered in terms of information processing models (Weinger and Slagle, 2002; Shepherd and Stammers, 2005; Burke, 2005). Numerous models are available to analyse the task, depending on the goal of the analysis and the type of task (Ainsworth, 2001).

The type of task analysis that is selected is dependent on the purpose of the analysis and may be done to determine knowledge requirements and training needs, to identify errors, or to assist with device and interface analysis (Stanton and Annett, 2000). This method of studying work has been used in a variety of work contexts (Watts and Monk, 2000) and has a broad application base (Shepherd and Stammers, 2005) as well as often being a precursor for various other tools such as reliability analyses or risk assessments (Bridger, 2009; Ainsworth, 2001).

As task analysis can vary from a general perspective to a highly detailed perspective, as well as being a lengthy and resource exhaustive process, limitations to the analysis need to be set, based on the reasons and requirements of the analysis (Shepherd, 2001). The tasks to be analysed and the depth of the analysis are identified through several means such as the reason for the analysis, requirements and specifications for the analysis (Shepherd, 2000). One technique used to assist in identifying which tasks to analyse as well as identifying when to cease an analysis is the P x C rule which was developed from the critical incident technique (Annett and Duncan, 1967 as citied in Shepherd, 2001).

Critical Incident Technique and the P x C Rule

The critical incident technique is an analysis methodology proposed by Flanagan (1954) which analyses activity requirements with specific focus on the critical requirements of the task (Flanagan, 1954) that have been demonstrated to make a difference between the success and failure of completing this task (Shepherd, 2001). This technique has been further developed as a rule of thumb, the P x C rule (Annett and Duncan, 1967 as citied in Shepherd, 2001), which can be used for the identification of which tasks to analyse and when to cease an analysis (Flanagan, 1954; Shepherd, 2001).

The P x C rule assists with determining whether a task needs to be analysed on the basis of the probability of inadequate performance (P) and the cost of an error occurring (C) (Annett and Duncan, 1967; as citied in Shepherd, 2001). This rule is usually applied informally as a judgment process and selects significant operations or tasks for analysis. A task that fails the P x C criterion is defined as a significant operation (Annett, 2005). If a task is likely to be carried out well (low but finite P), but error will result in a catastrophe such as loss of life (unacceptably high C), then P x C implies unacceptable risk and examination of that task must follow (Annett, 2005; Shepherd and Stammers, 2005). If a task is likely to be carried out badly (high P), yet the resultant error is of no consequence (insignificant C), then P x C will be insignificant and the task will not be worth examining. Tasks and sub-goals that are classified as significant may then need to be altered to ensure that the risk of error is reduced (Shepherd and Stammers, 2005).

Once the tasks and the depth of the analysis have been identified, the specific task analysis method is implemented (Shepherd, 2001). There are various methods available for task analysis depending on the main objective of the analysis and the characteristics of the task, for example cognitive task analysis, team task analysis (Burke, 2005) or hierarchical task analysis (Shepherd and Stammers, 2005). Hierarchical task analysis best suited the aims of this research, and therefore will be described in more detail.

Hierarchical Task Analysis

Hierarchical task analysis (HTA) was developed in 1967 by Annett and Duncan (Shepherd, 2001) and provides a framework to analyse tasks by systematically decomposing a task into the necessary goals in order to meet the overall task requirements (Ainsworth, 2001; Phipps *et al*., 2008; Shepherd, 2001; Shepherd and Stammers, 2005). This technique is based on systems theory to explain complex systems and human performance (Shepherd, 2000; Shepherd 2001). Systems theory states that subsystems interact in order to achieve the goal of that system, and the interaction occurs as a result of inputs and outputs from various subsystems (Shepherd, 2001). As a system is predominantly not in isolation and is subject to a wider context, the system within which the task exists needs to also be considered including the environment and interactional effects (Shepherd, 2001). As humans have a versatile nature of coping with tasks demands and potentially numerous ways exist to achieve task goals, tasks need to be analysed from the perspective of demands that need to be met (Shepherd, 2000; Shepherd, 2001).

HTA requires the task to be expressed in terms of a goal that the worker is required to attain (Shepherd and Stammers, 2005; Shepherd, 2001). This is then further divided into sub-goals and plans which can be analysed in terms of input, action and feedback (Ainsworth, 2005; Shepherd and Stammers, 2005; Annett, 2005). Input refers to information and initiating stimulus from the environment, action refers to the process of the attainment of the goal and feedback refers to the indications of goal attainment (Shepherd, 2000; Annett, 2005). The sub-goals alternatively referred to as operations, can then be categorised as actions, communications, monitoring, or decision making (Shepherd 2001; Ormerod *et al*., 2000). Plans provide the necessary timing and sequencing relationships in order to obtain the overall goal (Ainsworth, 2001; Shepherd, 2001; Shepherd 2000) and allow for the capturing of greater detail and potential complexity of tasks (Ainsworth and Marshall, 2000). There are six prominent forms of plans namely fixed sequences, contingent sequences, choices, optional completion, concurrent operations and cycles (Shepherd, 2001; Shepherd and Stammers, 2005) but most plans used in HTA are composites of these types of plans. From this information, one should then be able to infer which tasks contain monitoring, judgment and decision-making tasks (Ainsworth, 2001; Shepherd and Stammers, 2005). As a holistic approach is required for task analysis, the results of the analysis will determine the hypotheses for potential solutions and will identify the cost-benefits. This will lead to the goal potentially being re-described (Shepherd, 2001).

An advantage of this technique is that it can provide a very detailed perspective of a task resulting in an exhaustive analysis, which assists the analyst to ensure that no important subtasks have been excluded (Ainsworth, 2001). But with this advantage is an associated disadvantage in that this method, depending on the required complexity, can be quite time-consuming and lengthy in procedure (Annett, 2005).

Despite this, this task analysis method is a flexible tool, and can be adapted to a range of purposes (Annett, 2005) such as analysing team work, used for the development of staff training programmes, designing support documentation and, as it also allows for one to determine what is required for the tasks by the worker, it can assist human resource management to ensure systems are properly staffed (Shepherd, 2001). As a result of the information provided by this technique, HTA has often been used in error when other risk analysis methods would have been better, such as TAFEI (task analysis for error identification) and SHERPA (System Human Error Reduction and Prediction Approach) for predicting human error (Annett, 2005; Stanton and Young, 1999). HTA has been used in the numerous fields including the medical field studying clinical workflow in the operating room regarding surgeries (Stone and McCloy, 2004), in emergency rooms, pharmacies, in an intensive care unit with the focus of identifying and quantifying errors (Donchin *et al*., 2003), as well as for tasks performed by ward nurses, anaesthesiologists and radiologists (Weinger and Slagle, 2002).

HTA provides a framework of what individuals should do to complete a task, but that is not necessarily the means of how individuals complete the task in each scenario (Shepherd 2001). In order to assess and determine how to improve human performance, task analysis in the form of a behavioural task analysis, used in addition to other techniques, needs to assess how a task is physically completed (Shepherd, 2001). In conjunction with psychophysiological measures, subjective ratings and performance measures, task analysis can provide a more comprehensive indication of an individual's experienced workload than if these techniques were used in isolation (Shepherd and Stammers, 2005; Ainsworth, 2001; Gaillard and Kramer, 2000; Boucsein, 2001).

PSYCHOPHYSIOLOGICAL VARIABLES

Psychophysiological variables are physiological responses that give an indication of the psychosomatic state of an individual (Brookhuis, 2005; Gaillard and Kramer, 2000; Boucsein, 2001; Kumashiro, 2005). As these variables are based on the assumption that physiological response patterns reflect psychological states such as cognitive and emotional behaviours (Boucsein, 2001), they have been recurrently used as an index of the level of cognitive demand associated with a task (Boucsein and Backs, 2000). Psychophysiological variables provide the most information when used with a multivariate approach to integrate behavioural, performance, subjective and physiological data (Boucsein, 2001). Using this multivariate type of approach allows for the study of concepts such as arousal, information processing, learning, work strain, emotion, motivation and stress (Boucsein, 2001).

As these variables can be measured using ambulatory methods and provide indications of physical and cognitive loads, they have been adapted to study work strain and evaluate task load (Brookhuis, 2005; Gaillard and Kramer; 2000). During a task, the worker will produce a behavioural response to the task demands, a subjective response to the current emotional state and finally produce a physiological response to the physical demands of the task (Gaillard and Kramer, 2000). In addition to the physical demands, both the behavioural and emotional response will also be reflected through physiological reactions (Gaillard and Kramer, 2000). This makes psychophysiological variables a versatile tool that may provide a great deal of information regarding the worker’s current state (Kramer, 2001).

Psychophysiological variables allow for the analysis of complex task environments as that data can be captured fairly unobtrusively, easily and continuously in the work environment without hindering the workflow and performance (Brookhuis, 2005; Boucsein, 2001; Boucsein and Backs, 2000; Gaillard and Kramer, 2000; Kramer, 2001). These measures are affected by workload and effort which is normally the focus of the study, but are also affected by stress, emotions, physical environment and physical exercise as well as the internal and external environment (Gaillard and Kramer, 2000). This may initially appear as a disadvantage but, as things do not occur in isolation, it provides a more accurate current state of the worker as s/he completes the task (Gaillard and Kramer, 2000). These variables have numerous advantages and, when utilised correctly, they provide valuable insight into the worker’s current state (Boucsein, 2001); but for this to occur the disadvantages associated with these variables need to be considered. One of these considerations is that when utilising psychophysiological variables, the majority of these variables have been only validated in the laboratory (Gaillard and Kramer, 2000). Also an additional disadvantage is that there is a large variability of single responses between individuals as well as over time and therefore data needs to be interpreted after repeated measures or after aggregation on a group level (Gaillard and Kramer, 2000).

Several psychophysiological variables include heart rate, blood pressure, ectodermal activity, eye movements and endocrine measures (Boucsein, 2001; Brookhuis, 2005; Boucsein and Backs, 2000; Kramer, 2001). As this research aimed to assess workload, a multivariate approach was adopted using the psychophysiological measures associated with heart rate in addition to subjective measures and behavioural analysis. A large amount of information is obtainable from heart rate measures, with the variables providing different pieces of information (Schubert *et al*., 2009). Heart rate measures provide indications of both physical and cognitive workload in that physical and cognitive strain shows in the variation of heart rate frequency and cognitive effort is predominantly indicated in heart rate variability (Boucsein and Backs, 2000).

Heart Rate, Stress and Workload

Heart rate frequency is the rhythm produced by the autonomous cardiac system (Kapitaniak, 2001) at which deoxygenated blood is pumped to the lungs and oxygenated blood pumped to the rest of the body (McArdle *et al*., 2007). It is measured as the number of heart beats per minute (Dick, 2007; Mulder *et al*., 2005) and the normal range of most adult’s resting heart rate falls between 60 and 90 beats per minute (Kapitaniak, 2001). The demands placed on the body are reflected in heart rate frequency (Kumashiro, 2005) and as a result of this, this variable can be used to determine the effort exerted or the strain experienced by an individual (Noakes, 2001; Schubert *et al*., 2009; Boucsein, 2001). The demands an individual is exposed to may be physical, cognitive or emotional stress (Boucsein and Backs, 2000) and as the demands increase, so heart rate will increase to supply the necessary oxygen to the tissues (McArdle *et al*., 2007). Because of this, the type of activity an individual is participating in will influence heart rate and this hence can be used as an indicator in workload studies (Kumashiro, 2005).

Heart rate is influenced by numerous factors including physiological factors such as various intrinsic controls like the sinoatrial node, and extrinsic controls like hormonal controls, sympathetic and parasympathetic neural input, and non-modifiable and modifiable factors (McArdle *et al*., 2007; Seeley *et al*., 1995). Non-modifiable factors include factors include age and sex (Trew and Everett, 2001), and modifiable factors include posture, blood pressure, lifestyle, cognitive workload, stress, environmental influences (Kapitaniak, 2001), excess body weight and physical activity (Valentini and Parati, 2009). One such influential modifiable factor on the cardiovascular system is stress, whether it is physical or psychological in nature (Morméde *et al*., 1990 as citied in Lemaire and Mormède, 1995).

The exposure to stress or any demand on the body results in an increase in heart rate frequency as a result of the activation of the sympathetic nervous system and the inhibition of the parasympathetic nervous system (Kapitaniak, 2001; Trew and Everett, 2001; Taelman *et al*., 2008; Valentini and Parati, 2009). During these occurrences, the motor centre in the brain is responsible for recruiting the required muscles for the task (McArdle *et al*., 2007). The somatomotor central command centre transmits impulses along afferent nerves to the cardiovascular centre in the medulla (McArdle *et al*., 2007). This results in the heart and blood vessels adjusting to allow for sufficient tissue perfusion so that the necessary oxygen is pumped to the muscles that need it (Trew and Everett, 2001).

As the somatomotor central command centre is involved in this process, this allows for the explanation of why emotional and cognitive states also affect cardiovascular responses (McArdle *et al*., 2007; Hjortskov *et al*., 2004). Emotional stress situations, such as working under time constraints, individual anxieties, increased responsibility and occurring of an accident or danger, can also lead to an increased heart rate (Kapitaniak, 2001). During these emotional reactions, suprarenal catecholamines are steadily released, and this results in an accelerated heart rate (Kapitaniak, 2001).

Heart rate has been used predominantly to assess the cardiovascular strain placed on the body, but heart rate has also been shown to increase as a result of cognitive stress (Mulder *et al*., 2005; Kumashiro, 2005). Tasks that demand a moderate level of cardiovascular intensity are more susceptible to heart rate changes as a result of factors other than workload, such as emotional stress and cognitive workload (Mackinnon, 1999). As both physical and cognitive demands result in eliciting autonomic reflexes which cause fluctuations in heart rate (Garde *et al*., 2002), additional analyses are required to attempt to differentiate between the effects these sources have on the body (Kumashiro, 2005; Gaillard and Kramer, 2000). Research then began to focus on the interbeat interval during heart rate observation and the practical use of heart rate variability in workload research (Kumashiro, 2005; Taelman *et al*., 2008). From this development, it was determined that heart rate variability could be used to assess the influence of cognitive stress on an individual (Vuksanovic and Gal, 2007; Kumashiro, 2005).

Heart Rate Variability

Heart rate variability refers to the variations of time durations between heartbeats (Mulder *et al*., 2005; Acharya *et al*., 2006) or alternatively the oscillations between consecutive heart beats (Rowe *et al*., 1998; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). This variability manifests as alterations in the wavelength and amplitude of the heart rate frequency, or alternatively heart rate acceleration or deceleration (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996; Acharya *et al*., 2006). The two main sources of this variability are the respiratory sinus arrhythmia and spontaneous fluctuations predominantly related to short-term blood pressure control (Mulder *et al*., 2005). The latter occurs as a result of continuous changes in the sympathetic and parasympathetic balance (Karim *et al*., 2011). This measure is most commonly used to investigate the central regulation of the autonomic system (Acharya *et al*., 2006), physiological and psychological processes such as information processing (Rowe *et al*., 1998), and mental effort and stress (Mulder *et al*., 2005; Kapitaniak, 2001; Kumashiro, 2005; Task Force of the European Society of Cardiology and the North

American Society of Pacing and Electrophysiology, 1996). Despite certain studies not finding an association between mental effort and heart rate variability (Vicente *et al*., 1987; Garde *et al*., 2002), the majority of the research suggests that, as cognitive or mental effort increases, so heart rate variability in all frequency bands decreases (Mulder *et al*., 1981; Rowe *et al*., 1998). These measures have become a popular addition to research regarding cognitive workload and effort (Taelman *et al*., 2008; Rowe *et al*., 1998) due to its non-invasive nature (Acharya *et al*., 2006; Rowe *et al*., 1998) and rapid response to changes in cognitive workload (Rowe *et al*., 1998).

Heart rate variability is determined from either the R-R interval tachogram or by obtaining a continuous signal as a function of time (Acharya *et al*., 2006; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). There are two predominant methods available to interpret heart rate variability, namely time domain analysis and frequency domain analysis (Sztajzel, 2004; Taelman *et al*., 2008; Valentini and Parati, 2009), and within each of these domain methods there are various statistical methods available for analysis with the selection of the statistical method dependent on the particular aim of the study (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

Time Domain Analysis

Time domain methods are among the more simple methods of heart rate variability analysis (Acharya *et al*., 2006; Karim *et al*., 2011). They analyse the changes in heart rate for R-R intervals between normal heart beats or for successive interbeat intervals for a specific time period (Acharya *et al*., 2006; Sztajzel, 2004; Kim *et al*., 2009). This analysis technique however does not differentiate between sympathetic and parasympathetic activity (Acharya *et al*., 2006). The SDNN variable is an example of a time domain variable which calculates the standard deviation of all the N-N intervals for a specific time period from intervals between normal heart beats is (Kobayashi *et al*., 1999, Sztajzel, 2004; McNames and Aboy, 2006) but for this variable, durations assessed need to be of the same duration (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Examples of time domain variables calculated using statistical methods from differences between intervals used in this research include the pNN*x* and rMSSD as these variables correspond to short-term heart rate variability changes (Sztajzel, 2004). The rMSSD refers to the square root of the mean of the squared differences between successive N-N intervals in milliseconds (Sztajzel, 2004) while the pNN*x* refers to the percentage of differences between successive N-N intervals that are greater than *x* milliseconds, where *x* can be any value above 0 milliseconds (Kim *et al*., 2009; Mietus *et al*., 2002; Karim *et al*., 2011).

Frequency Domain Analysis

The frequency domain analysis provides information regarding the amount of variance in heart rate explained by periodic oscillations at various frequencies (Karim *et al*., 2011) that are elicited as a result of the autonomic nervous system (Kobayashi *et al*., 1999). Frequency domain analysis is calculated either using Fast Fourier Transformation or autoregressive techniques (Acharya *et al*., 2006; Sztajzel, 2004). For this study, heart rate variability determined using the Fast Fourier Transformation was utilised, which transforms the N-N intervals into bands of different frequencies (Sztajzel, 2004). There are three frequency bands calculated from short-term recordings of 2 to 10 minutes that range from 0 to 0.5 Hz namely, the very low frequency (VLF), the low frequency (LF), and the high frequency (HF) components (Rowe *et al*., 1998; Acharya *et al*., 2006). A fourth frequency band, the ultra-low frequency (ULF), is only used for long-term recordings (Sztajzel, 2004). Multiple studies have demonstrated that short-term measures of heart rate variability rapidly return to baseline values after momentary disturbances (Rowe *et al*., 1998) which makes them useful indicators of cognitive workload (Kumashiro, 2005).

The HF band, or respiratory sinus arrhythmia band (Kumashiro, 2005), is measured at frequencies between 0.15 to 0.4Hz. It reflects respiration (Gaillard and Kramer, 2000; Schubert *et al*., 2009) and serves as an indicator of parasympathetic activity (Acharya *et al*., 2006; Karim *et al*., 2011; Redondo and Del Valle-Inclán, 1992). The LF band, which is as a result of the Mayer-wave-related sinus arrhythmia component (Kumashiro, 2005), is measured at frequencies between 0.05 to 15Hz (McNames and Aboy, 2006), and reflects blood pressure regulation, task situation and body temperature control (Karim *et al*., 2011; Gaillard and Kramer, 2000). While some research suggests that the LF band results from sympathetic nerve activity, the majority of the research suggests that it also reflects both sympathetic and parasympathetic nerve activity (Kobayashi *et al*., 1999; Valentini and Parati, 2009) as a result of the baroreceptor reflex (Acharya *et al*., 2006; Kumashiro, 2005; Kobayashi *et al*., 1999; Karim *et al*., 2011; Redondo and Del Valle-Inclán, 1992). The LF band is said by some to provide the greatest indication of cognitive workload (Rowe *et al*., 1998), while others have suggested that the heart rate variability measures that reflect parasympathetic nervous activity are the more sensitive indicators of mental stress (Hjortskov *et al*., 2004). The VLF band, which is measured at frequencies between 0.003 to 0.05Hz, provides an indication of sympathetic activity (Redondo and Del Valle-Inclán, 1992) and reflects thermoregulation of the body (Kobayashi *et al*., 1999). The fourth frequency band, the ULF band, is measured below frequencies of 0.003Hz and reflects the circadian rhythm (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).

In addition to using the frequency bands in the analysis of heart rate variability, the central frequency, total power, and LF to HF ratio can be used to provide additional information (Sztajzel, 2004). The central frequency and the power of the LF and HF may provide indications of autonomic changes in heart rate (Karim *et al*., 2011), while with regards to the LF to HF ratio, literature is unclear about the information this measure provides (Sztajzel, 2004; Karim *et al*., 2011). Some literature suggests that the LF to HF ratio can be used as an indicator for the balance between sympathetic and parasympathetic activity (Sztajzel, 2004), while other literature suggests that, as a result of the LF band reflecting both sympathetic and parasympathetic activity, this variable is more of an indicator of sympathetic activity (Karim *et al*., 2011; Kobayashi *et al.*, 1999).

The significance and interpretation of results using heart rate variability is fairly complex, and therefore there is the potential for incorrect conclusions (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). In a simplified form, when an individual needs to expend mental effort during a task, heart rate increases while heart rate variability decreases in all frequency bands when compared to a resting situation (Mulder *et al*., 2005). But the researcher needs to consider that heart rate variability varies from one individual to the next and is influenced by numerous factors such as age, gender, environment (Taelman *et al*., 2008), body posture, health (Acharya *et al*, 2006), emotions, physical activity, time of day, and stress (Karim *et al*., 2011).

Using heart rate measures to determine workload has the advantage that one can constantly monitor the worker with very little inconvenience and interference (Kapitaniak, 2001). But a disadvantage that the researcher needs to bear in mind is that, when using heart rate and heart rate variability measures, the response does not hold under all circumstances and the most stable results are usually obtained during short-duration laboratory tasks (Mulder *et al*., 2005). As heart rate variables reflect both loads, physical and psychological, these variables need to be used in conjunction with other methods such as work behaviour observation (Kapitaniak, 2001), task analysis and subjective ratings in order to be able to establish which load is causing the strain and what is responsible for the reaction indicated by heart rate (Kumashiro, 2005, Boucsein, 2001).

SUBJECTIVE RATINGS: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION-TASK LOAD INDEX

The National Aeronautics and Space Administration-Task Load Index (NASA-TLX) is a subjective workload assessment tool that provides an overall workload score (Young *et al*., 2008) and was developed by the Human Performance Group at the NASA Ames Research Laboratory (Hart and Staveland, 1988). This tool provides an indication of overall subjective workload and the effect of specific contributing factors of the task (Mazloum *et al*., 2008; Hart and Staveland, 1988).

As the NASA-TLX is based on the definition of workload as a result of loading imposed by various sources, it comprises a two-part evaluation system where six different subscales and their weightings determine an overall workload score (Hart and Staveland, 1988; Luximon and Goonetilleke, 2001). The weighting system allows for the consideration of the various workload contributors, and this is necessary as the effect of these various factors on different tasks is not uniform (Hart and

Staveland, 1988; Young *et al*., 2008). The rater is required to give a numerical rating for each scale that reflects the magnitude of that factor in a given task following the execution of the entire task, during the task, or after task segments (Human Performance Research Group). The weighting, which increases the sensitivity of the tool, uses the rater's perspective to determine the loading of these factors through a pair-wise comparison among the six factors which, in turn, will affect the overall workload score (Hart and Staveland, 1988; Human Performance Research Group). Of the six subscale ratings, three dimensions relate to demands (mental, physical and temporal demands) and three to the interaction of an individual with the task (effort, frustration, and performance) (Young *et al*., 2008). Each of the subscales, their description and the endpoints of the scale are described in Table I.

The NASA-TLX has been proven by Hill and colleagues (1992) to provide a sensitive and reliable measure of total subjective workload. It has been extensively validated by a study which tested both the adequacy of the six subscales to characterise variations in workload sources (that the weights with respect to the workload source are accurate for that task) and also tested the sensitivity of the overall workload score within and between tasks (Hart and Staveland, 1988). The individual subscales have been previously used by Mazloum and colleagues (2008) to gain more insight regarding the overall subjective workload. They found that the type and level of loading imposed on separate capacities of the participants were distinguishable.

The advantages of this tool are that it is non-invasive, inexpensive, has high face validity (Young *et al*., 2008), and is easy to obtain and use (Bowers and Jentsch, 2005). Furthermore it allows for fairly easy data capturing in operational settings as ratings can be easily and quickly given by the participant (Hart and Staveland, 1988). It has been tested in a variety of experimental tasks in the field and laboratory studies where the derived workload scores have been found to have considerably less between-rater variability than one-dimensional workload ratings, as well as providing indicative information about the sources of load (Young *et al*., 2008). This tool is widely regarded as the strongest one available for reporting perceptions of workload (Young *et al*., 2008; Bowers and Jentsch, 2005).

Table I: NASA-TLX rating scale definitions (Hart and Staveland, 1988)

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

Even though the NASA-TLX was developed for the aeronautics industry, several studies have used this tool in various other industrial fields, whether alone, in conjunction with other workload measures or in combination with physiological measures, and it proved to be a reliable workload assessment tool (Young *et al.*, 2008). The NASA-TLX has been used to evaluate subjective workload in psychology (Haga *et al*., 2002), in the aeronautical (Becker *et al*., 1995; Rantanen *et al*., 2004) and transportation industries (Harbuk and Noy, 2002), as well as in technology-related fields, for example computer-related work (Mayes *et al*., 2001). However, only limited studies have reported on its use in the healthcare field. It has been used to compare anaesthesia provider workload in various cases involving both doctor and nursing staff (Weigner *et al*., 2004; Young *et al*., 2008), to evaluate the use of graphic monitors related to patient treatment (Aggutter *et al*., 2003) and to evaluate the subjective mental workload of cardiovascular critical care nurses (Greg, 1993).

HOSPITAL ERGONOMICS

Healthcare is differentiated from many other industries due to the main work object being human centred (Carayon and Friesdorf, 2006; Hignett, 2001). Healthcare needs to meet six requirements in the care that it provides, namely: to be safe, effective, efficient, personalised, timely and equitable (Institute of Medicine Committee on Quality of Health Care in America, 2001). The healthcare work environment is a sociotechnical system (Carayon and Friesdorf, 2006; Buckle *et al*., 2006) and, as this work system is dynamic and rapidly changing, it can be defined as a complex system (Carayon and Friesdorf, 2006; Janowitz *et al*., 2006). In a sociotechnical system, many tasks require interaction not only with the patient but also with numerous machines (Carayon and Friesdorf, 2004). In addition to this healthcare requires team work, as numerous members work towards the common goal of providing healthcare even if not all of them have direct contact with the patient (Carayon and Friesdorf, 2006; Janowitz *et al*., 2006). The amount of contact with the patient is dependent on the specific services that these workers provide to meet the patient’s healthcare requirements. One of the most predominant working forces that comes in direct contact with patients in the hospital setting is that of the nursing staff (Coovadia *et al*., 2009; Van der Walt and Swartz, 2002).

Nursing, which is a female-dominated profession (Yildirim and Aycan, 2008), requires a variety of tasks to be performed throughout the work day, the majority of these being patient-centred (Gurses and Carayon, 2009). The main goal of nursing is to provide the patient with care and treatment (Shepherd, 2001) and this is done through a range of tasks that vary from low intensity tasks, such as administrative work, all the way to more intense work involving patient care (Hignett, 2001). Administrative tasks include updating patient files and the related paperwork for discharging or admitting a patient (Gurses and Carayon, 2009).The more intense work tasks include such work as washing and feeding the patient, gathering information from the patient, and administering medication (Gurses and Carayon, 2009).

Nursing staff need to be able to follow rigid procedures as well as use their discretion for tasks where decisions regarding treatment and course of action are required (Shepherd, 2001). Interpersonal and social skills are required to interact not only with the patient but also with the various members of the healthcare team as well as the patient's visitors (Shepherd, 2001). The nurse needs to regularly monitor the patient both to ensure her/his health does not deteriorate and to detect declines in health as soon as possible (Shepherd, 2001). In addition to the above-mentioned skills, team work and good communication skills in nursing staff are required (Shepherd, 2001). This is necessary as patients require continuity of care, 24 hours a day, and nursing staff need to work as a team and liaise with other shifts to try and provide this (Shepherd, 2001). To this end, continuous records of treatment and the patient status throughout the shift need to be kept (Shepherd, 2001). Nurses also need to collaborate with doctors and other staff in the healthcare environment in order to treat the patient (Shepherd, 2001; Carayon and Friesdorf, 2004). Because of these various subsystems working together to provide healthcare to the patient, the potential for communication errors arises (Carayon and Friesdorf, 2004). As a result of the dynamic and diverse nature of nursing work (Hignett and Richardson, 1995), with its emotional and psychological component of caring for patients (Janowitz *et al.*, 2006; Hignett and Richardson, 1995), it is often classified as demanding, highly repetitive (Lee-Treweek, 1997 as citied by Hignett, 2001), physically fatiguing (Janowitz *et al.*, 2006; Hignett and Richardson, 1995) and associated with high levels of work stress (Munro *et al*., 1998; Verhaeghe *et al*., 2008; Chang *et al*., 2006).

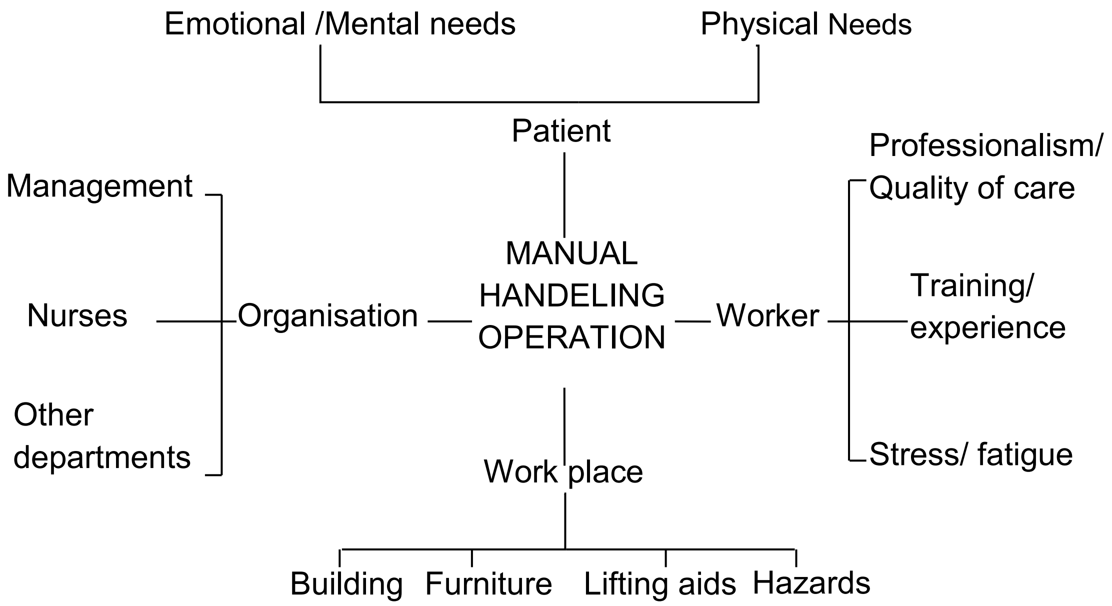


Figure 4: A model of factors which influence patient handling and impact on nurses' stress (Hignett and Richardson, 1995).

A model of factors which influence manual patient handling has been described by Hignett and Richardson (1995), but this model can be applied more broadly to identify potential influencing factors for patient-centred tasks, which in turn would influence nursing workload (Hart and Staveland, 1988). This model is depicted in Figure 4. The patients themselves play a large role in the task of patient care as the tasks centre on them (Hignett and Richardson, 1995). A difficult and non-compliant patient will increase the difficulty of the task for the nurse in comparison to a willing patient (Carayon and Friesdorf, 2006). Similarly the nurses' own attributes, such as experience and current physical state, will also play a very important role not only in how the task is approached but also in how it affects the experience of workload (Gurses and Carayon, 2009; Hignett, 2001). Organisational factors will also have a direct effect on the task the nurse is to perform; an example of this is a reduced number of staff results in each nurse having to perform more tasks (Gurses and Carayon, 2009; Hignett, 2001). For the context of workload, the work place with regards to available equipment (Hignett, 2001) and the type of ward where the nurse is working may also have an impact (Carayon and Gurses, 2008). As healthcare can be defined as a complex system, with this comes the characteristic of uncertainity which manifests itself as imperfect information regarding numerous factors related to the patient (Carayon and Friesdorf, 2004).

The workload experienced by nurses can be measured on four levels, namely, on the situation or patient levels which are embedded in the unit and job levels (Carayon and Gurses, 2008). One of the ways of measuring workload at a unit level is by assessing nurse-patient ratio (Carayon and Gurses, 2008; Joubert, 2009), which is the number of patients compared to the number of available nurses to provide care for these patients (Joubert, 2009). This ratio can be measured across an entire medical facility or for each ward which provides a more accurate measure (Joubert, 2009). A high nurse-patient ratio has been associated with having a negative impact on patient outcomes (Carayon and Gurses, 2008). This workload assessment technique assesses workload at a macro level and does not consider contextual or organisational characteristics of a particular environment (Carayon and Gurses, 2008). Workload assessment at a job level considers the demands specific to the ward wherein the nurse works but fails to consider specific contextual influences on nursing for nurse workload (Carayon and Gurses, 2008). At the patient level, workload is said to be predominantly influenced by the patient's condition (Carayon and Gurses, 2008). But, similar to the previous levels, this one also does not consider all the necessary contextual influences (Carayon and Gurses, 2008). A fourth level, suggested to account for all the shortcomings of the previous three, is that of assessing workload on a situation-level (Carayon and Gurses, 2008). This level encompasses all of the above-mentioned considerations in the other levels (Carayon and Gurses, 2008).

As a result of the numerous challenges that the healthcare system faces, the work environment is becoming increasingly stressful for nursing staff (Hallin and Danielson, 2007). The nursing workload in itself is a large cause of stress in the psychological sense (Chang *et al*., 2006) and this is exacerbated by the worldwide nursing shortages (Lambert *et al*., 2004). The stress and workload associated with nursing occur as a result of numerous factors, one of them being organisational context and work environment. As the organisational context and work environment are culturally influenced and country-specific, one needs to consider the specific context in order to understand the context wherein the nursing staff work (Lambert *et al*., 2004).

THE SOUTH AFRICAN CONTEXT

Prior to 1994, as a result of the Public Health Amendment Act of 1897, race influenced access to health services (Coovadia *et al*., 2009). Racial discrimination has since been removed from the healthcare system (Van der Walt and Swartz, 2002) and the public health system has been transformed since 1994 (Coovadia *et al*., 2009). Through redirecting the funding to previously disadvantaged areas, the government has aimed to improve and deliver better healthcare for all races (Coovadia *et al*., 2009; Benatar, 2004). Despite this being one of the main goals of government, the primary healthcare system still faces a substantial human resource crisis as a result of emigration of healthcare professionals (Vujicic *et al*., 2004) and diseases such as HIV and TB which exacerbate this situation (Coovadia *et al*., 2009; Benatar, 2004).

Within the South African healthcare system there are private and public sectors. The public sector is funded with taxpayers' money and is usually under-resourced and over-utilised as this caters to about 80% of the population (Brysiewicz and Bruce, 2008), while the private sector only caters to about 20% of the population (Coovadia *et al*., 2009). This has a direct effect on the public healthcare staff's workload. To address this imbalance in resource and demand mentioned above, partnerships between the public and private sectors have started to collaborate, and an example of this is Settlers hospital in Grahamstown (South Africa.info, 2007).

The public hospital sector has three tiers, namely tertiary, regional and district sectors (Coovadia *et al*., 2009). In the primary healthcare system, district services, including hospitals and community health centres, are predominantly nurse-driven and this affects the ward and hospital organisation (Coovadia *et al*., 2009; Van der Walt and Swartz, 2002). The ward organisational practice adopted in the South African hospital environment is that of task orientated nursing, characterised by the division of labour (Van der Walt and Swartz, 2002). Task orientation has become a routine practice in the South African public healthcare setting, probably because it is included in the tertiary education nursing syllabus (Van der Walt and Swartz, 2002). An advantage of this organisational practice is that it enables nurse managers to maintain maximum control over the performance of the staff (Van der Walt and Swartz, 2002). To become a professional or registered nurse, one needs to complete a 4-year university degree, or a 4-year nursing diploma at a nursing college (Brysiewicz and Bruce, 2008).

Trauma is one of the leading causes of death in South Africa, and many patients in the healthcare system are victims of violence or trauma (Brysiewicz, 2002; Abdool and Brysiewicz, 2009). As a result, nurses are exposed to high levels of emotional stress associated with treating such patients (Abdool and Brysiewicz, 2009). These nurses are also exposed to difficult working circumstances, with limited resources of both equipment and staff, and rapidly increasing HIV and TB cases (Brysiewicz and Bruce, 2008). Increased stress, both in workload and financial terms, has been placed on the public health system as a result of the AIDS epidemic (Coovadia *et al*., 2009) and as a result of a decrease in the number of nurses available to work, due to migration not only to other countries but also from the public sector to the private sector (Coovadia *et al*., 2009). A report by Bateman (2009) suggests the nurse-patient ratios in the public health sector is about 1 to 18 patients with certain areas, such as the Eastern Cape where the ratio is up 1 nurse to 50 patients. Sub-Saharan countries, South Africa included, are suffering from an unparalleled out-migration of nurses (Chirwa *et al*., 2009). This migration of healthcare professionals adversely affects the healthcare system but also in turn affects the workers remaining in the country (Vujicic *et al*., 2004). In South Africa, as a result of inadequate staff levels, nurses are often overburdened (Brysiewicz, 2002) and in addition to this they are expected to work with suboptimal equipment (Brysiewicz, 2002) and worsening working conditions (Kingma, 2007). Some of the reasons for migration out of South Africa are heavy workloads, crime, violence, and a declining health service (Vujicic *et al*., 2004). As a result of these it is important to understand nurses' working conditions and to attempt to improve them and heighten job satisfaction (Chirwa *et al*., 2009).

Heavy nursing workloads not only affect the nurse, but are also related to reduced levels of patient care (Carayon and Gurses, 2008). As a result of heavy nursing workload, nurses have less time to perform the required duties, and this may result in errors occurring in their work (Carayon and Gurses, 2008). Errors in this area are not only costly from a financial perspective but may have severe consequences regarding patient health (Berguer, 1999; Carayon and Friesdorf, 2004). Because of the above-mentioned facts, ergonomic designs and interventions can play a crucial role in improving nursing workload and potentially reducing nursing error (Carayon and Gurses, 2008). To date, ergonomic research has investigated problems in intensive care units and gastrointestinal endoscopy, as well as care workers and medical and surgical staff nurses (Berguer, 1999). Ergonomic research has also assessed nurses' perceptions regarding work strain (Milisen *et al*., 2004), manual handling in nursing work (Hignett and Richardson, 1995; Hignett, 2001), work-related musculoskeletal disorders (Hignett and Richardson, 1995; Karwowski *et al*., 2005), stress and coping related to nursing (Lambert, 2004; Munro *et al*., 1998; Chang *et al*., 2006) and the relation between nursing work and home settings (Yildirim and Aycan, 2008; Van den Berg *et al*.,2006). Despite this fair amount of research into this field, as the healthcare environment is a complex work system that is dynamic and changing with the development of technology (Carayon and Gurses, 2008), additional ergonomic research is required to better understand this system.

CHAPTER III
METHODOLOGY

AIMS AND OBJECTIVES

The aim of this study was to establish the strain experienced by healthcare workers associated with various patient-centred hospital tasks during a day shift. In this context, three objectives were defined. The first objective was to establish through the assessment of psychophysiological responses the strain level of specific hospital tasks. The second objective was to, through task analysis; establish qualitatively the components of various hospital tasks. The final objective within this study was to identify potential strain-influencing and performance shaping factors.

The information determined in this phase of the research is intended to broaden the understanding of strain associated with specific tasks in the hospital workplace, and to identify possible factors that affect the experience of the strain resulting from these tasks. This will assist in identifying areas that need attention and may require alterations. Furthermore, this research should contribute to a better understanding of the demands placed on Eastern Cape nurses and should provide a base for intervention to reduce the strain and to optimise efficiency of the daily hospital organisation. This will improve not only the working environment of the worker but also patient treatment quality by identifying possible tasks that may need more attention or supervision. The data obtained in this study also provides the background and the foundation for Section Two.

RESEARCH CONCEPT

This research concept, based on the extended stress-strain concept of Luczak (1975, as citied in Luczak and Göbel, 2000) as depicted in Figure 5, was aimed at determining the strain levels caused by the workload of nurses performing specific hospital tasks, and identifying potential contributing factors. The areas of interest to this study within the stress-strain concept are depicted by the bold boxes in Figure 5.

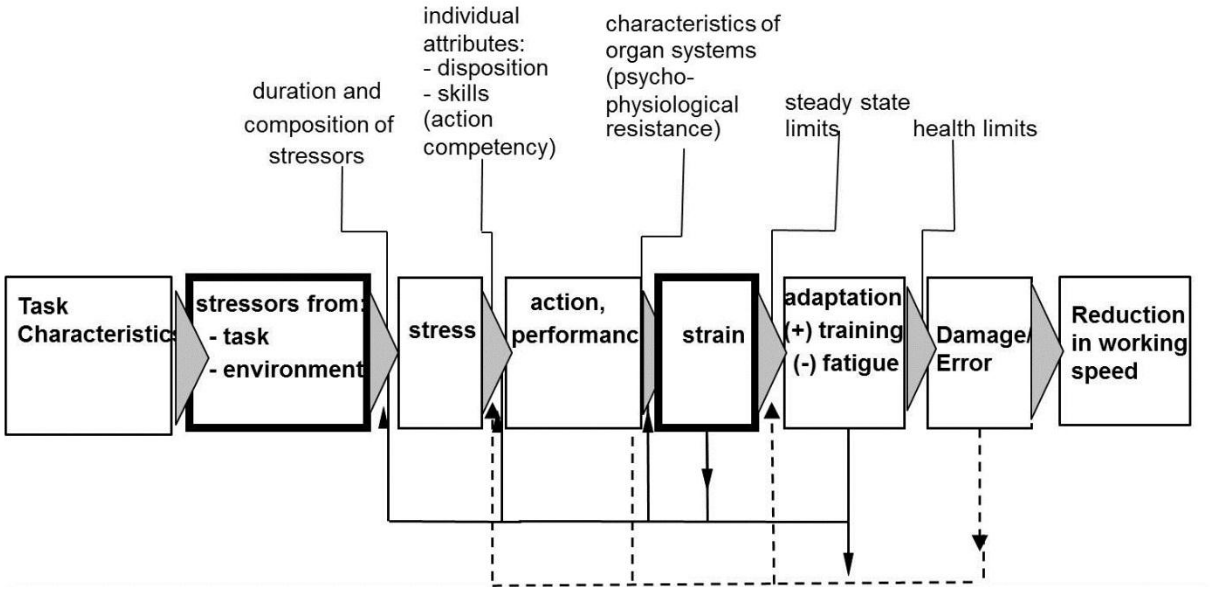


Figure 5: The extended stress and stain concept (according to Luczak, 1975, as cited in Luczak and Göbel, 2000).

This study focused on stressors, from a workload perspective, and the effects they have on the strain level experienced by nurses. The main stressor in the context of this research referred to the workload nurses were exposed to and the strain that resulted from the workload. As stress related to a task cannot be directly measured, strain, the unique individual experience of these stressors, was assessed (Matthews *et al*., 2000). Strain as a result of workload is an important work consideration as it will lead to adaptation, manifested as either training or fatigue (Bridger, 2009). Strain levels were assessed using psychophysiological measures as these provide an indication not only of physical workload but also of the subjective experience and mental effort required (Mulder *et al*., 2005; Kumashiro, 2005). Different tasks elicit different levels of strain which can be due to the differing task requirements, durations or situational contexts (Hart and Staveland, 1988). Furthermore, the stresses associated with a task originate from both the task components and the working conditions, and therefore a comprehensive task analysis was performed in conjunction with measuring strain level.

The strain level for the specific hospital tasks was established through a field-based study, as this provided an optimum medium to gather information on nurses in their work environment, and also included the effects of the organisational environment (Hendrick, 2005). Furthermore, this allowed for the identification of the worker-environment interaction required to complete the task (Stanton *et al*., 2005). All measurements were taken as unobtrusively as possible so as not to disrupt the nurses' work. This concept was studied at three different levels namely at a work environment, task structure and a task execution levels. The information gathered in this section of the research provided the basis for error probability to be assessed at a work environment level and a task structure level in Section two.

STATISTICAL HYPOTHESES

The independent variable for this study was the task stressors, which included the task characteristics and the organisational conditions assessed by the task analysis. The dependent variable was the strain experienced by the nurses, and this was measured through the use of psychophysiological responses and subjective ratings. This study aimed at explaining the part of variance in strain elicited by the task done, and not by the intra-individual variability. Furthermore, this research aimed to identify the variance caused by the various work factors that elicited the change in strain levels.

Null hypothesis 1, Ho: $\mu_{SL1} = \mu_{SL2} = \mu_{SL3}$ ...
Alternative hypothesis 1, H_A: $\mu_{SL1} \neq \mu_{SL2} \neq \mu_{SL3}$ ...
Where:

SL1= Strain level experienced by the nurse for task 1

SL2 = Strain level experienced by the nurse for task 2

SL3 = Strain level experienced by the nurse for task 3

PROTOCOL

PILOT STUDY: OBSERVATION PHASE

The pilot study included several observation sessions and meetings in the hospital. From the meetings held with the hospital management, the infrastructure of the hospital and the context and availability of areas for research were established, and the necessary approval to conduct research in Settlers Hospital was obtained. Following these meetings, several observation sessions were spent in the hospital to determine the functioning of the nurses in the different wards and to determine the number of nurses that could be observed at one point.

Two wards were identified as suitable areas for this research, owing to the similar nature of the tasks performed there, the available participant size, and the environment allowing for testing and observation. The wards were the government surgical ward and the government medical ward.

EXPERIMENTAL DESIGN

This protocol consisted of three different analyses, namely a work environment, task structure and task execution analyses. As a large portion of the data captured was qualitative in nature, to assist with analysing this data, the results obtained were categorised according to these three analyses. The experimental design of this study is depicted below in Figure 6.

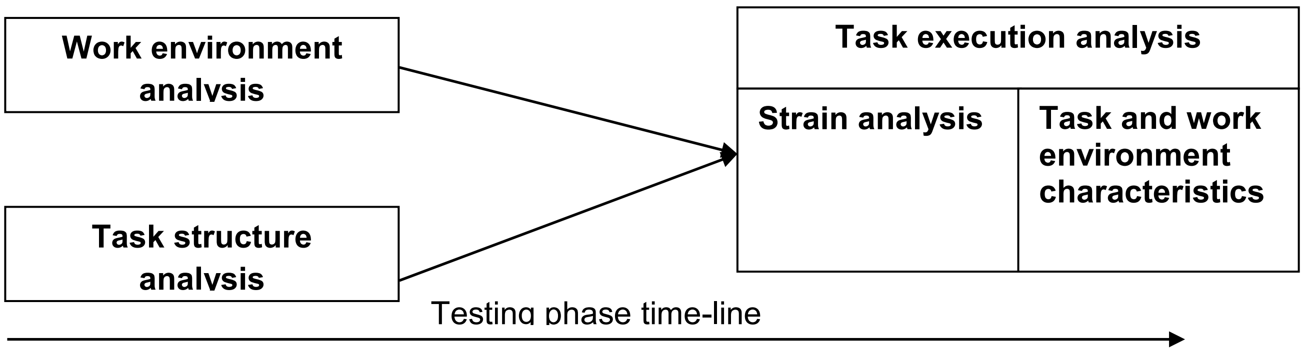


Figure 6: The experimental design and layout of this field study.

All data collection took place within the government surgical and medical wards at Settlers Hospital in Grahamstown. The first and second analyses, the work environment and task structure analyses, were performed in conjunction using a questionnaire, observation phase and a series of interviews. The objectives of the work environment analysis were to determine the organisational structure within the relevant wards as well as to identify which tasks should be analysed in further detail. The workers' physical and organisational environments influence the experience of strain and how they experience workload (Hart and Staveland, 1988); therefore the environment was an important influencing factor that needed to be considered. The tasks that were identified in the work environment analysis became the focus of the task structure analysis, and they needed to meet the requirements of being a daily routine task, a patient-centred task and a critical task. Tasks were defined as critical if an error in this task had a potential negative effect on the patient's health status. The task structure analysis aimed at determining the various task components using hierarchical task analysis, as it is necessary to determine the requirements of a task before one can perform a behavioural task analysis (Shepherd, 2001). Finally, the task execution analysis was performed to determine situational contexts for the tasks identified and the resulting strain levels for these tasks. The aim of the observation and behavioural task analysis, used within the task execution analysis, was to record components of the task as well as environmental factors and organisational influences, as the task occurred in real time.

As a large portion of this research was qualitative and was recorded using observation techniques, only one researcher conducted the research and standardised the data from one external perspective only (Stanton *et al*., 2005). To overcome the disadvantage, associated with observation techniques, of the effect of a researcher's presence on the nurses' behaviour (Stanton *et al*., 2005; Stanton and Young, 1999), the nurses were well habituated prior to testing.

PROCEDURE

Briefing and habituation

The nurses were informed about the purpose and procedure of the research prior to testing by the researcher in both oral and written form. Once nurses had agreed to participate, they were habituated to the researcher's presence during a two week period prior to the testing phase. Participants were habituated to the Suunto heart rate monitors for a period of one hour prior to the gathering of data on each testing day. The researcher found no literature indicating the required duration for the habituation process for heart rate monitors, but from previous experience had determined that an hour would be sufficient for participants to become comfortable wearing the Suunto memory belt. The participating nurses were informed prior to the commencement of this research that at no time would their individual results be made available to any outside sources.

Work environment analysis*: *questionnaire, observation and interview

The hospital work environment analysis was conducted using a questionnaire, observation phase and interviews. The questionnaire (Appendix A) aimed at ascertaining the daily routine of the staff, which tasks they would define as critical, rules and protocols in place to prevent errors and procedures in place once errors have occurred. The latter answer was required for Section 2, and was directed at the chief and senior professional nurses who are responsible for managing the wards and its staff. Tasks were defined as critical if an error in the tasks had a potential negative effect on the patient's health status. This concept was based on the *p x c* rule developed from the critical incident technique (Flanagan, 1954; Shepherd, 2001). The tasks identified using this technique became the focus of the task analysis that followed. During the observation phase, a work time analysis was performed in order to determine the normal routine adhered to by the nurses and the procedure of the tasks defined as critical. The questionnaire (Appendix A) also aimed at ascertaining the rules and protocols in place to prevent errors, and the procedures in place once errors have occurred (this information was required for Section 2). The data collected during the observation phase was verified by senior nurses through interviews prior to the task analysis being performed. The interview guidelines are attached in Appendix A.

Task structure analysis: task analysis and interview

For the routine critical tasks, using data that was collected via observation and with the use of subject matter experts, a hierarchical task analysis was performed to construct task descriptions and task decomposition diagrams (Shepherd, 2001). The observation phase for the task structure analysis occurred in parallel with the work environment analysis. Using the task description, the researcher identified the task goal and then decomposed this into the numerous sub-goals needed to obtain the main goal of the task (Shepherd, 2001). Each task decomposition diagram considered how each sub-goal was attained, what might happen during each task, what can go wrong and what the consequences may be (Shepherd, 2001), the latter being necessary for Section 2. The decomposition of the tasks into sub-goals was ceased once a sufficient level of detail had been obtained, defined as the point where further decomposition would add little supplementary information of value in terms of this analysis (Phillips *et al*., 2008).

These tasks were then analysed using a general information processing model (Carswell and Stephens, 2001) and hierarchical task analysis terms to give a better understanding of the task requirements (Shepherd, 2001). From the decomposition diagrams, tables were constructed for use during the task execution analysis and are attached in Appendix B. Prior to the task execution analysis, the task decomposition diagrams were verified by senior registered nurses through interviews done during the work environment analysis. As individuals do not always complete tasks in the prescribed manner, the hierarchical task analysis was only able to provide a basis for the task execution analysis. The task execution analysis then directly assessed how the tasks were completed, the resulting workload, and the environment in which the task was completed (Shepherd, 2001).

Task execution analysis

Before the start of testing, the nurses were fitted with a Suunto memory belt, to measure the nurses' heart rate and heart rate variability continuously throughout the dayshift. Also throughout the day, a task analysis was completed via random sampling by the researcher for critical tasks only, using the tables constructed from the decomposition diagrams. The table recorded the components of the task, the duration and any additional notes the researcher found relevant. Furthermore, the time of day when each critical task was performed was recorded in order to couple the heart rate data with the correct task. Up to three nurses were fitted with heart rate monitors and observed on one testing day. This was possible as often the nurses had different responsibilities in their daily routine, and not all the tasks they performed throughout the day would have been defined as critical. Once the critical tasks had been completed and when the situation allowed, the nurses gave their subjective ratings of workload using the NASA task load index (NASA-TLX) (Hart and Staveland, 1988).

Concurrently with the behavioural task analysis, an analysis of the organisational environment was performed. In the analysis of the organisational environment, the staff capacity, bed occupancy and number of interruptions during the task were recorded. Interruptions were defined as any activity that resulted in the halting of the current task and were divided into two categories, namely physical and verbal interruptions. Physical interruptions were defined as any activity that resulted in the nurse ceasing the task under observation and leaving her post to perform another task. Verbal interruptions were defined as any activity that resulted in the nurse ceasing the task under observation to verbally address the cause of the interruption while still maintaining her previous physical position.

During the day, at a suitable time, the nurses were required to perform a reference task. This consisted of sitting quietly for five minutes, followed by reading a short text for an additional five minutes, in order to determine a reference level for heart rate frequency and variability. The first five minutes of the reference task were used to negate any short-term effects on heart rate frequency of the previous task they had completed (McArdle *et al*., 2007). Reading was then used as the cognitive reference task and was required as there is a cognitive component to nursing work (Janowitz *et al.*, 2006). Furthermore, a reference task was required as heart rate measures, which were used as the strain indicators, are affected by many other stressors, including non-work-related and personal stress (Kumashiro, 2005), as well as varying within an individual between different days. As the reference task was standard for all participants, it allowed for the effective comparison of the data between participants and between days.

Each nurse was observed on at least two different days, and the testing was carried out while not interfering with the nurses' daily work requirements. If the need arose, for example if the patient needed attention while the nurse was giving subjective ratings, data collection for this study was interrupted. In the days that followed the data collection phase, the participating nurses were required to complete a questionnaire, attached in Appendix B**,** which ascertained information with regards to experience, and provided the weighting scores for the NASA-TLX. After testing, nurses were not individually debriefed; however they were debriefed as a group in the form of a presentation on the research and the findings after the project was completed.

EQUIPMENT AND TOOLS

HEART RATE MONITORS

Suunto memory belts were used to record heart rate and heart rate variability in order to indirectly measure the strain of the task (Kumashiro, 2005; Mulder *et al*., 2005). Heart rate frequency was measured in beats per minute (Dick, 2007), heart rate variability was measured as a percent for the pNN30 of the time domain analysis, and the frequency domain analysis was measured in milliseconds squared (Sztajzel, 2004). The belt was placed around the subject's chest in alignment with the sternum and slightly below the pectoralis muscle. The measurements were recorded by sensors in the memory belt which detected electrical impulses from the heart, and stored the data on the integrated memory chip. This information was downloaded and analysed after the testing session using the Suunto memory belt docking station and the Suunto training manager program, version 2.2.0.8.

NASA TASK LOAD INDEX

The NASA-TLX was used to assess subjective workloads of the critical tasks. This tool uses a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of six subscale ratings (Hart and Staveland, 1988). The six subscale ratings include mental demands, physical demands, temporal demands, own performance, effort and frustration. The nurse was required after the tasks to give a numerical rating for each scale that reflected the magnitude of that factor in that specific task. As the loading of each of these scales are not uniform for all tasks, it is necessary to weight these scales when determining the overall subjective workload (Hart and Staveland, 1988). The nurse was asked to do a pair-wise comparison of the six factors in order to determine which of the factor pairs was dominant in creating the level of workload experienced in performing that specific task (Hart and Staveland, 1988). The pair-wise comparison was included in the questionnaire that followed the testing procedure. These values were then used to weight the results from the six scales by multiplying each rating by the weight given to the factor by the nurse (Hart and Staveland, 1988).

ETHICAL CONSIDERATIONS

INSTITUTIONAL ETHICS APPROVAL

This study was approved by the Ethics Committee of Rhodes University on the 05 May 2011. Thereafter ethical approval was obtained from the Department of Health of the Eastern Cape on the 25 May 2011, attached in Appendix C, and the ethics board of Settlers Hospital approved the study on the 25 May 2011.

INFORMED CONSENT

All nurses were informed of the purpose and procedure of this study by the researcher prior to the any data collection in both written (Appendix C) and oral form and all participation was completely voluntary. During the work environment analysis, senior nurses consented by filling in the questionnaire, and during the interview phase, the nurses were provided with an information letter (Appendix C) and an informed consent form to sign (Appendix C). Each participant signed an informed consent form (Appendix C) prior to the task execution analysis.

PRIVACY AND ANONYMITY OF RESULTS

The participants' rights to privacy and anonymity were respected in that their names were not recorded in any of the electronic data. All participants were assigned reference codes and, after data capturing, any documents connecting the reference codes to the participants' true identity were destroyed. If the name appeared on any forms, after having assigned a reference code, this was made illegible. With respect to preserving the confidentiality of the data, none of the individual results were made available at any point in the study.

PARTICIPANT CHARACTERISTICS: TASK EXECUTION ANALYSIS

A total of fourteen nursing staff from the government medical and surgical wards agreed to participate in the task execution analysis. The nursing staff that participated in this study were qualified as a registered nurse, a staff nurse or nursing assistant. Care givers were excluded from this study as they have no nursing qualification, despite their occasionally performing similar tasks to the nursing assistants. The number of participants recruited from each ward and the number of different nursing staff recruited for this study are featured in Table II.

Table II: The number and distribution of nurses that participated in this study.

	Medical ward	Surgical ward	Total
Registered nurse	5	1	6
Staff nurse	2	2	4
Nursing assistant	3	1	4
Total	10	4	14

The mean age of all fourteen nursing staff was 41.36 years (± 10.15), with a total of 11.48 years (±10.03) experience, while the experience at this specific hospital was 11.12 years (±10.36). Featured in Table III, is the mean age, qualification, total nursing experience and nursing experience at Settlers Hospital for the registered nurses, staff nurses and nursing assistants as well as the group mean.

Table III: The age, qualification, total nursing experience and nursing experience at Settlers Hospital for nurses that participated in this study.

	Mean	**SD**	**CV**
Age:			
Registered nurse	38.83	10.32	0.27
Staff nurse	37.00	4.40	0.12
Nursing assistant	49.50	11.09	0.22
Total	41.36	10.15	0.25
Qualification (years of study):			
Registered nurse	3.67	0.82	0.22
Staff nurse	2.50	1.00	0.40
Nursing assistant	1.75	0.50	0.29
Total	2.79	1.12	0.40
Total nursing experience (years):			
Registered nurse	10.61	11.56	1.09
Staff nurse	3.50	1.73	0.49
Nursing assistant	20.75	2.99	0.14
Total	11.48	10.03	0.87

	Mean	SD	CV
Experience (years of work at Settlers Hospital):			
Registered nurse	8.38	12.06	1.44
Staff nurse	2.35	2.08	0.88
Nursing assistant	20.75	2.99	0.14
Total	11.12	10.36	0.93

The greatest variation is regarding the total nursing experience and the experience at Settlers for registered nurses. The registered nurses that participated in this study varied in experience from the chief professional nurse of the ward to a newly qualified nurse completing her community service year at Settlers hospital.

TASK CHARACTERISTICS: TASK EXECUTION ANALYSIS

The focus of the task execution analysis consisted of seven tasks from two different task categories established during the work environment analysis, namely patient monitoring tasks and medication tasks. The medication tasks consisted of administering injection and pill medication, as well as setting up intravenous (IV) medication and changing IV medication. The patient monitoring tasks consisted of measuring blood pressure (BP), temperature (Temp) and blood glucose levels (BG). The seven different tasks were completed by one or more of the above three categories of nursing staff and were the focus of the task structure analysis and the task execution analysis. A total of 331 tasks were observed in the medical and surgical wards over approximately a two month period. Featured in Table IV, is the number of each task observed during the data capturing phase for each of the wards.

Table IV: The number and distribution of nurses that participated in this study.

	Injection	Set up IV	Change IV	Pill	BP	Temp	BG
Medical	60	8	6	73	69	16	35
Surgical	13	1	0	38	10	2	0
Total	73	9	6	111	79	18	35

DATA AND STATISTICAL ANALYSES

WORK ENVIRONMENT ANALYSIS

The data obtained from the observation and questionnaires was qualitative in nature and the researcher compiled the data to identify commonalities. The data was used to create a daily routine of the nursing staff in the wards, as well as identify the organisational structure. Through the use of the questionnaire the tasks that both wards classified as critical were identified.

TASK STRUCTURE ANALYSIS

From the observation phase, decomposition diagrams were established and verified by subject-matter experts during the interviews. These diagrams, once verified, were used to create tables for the task execution analysis. Once in tabular format, these tasks were analysed according to a general information processing model (Carswell and Stephens, 2001) and hierarchical task analysis terms as provided by Shepherd (2001).

TASK EXECUTION ANALYSIS

Task and Work Environment Characteristics

During the task execution analysis, the number of interruptions, the staff capacity, the patient number, and the bed occupancy were recorded. The number of interruptions was analysed as a percentage of the number of tasks observed, and also determined the percentage of physical and verbal interruptions that occurred. The bed occupancy was calculated as a percentage of the number of beds occupied within that ward. The number of patients and the number of staff were used to determine nurse-patient ratios.

Strain Analysis

Before further analyses were performed, the heart rate data was reduced using the Rhodes University HKE reduction tool version 3.3.10. This tool cut the heart rate data of the shift into the required sequences for the necessary tasks. Furthermore, this tool allowed for the evaluation of HRV with a maximum of 40% variation between beats and the interval length for the analysis was set at 60 seconds. The tool provided heart rate variability data in the form of both time and frequency domains. Of the heart rate variability measure, from the time domain analysis a heart rate variability measure of pNN30 was selected, and from the frequency domain the measures of high and low frequency, in addition to the percentage of low frequency relative to the sum of the low and high frequency, were used. All the heart rate measures were relativised by determining the difference of the heart rate measure elicited by the task in comparison to the reference task calculated as a percentage of the reference task. As heart rate varies between and within individuals, by relativizing this measure, one is able compare the data between the participants and between days. This is depicted in the equation below.

$$\text{Reference heart rate measure} \qquad = \frac{(HR_{\mathrm{OT}} - HR_{\mathrm{RT}})}{HR_{\mathrm{RT}}} \times 100$$

Where: HR_{OT} = Heart rate measure for the observed task

HR_{RT} = Heart rate measure for the reference task

The reduced heart rate data and the task and work environment characteristics data were then incorporated into an excel table, which was transferred to the STATISTICA (Version 10.0) statistical software programme. Descriptive statistical analyses were run on all relevant variables providing general information regarding the sample. The mean and standard deviation was established for the heart rate frequency and heart rate variability measures for each of the specified task. General linear models were used to assess the data. One-way ANOVAs were calculated to determine whether the strain indicators were dependent on various factors such as duration, task, and nurse-patient ratio. The null hypotheses were tested at a probability of $p<0.05$, providing a confidence level of 95%. Pearson product-moment correlations were calculated for the strain indicators and nurse-patient ratio and the weighted scale scores of the NASA-TLX to examine the relationship between them.

CHAPTER IV
RESULTS

INTRODUCTION

The aims of this combined quantitative and qualitative study were to identify the strain levels of various hospital tasks as well as potentially strain-influencing and performance shaping factors. In order to meet this aim, the organisational and work environments were analysed in conjunction with the task and strain levels experienced by nursing staff. From three different analyses, different information regarding work structure and workload was determined. The structure of the results presented is depicted in Figure 7.

Work environment analysis:

- Organisational structure, division of labour and daily routine
- Routine critical tasks

↓

Task structure analysis:

- Information processing model
- Hierarchical task analysis

↓

Task execution analysis:

- Task and work environment characteristics:
    - Task duration
    - Performance
    - Interruptions
    - Staff capacity
- Strain analysis:
    - Heart rate
    - Heart rate variability
    - Subjective workload

Figure 7: Representation of the structure of the results

The work environment analysis was used to determine the organisational structure, the division of labour and the daily routine for the medical and surgical wards. In addition to this, the analysis assisted in determining which tasks were going to be the focus of the analysis that followed. During the task structure analysis, these specific tasks were then decomposed into their necessary components and analysed using various models, which formed the basis for the task execution analysis. The task execution analysis aimed at determining task and work environment characteristics in addition to the strain level of these tasks in specific situations.

WORK ENVIRONMENT ANALYSIS

The work environment analysis compromised a questionnaire, an observation phase, wherein a work time analysis was performed, and an interview in order to ascertain the daily routine within the ward, the division of tasks among nursing staff and the normal procedure of specific tasks. In addition to this the questionnaire, directed at chief and senior professional nurses, was used to ascertain the most critical tasks that would be the focus of the task structure analysis that followed.

ORGANISATIONAL STRUCTURE, DIVISION OF LABOUR AND DAILY ROUTINE

From the observation phase, it was established that the Settlers Hospital implements task-orientated nursing as the ward organisational practice. This organisational practice, which is routine practice in the South African public health sector, breaks down patient care into complete distinct tasks performed by different staff members on the ward (Van der Walt and Swartz, 2002). The management and staff structure within each ward are hierarchical, where staff of each tier are responsible for different aspects of patient care. This is depicted in Figure 8. The staff in the higher levels of the hierarchy would have to have a higher qualification and these nurses are allowed to perform more of the tasks required by nursing staff, and are delegated more responsibility and the more medically orientated and specialised tasks. Examples of this include assisting the doctor on doctor’s rounds, administering medication and supervising the staff on the lower tiers of the hierarchy. This research focused on tasks performed by the staff members in the grey shaded blocks in Figure 8, namely professional nurses, staff nurses and nursing assistants.

The staff organisation within Settlers Hospital

Figure 8: The hierarchical management organisation of wards within Settlers Hospital.

Within this hospital, different wards have different patient capacities and, as a result of the functions of different wards, the types of tasks performed may differ slightly from ward to ward, and therefore the number of staff assigned to each ward differs. In Table V, the number of each type of staff member per day shift, the total number of day staff and the number of staff per ward investigated are featured.

Table V: The number of staff for the day shift for the medical and surgical wards.

	Medical		Surgical	
	Per day shift	**Total (day shift)**	**Per day shift**	**Total (day shift)**
Total number of nursing staff	Approximately 12	20	9	15
Chief professional nurses	1	1	1	1
Senior professional nurses	1	1	At least 3	5
Professional nurses	3 or 4	6		
Staff nurses	2	4	At least 1	2
Nursing assistants	2 or 3	5	At least 3	5
Care givers	2	3	At least 1	2
Number of beds	52		25	

Nursing staff are allowed to complete different nursing duties in accordance with their different qualifications. Table VI shows the division of these tasks or duties among nursing staff for both the medical and surgical wards. The tasks in red were tasks performed only in the surgical ward in addition to the remaining tasks. For the daily routine, these tasks are then delegated to different staff who hold the necessary qualifications. An example of this is that two registered nurses will be assigned to the doctor's rounds for that specific day which will include completing the doctor's orders throughout the rest of the day. A different registered nurse will only be assigned to the routine injection duties for that day and this duty is required to be performed twice a day. On a different day, different registered nurses will be assigned to these duties.

Table VI: The tasks assigned to the nursing staff of the medical and surgical wards. Tasks done only in the surgical ward are indicated in red.

Nursing staff		
Registered nurses	**Staff nurses**	**Nursing assistants**
Take reports		
Wash patients		
Feed patients		
Admission of patients		
Phone for blood test results	Blood glucose checks	Monitor vital signs
Doctor's rounds	Prepare pill medication trolleys	Assist patients to change bed clothes
Intravenous medication	Administer pill medication	Transport patient to theatre
Administer injections	Dress wounds	
Discharge patients		
Order medication		
Prepare injection and intravenous medication trolleys		
Assess patient's condition		
Prepare patient for theatre		

From the work time analysis it was established that, with regards to daily routine, the nurses within Settlers Hospital have a daily routine with a partial rigid structure that requires a degree of flexibility with regards to task starting times. The interviews and questionnaire revealed that certain tasks are done routinely, such as monitoring patients' conditions in the form of measuring vital signs (measuring temperature, blood pressure and heart rate) and delivering medication to patients. Some tasks are only performed as the situation arises, such as admitting a patient, while other tasks are only performed when there is available time, for example the paperwork regarding discharging patients. Even certain routine tasks are dependent on other environmental cues. An example of this is doctors' rounds, a routine task that occurs once a day during a week day, but as the doctors are assigned to more than one ward, they arrive at the first possible opportunity and then the rounds must commence immediately. Attached in Appendix D is the daily routine in each of the wards studied with approximate starting times of the various tasks performed by the nursing staff. The interviews also revealed that the duration required to complete various task shifts are dependent on the number of patients and number of staff available.

ROUTINE CRITICAL TASKS

The general questionnaire aimed at the senior professional nurses determined which tasks from the daily routine can be defined as 'critical'. Tasks were defined as critical if the potential existed for a negative effect on the patient's health status as a result of an error. This selection criterion of tasks was based on the *P x C* rule (Annett and Ducan, 1967 as citied by Shepherd, 2001) which is explained in Chapter X: Methodology. Additional selection criteria included the need for routine tasks to be patient-centred, in order to ensure they occurred frequently enough during the testing phase to produce results. The tasks were selected based on the above-mentioned criteria utilised during the questionnaire and observation phase of this research.

From the two wards, using the questionnaire, tasks identified as critical included tasks pertaining to medicating patients, monitoring patients' condition, dressing wounds, patient assessment and maintaining the cot-side of the bed up. Tasks related to medicating patients included administering pill, injection and intravenous (IV) medications, while tasks related to monitoring patients' conditions included measuring temperature, blood glucose levels, blood pressure and heart rate. In the medical ward, patient assessment was defined as a critical task but this refers to a series of tasks and observations as opposed to a discrete task. As patient assessment is more of a continuous process comprising various tasks that occur throughout the day than a discrete task, this was excluded from further analysis. Individual tasks that fell within patient assessment were included in the analysis that followed.

In addition to the patient medication and monitoring tasks, the surgical ward defined as critical the keeping up of cot-sides of patient beds and dressing wounds. Maintaining the patient's bedrail up was excluded from further analysis as it is a precautionary requirement being performed when required as opposed to routine tasks. Dressing wounds, which is imperative in order to maintain sterility to prevent further infection in the patient, was excluded hereafter from the analysis as it was noted during the observation phase that this task occurs more infrequently when compared to the selected tasks.

The final sets of tasks analysed in depth were selected from the administering medication category and the monitoring patient condition category. Tasks within the administering medication category included pill medication, injection medication and IV medication, and tasks in the category of monitoring patient condition included measuring blood glucose, temperature, blood pressure and heart rate.

TASK STRUCTURE ANALYSIS

The task structure analysis, through the use of observation and various models, aimed at determining the task components and the underlying psychological components. Both task categories were initially analysed using a general information processing model and, thereafter, the tasks were considered in hierarchical task analysis terms, which provided a detailed decomposition of the tasks. This approach was used to obtain a better understanding of the task requirements from various perspectives and to provide a framework for considering different influences on performance. The analysis provided a foundation for the task execution analysis that followed.

INFORMATION PROCESSING

The human-task interaction was examined using the general information processing model based on the combined work of Atkinson and Shiffrin (1968), Baddeley (1997) and Wickens (1992) (Carswell and Stephens, 2001) and is depicted in Figure 9. Both task categories predominantly commenced as a result of a time cue, as these tasks were required to be performed at specific times during the day shift. While the tasks that fell within the patient monitoring category can be seen as information acquisition tasks, the tasks that fell within the administering of medication category can be seen as prescribed action tasks.

The tasks that monitored patient condition, depicted by the red blocks in Figure 9, were performed using procedural knowledge, embedded in long term memory, of how to assess these values. Once the condition levels for that patient were established, using the sensory register, perception and the working memory, the nurses, as a result of the condition level, needed to decide whether the value obtained was within a healthy range and, if not, what further action would be required. In terms of the general information processing model, this falls in the decision making, response selection and response execution stages.

For the tasks that fell within the administering medication category, which are depicted by the blue blocks in Figure 9, the first task component involved determining the required medication from the patient file. Using this external stimulus, working memory, perception and procedural knowledge embedded in long term memory, information regarding how to prepare the mentioned medication was recalled. This is then followed by the appropriate response selection, namely, the selecting, preparing and administering of the correct medication.

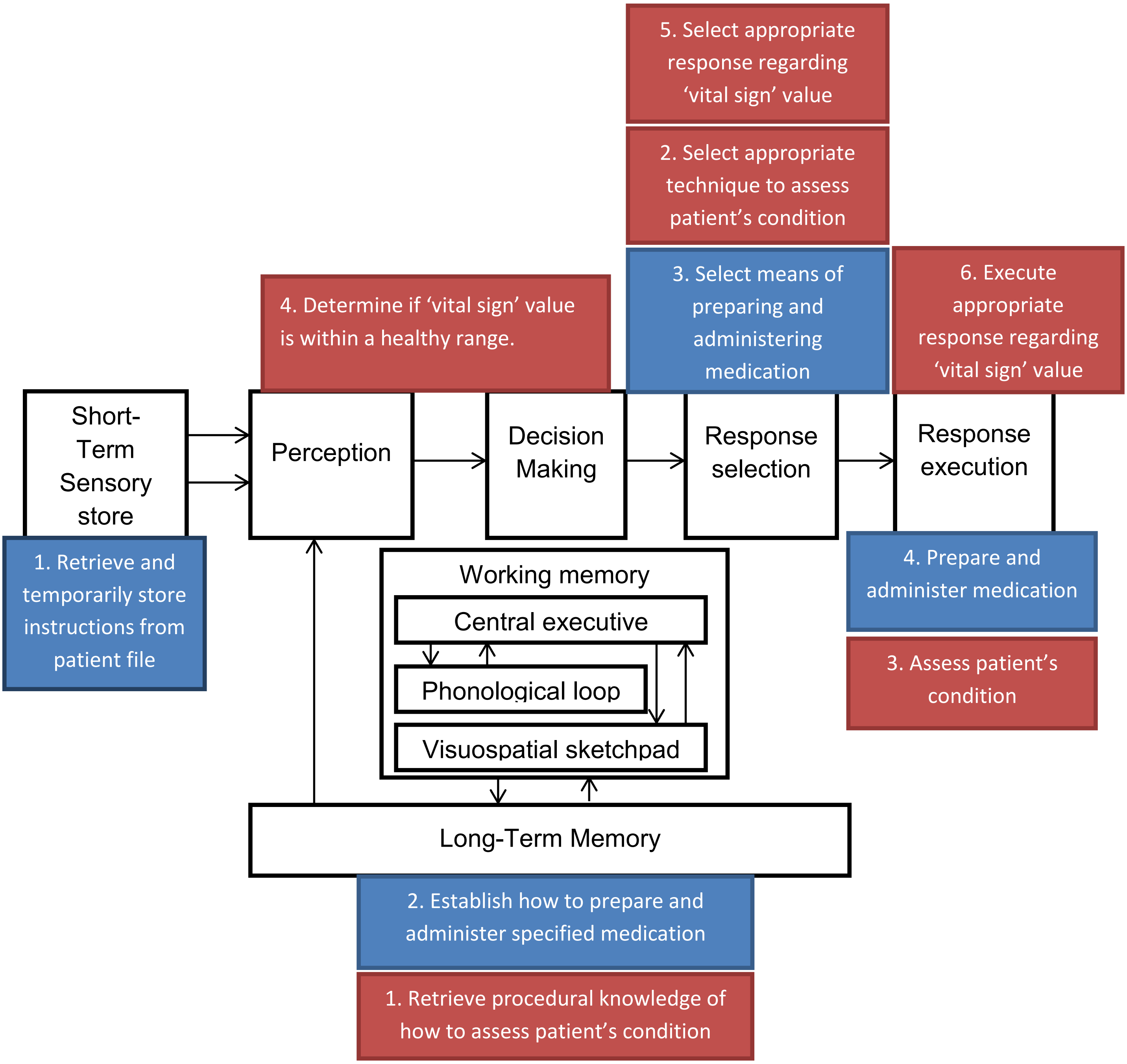


Figure 9: Steps for administering medication (in blue) and monitoring patient condition (in red) with regards to the general information processing model based on the combined work of Atkinson and Shiffrin (1968), Baddeley (1997) and Wickens (1992) (Carswell and Stephens, 2001).

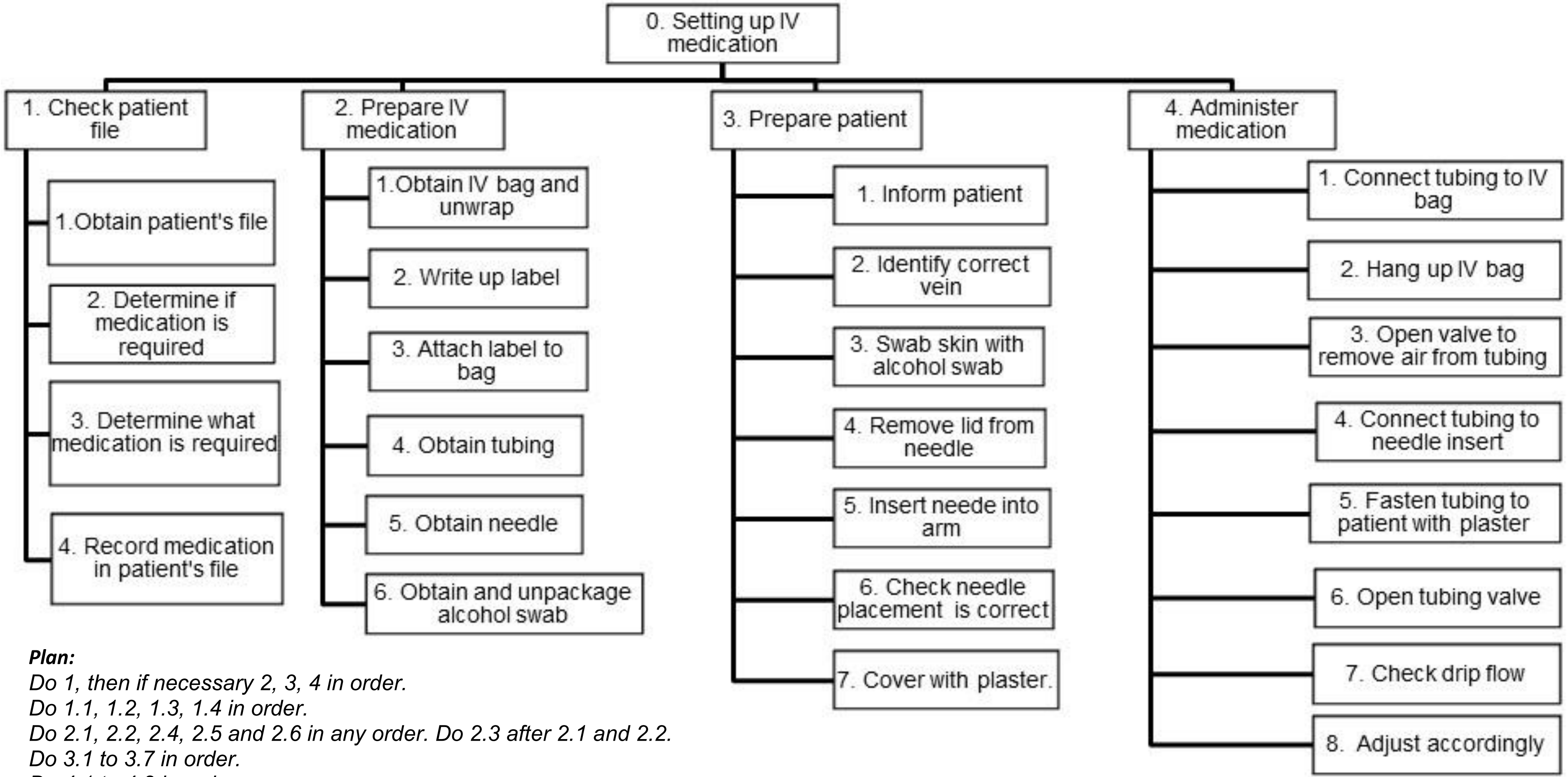
HIERARCHICAL TASK ANALYSIS

Administering medication tasks

According to hierarchical task analysis terms, this category of tasks can be classified as prescribed action tasks, the main goal being to administer medication to the patient as communicated via the patient file. All of these tasks contained several elements of communication, namely, obtaining the information regarding which medication was to be administered, communicating with the patient regarding the medication, and recording in the patient file the administered medication. The posture for all of these tasks was that of a standing position with the majority of the motor requirements being those of the upper body. Each individual task is analysed in more detail below. The tasks that fell within the administering medication category included administering pill, injection and IV medication. Injection and IV medication is only performed by registered nurses, while administering of pill medication is predominantly performed by staff nurses unless the pills are schedule 5 or 6 drugs, which require a registered nurse to administer them.

Setting up IV medication

This task can be described as the process of determining the correct medication required, inserting the drip entry site in the patient, preparing the IV medication and ensuring it is administered at the correct rate. This task and the decomposed goals and sub-goals are depicted Figure 10. The plan for the main goals 2 to 4 is contingent on the result of sub-goals 1.2 and 1.3, as the preparation and administering of the medication is dependent on the whether the patient requires the medication. The plan for the main goals 2 to 4 and sub-goals associated with goals 1, 3 and 4 is that of a fixed sequence, suggesting that this task has a more rigid structure and specific way of how to carry out this task. With regards to the sub-goals related to goal 2, there is a degree of flexibility as the nurse can elect the order of these goals, with the exception of goal 2.3 which can only occur once goals 2.1 and 2.2 have been achieved. Decisions are required at goals 1.2 and 1.3, while for goals 4.7 and 4.8, which form a cycle until the correct rate of IV medication administering is obtained, cognitive demands are required.



Plan:
Do 1, then if necessary 2, 3, 4 in order.
Do 1.1, 1.2, 1.3, 1.4 in order.
Do 2.1, 2.2, 2.4, 2.5 and 2.6 in any order. Do 2.3 after 2.1 and 2.2.
Do 3.1 to 3.7 in order.
Do 4.1 to 4.8 in order.

Figure 10: The hierarchical decomposition of the task of *Administering IV medication*.

Changing IV medication

The task description for the task of *Changing the IV medication* states that this task refers to the process of replacing the empty or incorrect intravenous medication with new intravenous medication and includes preparation and correct administering of the medication. The task decomposition into the required sub-goals is depicted in Figure 11.

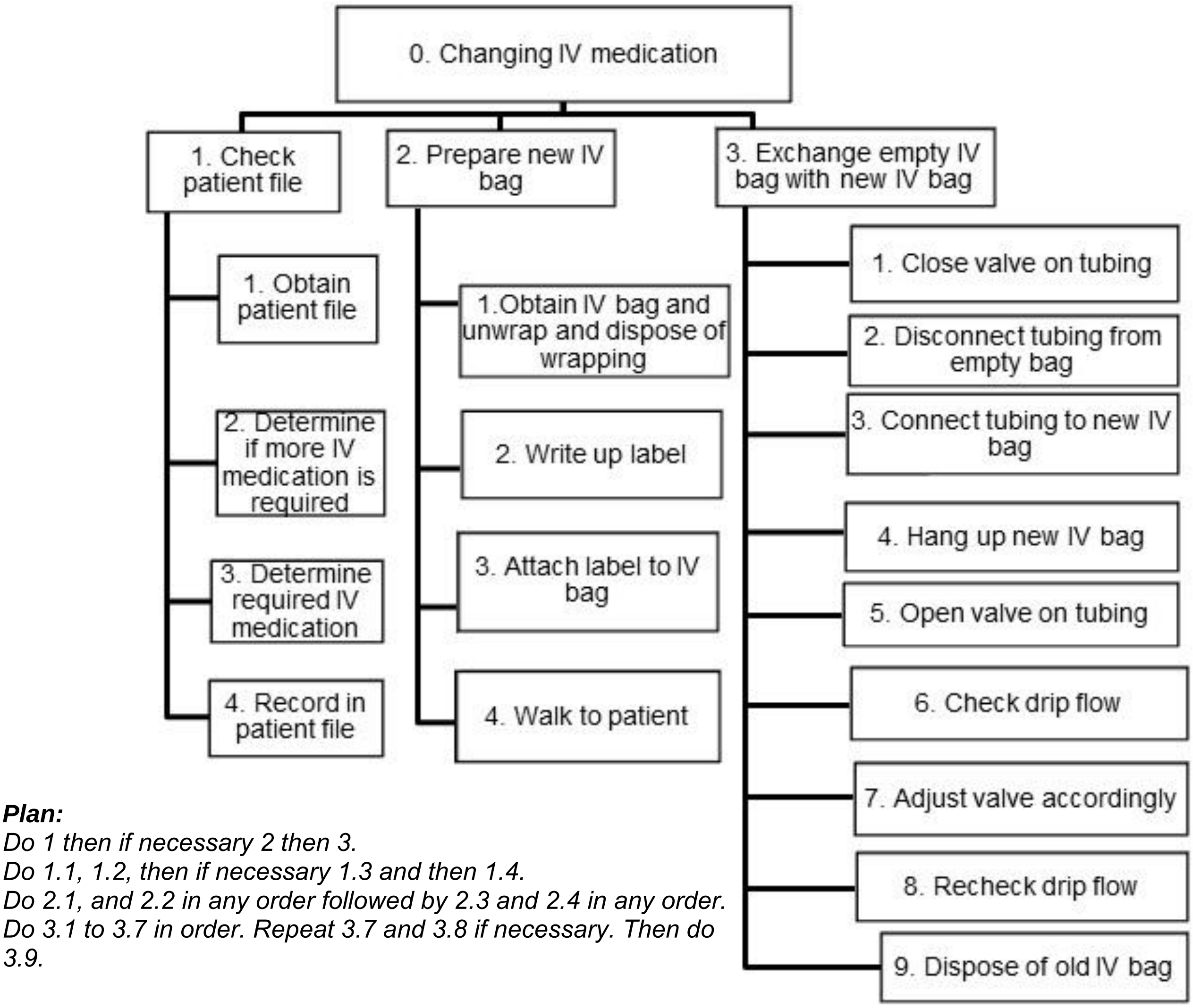


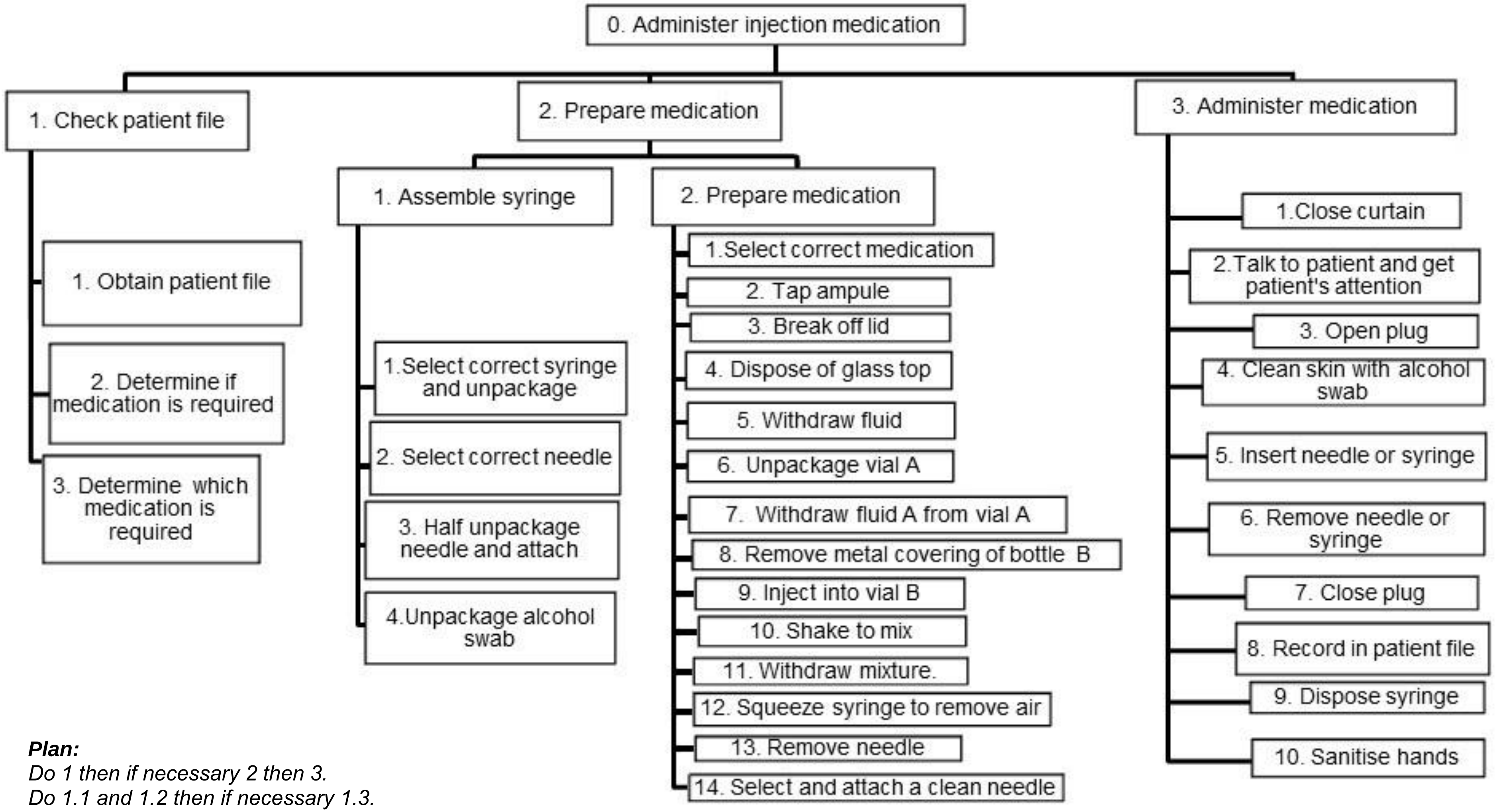
Figure 11: The hierarchical decomposition of the task of *Changing IV Medication*.

The plan for the main goals 1 to 3 is that of a fixed sequence, with the goal 1.3 and 1.4 being a contingent plan if more medication is required. Similarly to the previous task, the preparation and administering of the medication is contingent on the whether the patient requires the medication and so the plan for the main goals 2 and 3 is contingent on the result of sub-goals 1.2 and 1.3. Cognitive demands occur as a result of the decisions required for goals 1.2 and 1.3, as well as for goals 3.7 and 3.8, which form a cycle until the correct rate of IV medication administering is obtained. This task has a degree of flexibility as numerous goals the nurse can elect the order.

Administering injection medication

This task can be described as the process of determining, selecting, preparing and administering the correct injection medication required by the patient. The relationship between tasks and subtasks, as well as the resultant plans for deciding the order of the goals and sub-goals, are depicted in Figure12. Within this task, there are more sub-goals, alternatively understood as instructional steps to be followed, that need to be achieved in order to obtain the goals. As a result of this, this task may be classified as being more complex than the other tasks analysed in this category (Leplat, 1988) and result in a greater cognitive demand on the nurse.

The plan for the majority of the goals and sub-goals is that of a fixed sequence, suggesting that this task has a more rigid structure as the specifications for meeting the task requirements are stricter. The plan for the main goals 2 to 3 is contingent on the result of sub-goals 1.2 and 1.3, as the preparation and administering of the medication is dependent on the whether the patient requires the medication. The main goals of 2 and 3 are contingent on sub-goal 1.2, which indicates whether any medication is required. Similarly, how the medication is prepared is contingent on information from sub-goal 1.3. Sub-goals 1.3, 2.1.4, 2.2.13, 3.1 and 3.7 are all contingent goals depending on the specific situation, namely the specific medication and dosages required by the patient. Sub-goal 3.10 is a safety precaution for both the nurse and other patients to prevent cross contamination.

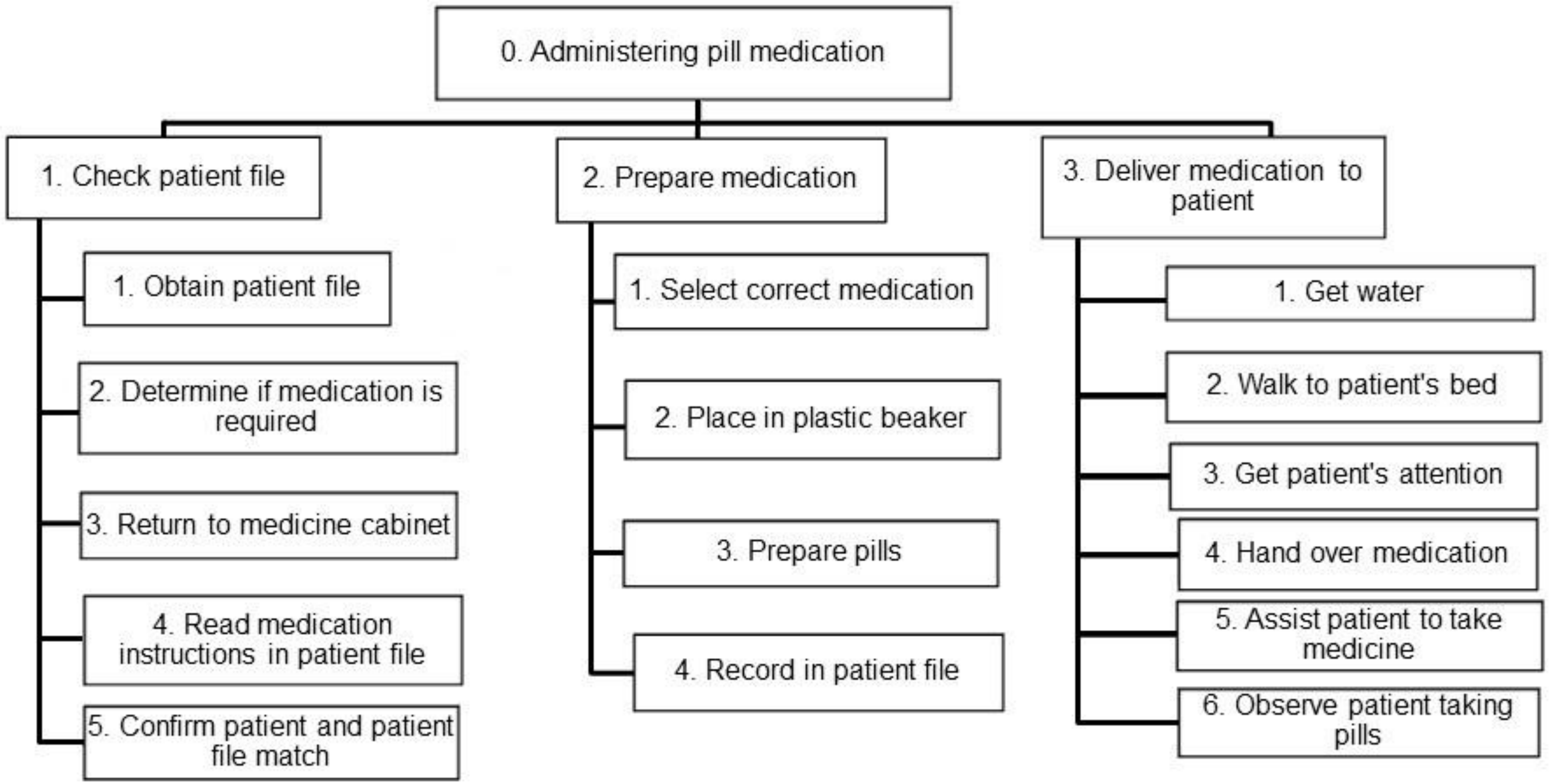


Plan:
Do 1 then if necessary 2 then 3.
Do 1.1 and 1.2 then if necessary 1.3.
Do 2.1 followed by 2.2
Do 2.1.1 and 2.1.2 before proceeding to 2.1.3.Do 2.1.4 if necessary. Do 2.2.1 then proceed to 2.2.2 or 2.2.5. If 2.2.2 is selected do up to 2.2.4. If 2.2.5 is selected do up to 2.2.9. Then do 2.2.10 to 2.2.12 in order. Do 2.2.13 if required.
Do 3.1 if necessary. Do 3.2, then 3.3 or 3.4. Then do 3.5. If necessary 3.7.Do 3.8 to 3.10.

Figure 12: The hierarchical decomposition of the task of *Administering injection medication*.

Administering pill medication

The task description for the task of *Administering pill medication* refers to the determination, selection, preparation and administering of the correct pill medication required by the patient. This task is hierarchically decomposed in Figure 13. Similar to administering injection medication, the plan for the majority of the goals and sub-goals for this task is that of a fixed sequence, suggesting that this task has a more rigid structure. The plan for the main goals 2 and 3 is that of a contingent plan as these tasks are dependent on the result of sub-goals 1.2 and 1.3, as the preparation and administering of the medication is dependent on whether the patient requires pill medication. The action to obtain sub-goal 3.5 is dependent on the health state of the patient, as this will influence the amount of assistance the nurse may need to provide to the patient. Both sub-goals 1.5 and 3.6 are safety precautions in order to ensure the correct patient receives the medication and that the patient does in reality swallow the medication.



Plan:
Do 1, then if necessary 2 then 3.
Do 1.1, then 1.2, then if necessary 1.3 and 1.4.
Do 2.1 then 2.2 or 2.3, followed by 2.4.
Do 3.1, when necessary. Do 3.2, 3.3, 3.4 then 3.5 or 3.6 in order.

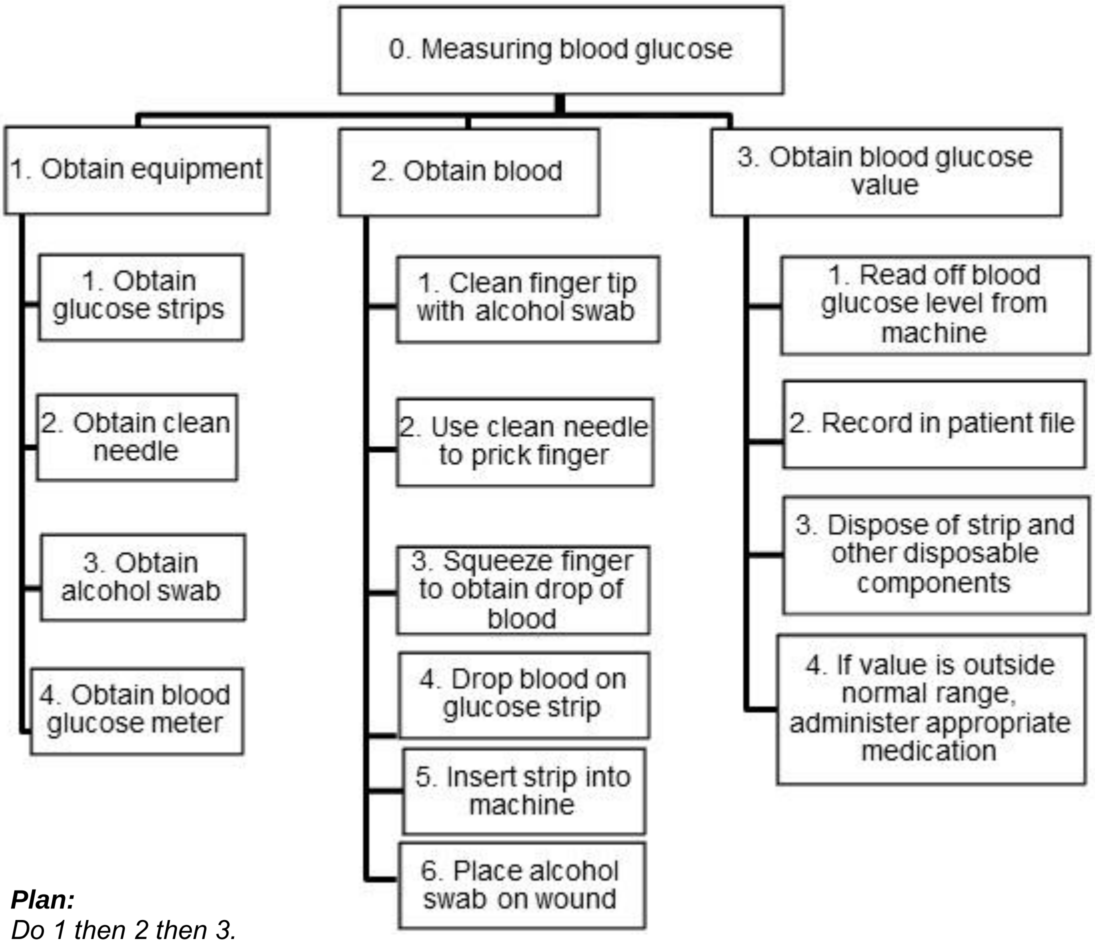
Figure 13: The hierarchical decomposition of the task of *Administering Pill Medication*.

Monitoring patient condition tasks

The tasks within the monitoring patient condition category can be classified as monitoring tasks, specifically monitoring steady state situations, as the main goal is to monitor the current condition of the patient through determining several physiological values. Actions as a result of this task will only occur if a deviation from the expected value is identified during the monitoring process. Predominantly, if the abnormalities have potential negative health implications, the nurse needs to take actions to return the value within a range defined as health or non-risk. The cue initiating these tasks results from a time stimulus, as these tasks are required to be performed twice a day during the day shift. Similar to the administering of medication tasks is the posture for these tasks, that of a standing position with the majority of the motor requirements being those of the upper body. The tasks that fall within this category include measuring blood glucose, temperature, heart rate and blood pressure. Measuring blood glucose is predominantly performed by staff nurses unless there are staffing shortages, and then it may be performed by registered nurses or nursing assistants. Measuring temperature, blood pressure and heart rate is performed by nursing assistants.

Measuring blood glucose level

The task description for the task of *Measuring blood glucose levels* states that the nursing staff assesses the patient's blood glucose level by obtaining a drop of patient's blood in conjunction with the blood glucose meter. This task is depicted in Figure 14. The main plan of goals 1 to 3, goals 2.1 to 2.6 and goals 3.1 to 3.3 is a fixed sequence, while the nurse is able to elect the order for goals 1.1 to 1.4 as the order in which the equipment is obtained is not crucial. It is only for goal 4 that an appropriate response selection is required, depending on whether the staff nurse decides the patient's blood glucose value is within a health range. If the value is above or below the normal range, the staff nurses needs to administer the appropriate medication to return this value to within the required range, but if the value is within a normal range it is only recorded in the patient file. Majority of these goals rely on motor abilities, while goals 2.5 and 3.1 requiring man-machine interaction.



Plan:
Do 1 then 2 then 3.
Do 1.1, 1.2, 1.3 and 1.4 in any order.
Do 2.1 to 2.6 in order.
Do 3.1 to 3.3 in order. If the value is above or below the normal range do 3.4.

Figure 14: The hierarchical decomposition of the task of *Measuring blood glucose levels*.

Measuring temperature

Measuring temperature can be described as the nursing staff using a thermometer to assess the patient's temperature by measuring it under the patient's arm. As for the organisational structure of this task, the plan is that of a fixed sequence as the previous goal needs to be successfully attained prior to the next goal being initiated. The hierarchical decomposition of this task is depicted in Figure 15. Goals 1 and 2 of this task predominantly rely on motor abilities and contain no decision components. As a result of the low number of goals required to complete this task, in comparison to the other tasks performed by the nurses, this task may be classified as a relatively simple task (Leplat, 1988). It is only after goal 4 that an appropriate response selection is required, depending on the decision of the nursing assistant or whether the patient's temperature is above normal range. If the value is above the normal range, the nursing assistant needs to inform the staff nurse, who will obtain the appropriate medication for the patient. But if the value is within a normal range it is only recorded in the patient file. The relationship between tasks and subtasks is depicted in the hierarchical diagram below.

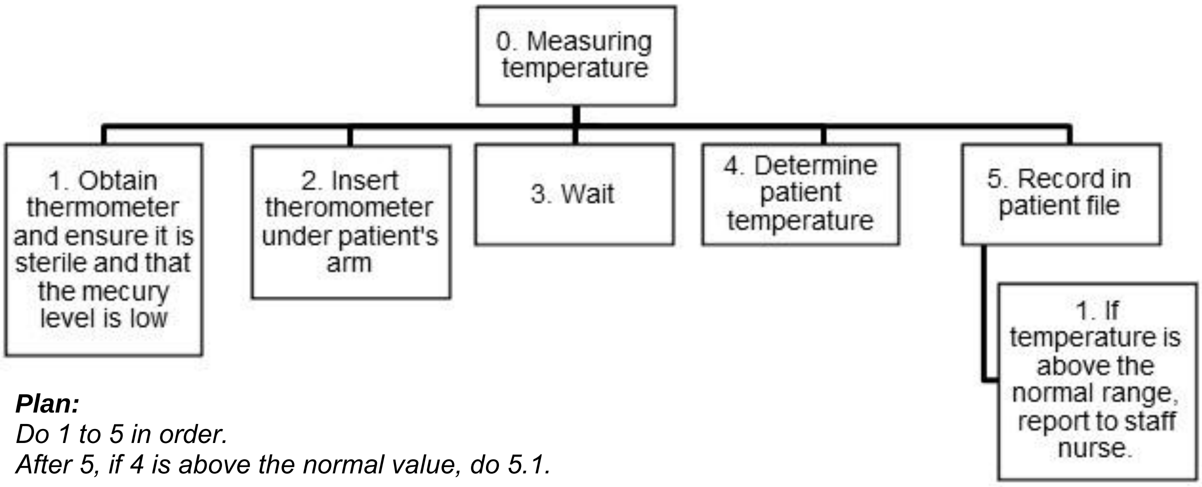


Figure 15: The hierarchical decomposition of the task of *Measuring temperature*.

Measuring blood pressure and heart rate

For the task of *Measuring blood pressure and heart rate*, the task description can be defined as: assessing the patient's blood pressure and heart rate by placing the blood pressure cuff on the patient's arm, operating the machine to determine values for blood pressure and heart rate, and correctly recording the values. This task is depicted in Figure 16. The plan for goals 1 to 8 is that of a fixed sequence, whereas the sequence of goals 6.1 to 6.3 is elected by the nurse, as the order in which the values are recorded is not relevant. It is only after goal 6.1 that an appropriate response selection is required, depending on the decision of the nursing assistant whether the patient's systolic blood pressure is above the value of 120 mmHG. If the value is above this, the nursing assistant needs to record the value in red ink as opposed to the usual black ink, and to inform senior staff. Similar to the task of measuring blood glucose, this task has a man-machine element for goals 4 to 6. Goals 1 to 3 and 7 to 8 rely on motor abilities.

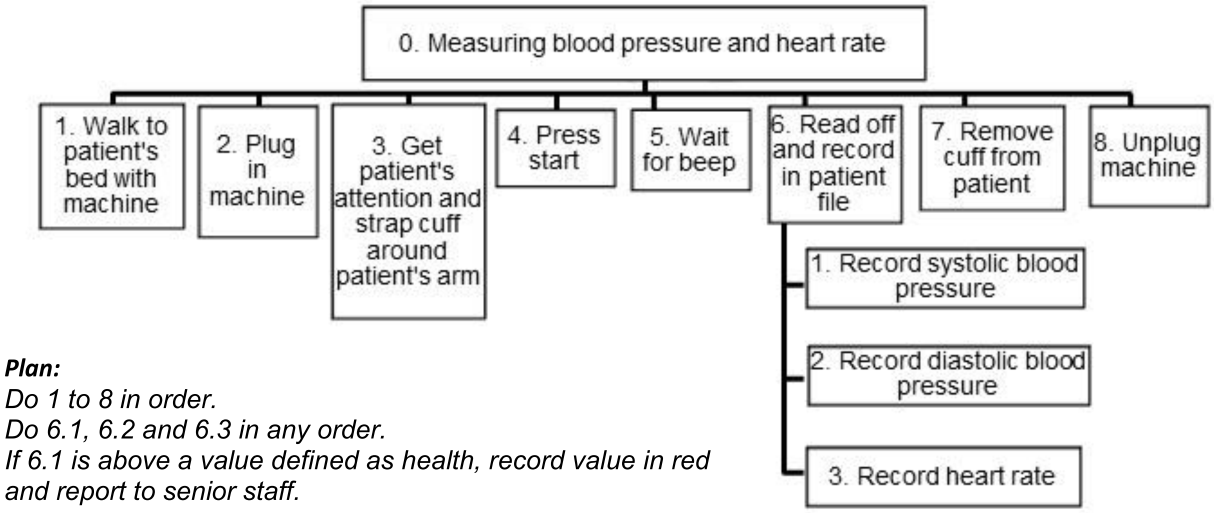


Figure 16: The hierarchical decomposition of the task of *Measuring blood pressure and heart rate.*

This task structure analysis allowed for the determination of the theoretical execution of these tasks according to subject matter experts, and the theoretical analysis of the information processing required for these two task categories. The next applicable step is to assess these tasks within specific contexts to see how they are conducted in real situations and their effects on the nursing staff within these situations.

TASK EXECUTION ANALYSIS

TASK AND WORK ENVIRONMENT CHARACTERISTICS

Task and work environment characteristics were established through the task execution analysis as a result of uninterrupted observation of the critical tasks in the work environment. The task characteristics which were identified and analysed included information regarding the duration of the selected tasks, specific task performance, and the number of interruptions during the task. The work environment characteristics that were analysed were staff capacity, bed occupancy, and the nurse-patient ratio. Statistical significance for the various measurements was determined using a two-way ANOVA with a 95% confidence interval and a Fischer LSD Post Hoc test.

Task duration

Duration was significantly different for the various tasks observed, indicated in Table VII, and the mean duration and standard deviations for the tasks are depicted in Figure 17. The brackets indicate which tasks were significantly different from each other.

Table VII: The analysis of variance for duration of various tasks. (significant difference)

Univariate Tests of Significance for Duration Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 3,194802					
	SS	**Degr. of - Freedom**	**MS**	**F**	**P**
Intercept	3493,372	1	3493,372	342,2606	< 0,000000
Task	756,447	6	126,074	12,3521	< 0,000000
Error	3306,990	324	10,207		

The task with the greatest duration, which also had the most variation, was the task of setting up intravenous medication. This had a mean duration of 10.89 minutes (SD 10.34) and was significantly different from all other tasks. Similarly the duration for measuring temperature was significantly different from all other tasks as well as having the second greatest mean duration of 7.66 minutes (SD 4.00). The task of the shortest duration was that of measuring blood glucose at 2.76 minutes (SD 1.63). This was significantly different from all tasks except the task with the second shortest duration, namely measuring blood pressure and heart rate, which had a mean duration of 3.30 minutes (SD 2.41). Both of these tasks were the only tasks with man-machine interaction.

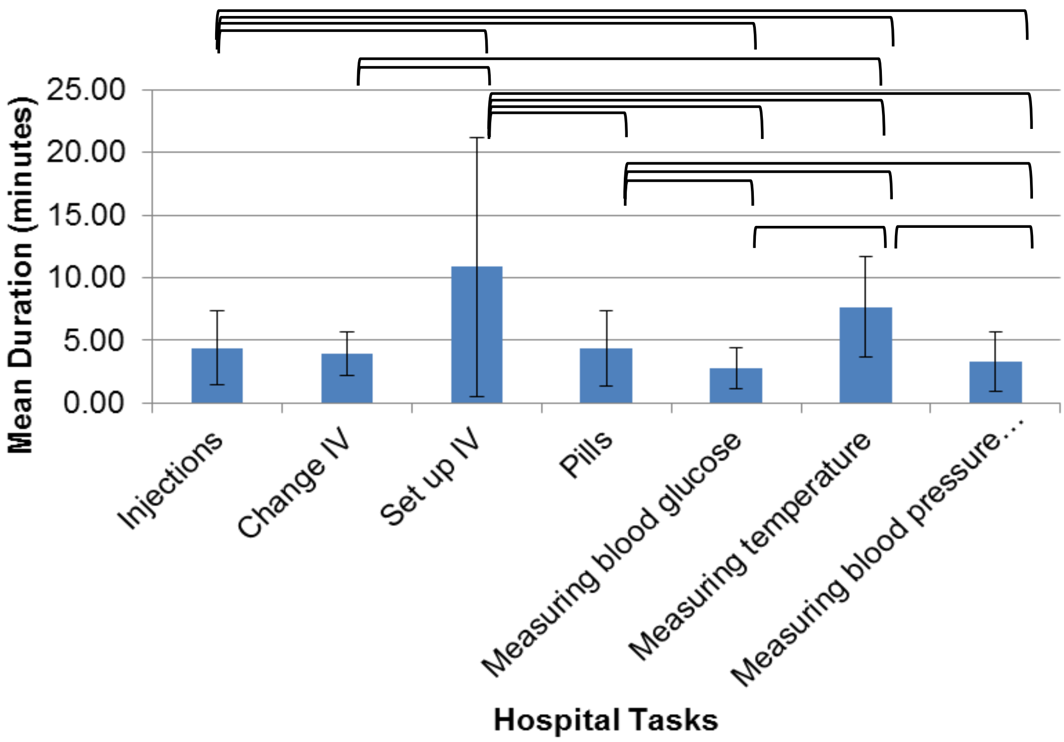


Figure 17: Mean duration of the observed tasks with brackets indicating significant difference between tasks.

The tasks of changing IV medication and administering pill medication had the third and fourth shortest durations respectively. The mean duration of changing IV medication was 3.95 minutes (SD 1.77) and for administering pill medication was 4.32 minutes (SD 3.01). The duration for changing IV medication was only significantly different from setting up IV medication and measuring temperature. For the task of administering pill medication, the duration was significantly different from all three patient monitoring tasks. The mean duration for the administration of injections was 4.37 minutes (SD 2.95) and this duration was significantly different from all tasks except changing IV medication and administering pill medication.

The tasks that had a duration of greater than one positive standard deviation were analysed to determine what characteristics they may share. The only significant characteristic established through the use of a two-way ANOVA at 95% confidence interval, was that of interruptions (featured in Table VIII). It was found that for all types of tasks, between 89 and 100% of these occurrences contained an interruption whether it was a physical or verbal interruption.

Table VIII: The analysis of variance for the effect of interruptions on the duration of the tasks. (significant difference)

Univariate Tests of Significance for Duration Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 2,897314					
	SS	**Degr. of - Freedom**	**MS**	**F**	**P**
Intercept	2212,449	1	2212,449	263,5616	0,000000
interruptions	255,638	1	255,638	30,4532	0,000000
Task*interruptions	82,211	6	13,702	1,6323	0,137598
Error	2661,034	317	8,394		

Interruptions

During the task execution analysis, the number and the form of interruptions were recorded. Interruptions were either classified physical or verbal. Physical interruptions were defined as any activity that resulted in the nurse ceasing the observed task and leaving her post to perform another task. Verbal interruptions were defined as any activity that resulted in the nurse ceasing the task under observation to verbally address the cause of the interruption. Depicted in Figure 18, is the percentage of all the tasks that were interrupted, and the form of interruption that occurred. Certain tasks contain more than one interruption but this is not depicted in the graph.

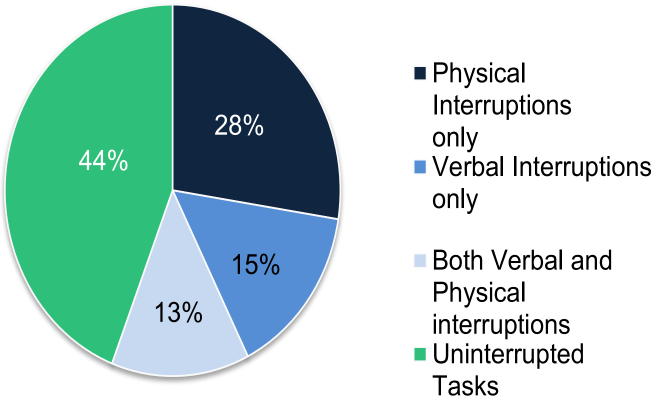


Figure 18: The percentage of tasks wherein a physical, verbal or both forms of interruption occurred.

Of the total 331 task instances observed, 185 task instances (55.89%) had one or both forms of interruptions occurring. Of the 185 interrupted tasks, 91 task instances (27.49%) had a physical interruption, 50 task instances (15.11%) had a verbal interruption and 44 task instances (13.29%) had an occurrence of both forms of interruption. As previously stated, duration was significantly different for tasks that included an interruption, but none of the strain indicators were significantly different for tasks containing an interruption.

Task performance

As part of the task execution analysis, it was recorded if any equipment or medication was missing from the necessary trolleys, if any medication or the value from patient monitoring tasks were re-assessed, if any tasks were not completed successfully, and if any machine error occurred such as returning an inaccurate reading. The number of each occurrence was calculated as a percentage of the number of relevant tasks. The instances where equipment or medication was missing, and when a value or patient medication was re-checked, were all calculated as a percentage of the total number of tasks, namely 331 tasks. The number of occurrences of machine error was calculated as a percentage of the total number of the tasks that used a machine namely the tasks of measuring blood glucose, blood pressure and heart rate (191 tasks). Task failures were all calculated as a percentage of the total number of tasks, namely 331 tasks, and the number of medication errors was calculated as a percentage of the total number of all tasks that fell within the patient medication category (114 tasks). These results are featured in Table IX.

Table IX: Relative and absolute occurrence of tasks that contained errors, where equipment or medication was missing, and where value or medication was re-checked.

	Missing Equipment/ Medication	Rechecked Value/ Medication	Number of Task Failures	Machine Error	Medication Error
Number of occurrences	20	28	5	16	3
Percentage of relevant tasks (%)	6.04	8.46	1.51	14.04	1.51

Missing equipment or medication occurred within 6.04% of all tasks observed. A value or medication was re-checked a total of 8.46% of all tasks observed, while 1.51% of all tasks observed resulted in the task not being completed successfully. Machine error occurred in 14.04% of the 191 tasks observed for measuring blood glucose, and blood pressure and heart rate. All the instances of machine error observed occurred during the task of measuring blood pressure and heart rate. Therefore it would be more accurate to state that machine error occurred in 20.25% of all blood pressure and heart rate monitoring tasks observed. Medication errors occurred in 1.51% of all administering medication tasks and all of these errors were timeously corrected by the nursing staff.

Staff assistance, staff capacity, bed occupancy and nurse-patient ratio

The number of staff assisting in individual tasks, the staff capacity and the bed occupancy were recorded in order to determine the degree of team work for the individual tasks analysed and to determine the nurse-patient ratio. This ratio was determined using the staff capacity and the bed occupancy.

Staff assistance

Of the 331 tasks observed, only 9 instances (2.72%) were tasks where fellow staff members assisted in completing these tasks. Of these nine instances, five were pill administering tasks, two were setting up IV medication, one was changing IV medication and one was measuring blood pressure and heart rate. From the observation of these instances, for the pill administering tasks two nurses perform this task concurrently on a daily basis and it would appear that not always each trolley is stocked with the same medication, so they assist each other when necessary. For the two instances of setting up IV medication, the nurses needed assistance with correctly placing the needle within the vein. More specifically in one instance the patient was in a very frail condition, resulting in several staff members attempting to complete this task which eventually was not completed successfully and was left to be completed at a later point in time. For the task of changing the IV medication, assistance was needed in locating the correct medication; and for the task of measuring heart rate and blood pressure, another nursing assistant aided the staff member who initially commenced the task as she had completed her other duties and the reading needed to be retaken due to mechanical error.

Bed occupancy

The bed occupancy was calculated as a percentage of the number of beds occupied within that ward and was assessed twice on each testing day, once at the start of the 7:00 am shift and the second time at 1:00 pm. The results are featured in Table X, and it can be determined from the data that the bed occupancy for both wards is greater in the morning than in the afternoon. During the morning, the medical ward had a higher bed occupancy percentage of 75.90 % while the surgical ward was at a capacity of 70.22%. In the afternoon, the difference in bed occupancy percentage was far less with the medical ward at a filled capacity of 68.43% and the surgical ward at 68.67%. This would suggest that patients are generally discharged during the morning, resulting in the bed occupancy being lower in the afternoon. From the results, one can determine that there is greater variability in the bed occupancy percentage between days for the surgical ward, and this may be as a result of the nature of cases that are treated in this ward.

Table X: The bed occupancy rate for the medical and surgical wards for the morning session of 7:00 am to 1:00 pm (am) and for the afternoon session of 1:00 pm to 7:00 pm (pm).

		Bed Occupancy (%)	
Time of day		Am	PM
Medical Ward	Mean (SD)	75.90 (9.94)	68.43 (14.56)
Surgical Ward	Mean (SD)	70.22 (30.27)	68.67 (18.14)

Nurse-patient ratio

The nurse to patient ratio was calculated by determining the number of patients per nursing staff as well as calculating the number of patients per registered nurse. To determine this, the number of patients admitted to the ward and the number of staff were recorded twice on each testing day, once at the start of the shift and the second time at 1:00 pm. This was done as some staff only worked until 1:00 pm. Both nursing staff-patient ratio and registered nurse-patient ratio were determined in order to comprehensively compare these results to current literature which does not always specify which nursing staff were used in analyses. These results are featured in Figure 19.

From the graph, it can be concluded that, irrespective of the time of day, both ratios were higher for the medical ward than for the surgical ward. During the morning, the medical ward had a nursing staff-patient ratio of 4.25 patients (SD 0.59) and the surgical ward had a ratio of 2.19 (SD 1.15). During the afternoon, the medical ward's nursing staff-patient ratio rose to 5.30 patients (SD 1.66) and the surgical ward rose to 3.08 (SD 1.47). As can be seen in Figure 19, the registered nurse-patient ratio was higher than the nursing staff-patient ratio in all cases, but this was expected as the nursing staff-patient ratio encompassed registered nurses, staff nurses and nursing assistants. The registered nurse-patient ratio for the surgical ward in the morning was 5.28 patients (SD 1.58) per registered nurse and in the afternoon was 8.08 patients (SD 5.28) per registered nurse. The registered nurse-patient ratio for the medical ward in the morning was 9.15 patients (SD 1.75) per registered nurse and in the afternoon was 11.66 patients (SD 4.69) per registered nurse.

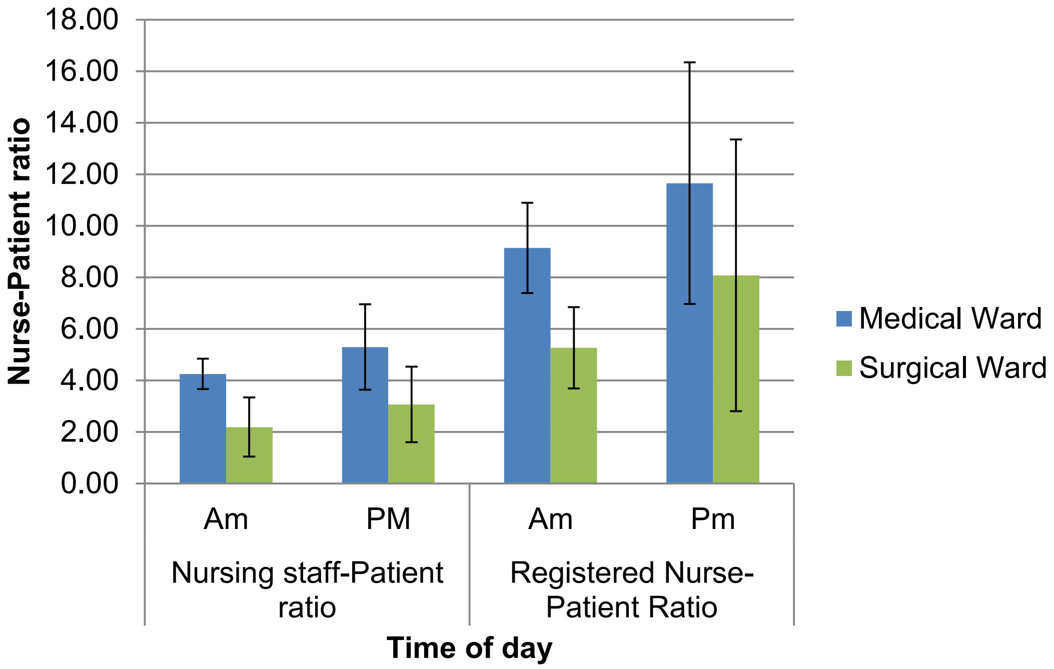


Figure 19: The nursing staff-patient ratio and the registered nurse-patient ratio for the medical and surgical wards for the morning and afternoon.

STRAIN ANALYSIS

The strain for these seven tasks was assessed in the field by measuring heart rate and heart rate variability, and by recording subjective ratings using the NASA-TLX. The statistical tool used in this analysis was a two-way ANOVA with the variables considered being the task and the various strain variables, namely heart rate, heart rate variability and NASA-TLX score. In addition to this, a Fischer LSD Post-Hoc test was performed for the significant results. All statistical results were determined with 95% confidence interval. Relativised measures for all heart rate and heart rate variability measures were determined as the difference of the task from the reference task as a percentage of the reference task. This allowed for the comparison across participants and on different testing days. Furthermore by relativising the data, individual effects such as personal stress would have been accounted for, and would have resulted in the remaining variability being as a consequence of the current task and environment in that specific context. The statistic tables for the Post Hoc analyses are attached in Appendix E.

Heart rate

Heart rate was significantly different for the various tasks observed, with the results of the analysis of variance featured in Table XI. The mean duration and standard deviations for the tasks are depicted in Figure 20.

Table XI: The analysis of variance for the effect of tasks on heart rate. (significant difference)

Univariate Tests of Significance for heart rate Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 9,233920					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	20142,20	1	20142,20	236,2298	0,000000
Task	1562,27	6	260,38	3,0537	0,006403
Error	27625,95	324	85,27		

The task with the highest percentage difference from the reference task was that of measuring temperature with an 18.68% (SD 11.21) increase above the reference task. It was significantly different from administering pill medication which elicited a 13.45% (SD 8.42) increase, measuring blood glucose levels which elicited an 11.81% (SD 11.98) increase, administering injection medication which elicited a 10.25% (SD 8.27) increase, and changing IV medication which elicited a 7.42% (SD 5.94) increase. The task with the second highest percentage difference from the reference task was that of measuring blood pressure and heart rate with a 14.46% (SD 9.36) increase above the reference task. This was only significantly different from the task of administering injections. The task with the lowest percentage difference from the reference task was that of changing IV medication, which was only significantly different from the task of measuring temperature. The task of setting up intravenous medication was not significantly different from any of the other tasks with a percentage difference from the reference task of 13.37% (SD 10.44).

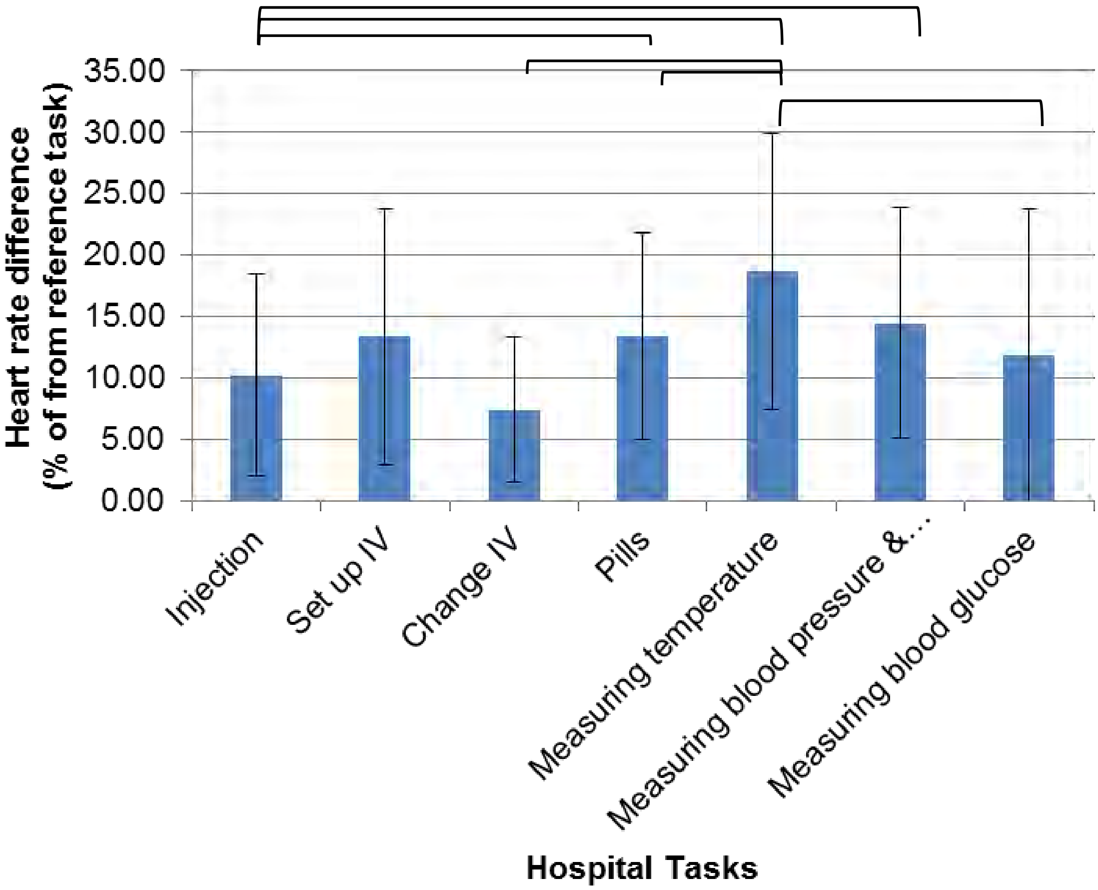


Figure 20: Heart rate difference as a percentage of the reference task for the observed tasks with brackets indicating significant difference between tasks.

For these tasks, no significant differences regarding duration and interruptions were established for heart rate. A significant difference for heart rate was found for nursing staff-patient ratio, and is featured in Table XII. The Product moment correlation was calculated at – 0.397739.

Table XII: The analysis of variance for the effect of nursing staff-patient ratio on heart rate. (significant difference)

Univariate Tests of Significance for heart rate Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 8,766376					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	17928,65	1	17928,65	233,296	0,0000
Nursing staff-patient ratio	3904,78	1	3904,78	50,8109	0,0000
Error	25283,44	329	76,85		

Heart rate variability

Time domain analysis: pNN30

This heart rate variability measure was significantly different for the various tasks observed. The analysis of variance results are depicted in Table XIII.

Table XIII: The analysis of variance for heart rate variability (pNN30) for the different tasks. (significant difference)

Univariate Tests of Significance for HRV: PNN30 Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 107,7680					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	140233	1	140233,4	12,07456	0,000587
Task	304180	6	50696,7	4,36516	0,000304
Error	3484186	300	11614,0		

The mean duration and standard deviations for each of the tasks was determined and is depicted in Table XIV. The task with smallest positive difference in percentage from the reference task was the task of administering pill medication with a mean percentage difference of 0.91% (SD 80.91). This task was significantly different from the tasks of administering injections, setting up IV medication and measuring blood glucose. Only one task had a negative difference percentage. This was the task of measuring temperature with a negative 21.55% (SD 101.94) difference, and this suggests that the majority of the tasks had a heart rate variability measure that was less than the reference task.

Table XIV: The standard deviations and mean percentage of the difference in the time domain analysis variable, pNN30, from the reference task for the critical tasks in addition to the tasks that are statistically different from each other.

Task	***Mean percentage of pNN30 (SD)***	***Tasks that are significantly different from each other***
Administering Injections	65.54 (129.53)	Administering Pills, Measuring Temperature, Blood pressure & Heart Rate
Setting up IV medication	116.17 (286.13)	Administering Pills, Measuring Temperature, Blood pressure & Heart Rate
Changing IV medication	30.55 (90.95)	-
Administering Pills	0.91 (80.91)	Administering Injections, Setting up IV, Measuring Blood Glucose
Measuring Temperature	-21.55 (101.94)	Administering Injections, Setting up IV, Measuring Blood Glucose
Measuring Blood pressure & Heart Rate	6.55 (96.97)	Injection, setting up IV, measuring blood glucose
Measuring Blood glucose	53.16 (109.67)	Administering Pills, Measuring Temperature, Blood pressure & Heart Rate

The task with the largest alteration in heart rate variability from the reference task was the task of setting up IV medication with a 116.17 % (SD 286.13) increase. This task was significantly different from administering pill medication, measuring temperature, and measuring blood pressure and heart rate. A significant difference for the heart rate variability measure of pNN30 was also found for nursing staff-patient ratio (depicted in Table XV) and the Product moment correlation was calculated at 0.245861.

Table XV: The analysis of variance for the effect of nursing staff-patient ratio on the heart rate variability measure of pNN30. (significant difference)

Univariate Tests of Significance for HRV: PNN30 Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 108,0280					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	111576	1	111575,9	9,56087	0,002171
Nursing staff-patient ratio	228999	1	228998,6	19,62275	0,000013
Error	3559368	305	11670,1		

Frequency domain: high frequency band

Significant differences were established for the power of the high frequency band for the various tasks, and these results are depicted in Table XVI.

Table XVI: The analysis of variance for heart rate variability (high frequency: power) for the different tasks. (significant difference)

Univariate Tests of Significance for high frequency: power Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 6788,077					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	5,752234E+08	1	575223439	12,48369	0,000470
Task	1,825269E+09	6	304211583	6,60210	0,000001
Error	1,492927E+10	324	46077994		

Similarly to the time domain analysis of heart rate variability, only one task had a negative difference percentage and this was again the task of measuring temperature with a negative 9.66 % (SD 47.239) difference. The task with the smallest positive difference percentage from the reference task was the task of measuring blood pressure and heart rate with a mean percentage difference of 21.81% (SD 111.64). This task was significantly different from the tasks of administering injections and setting up IV medication. The task with the largest alteration in the power of the high frequency band from the reference task was the task of setting up IV medication with a 5685.46% (SD 10234.20) increase. This task was significantly different from administering pill medication, measuring temperature, blood glucose, blood pressure and heart rate. These results are depicted in Table XVII.

Table XVII: The standard deviations and mean percentage of the difference in the power for high frequency components from the reference task for the critical tasks in addition to the tasks that are statistically different from each other.

Task	***Mean HF: power (SD)***	***Tasks that are significantly different from each other***
Administering Injections	5512.80 (13735.86)	Administering Pills, Measuring Temperature, Blood glucose, Blood pressure & Heart Rate
Setting up IV medication	5685.46 (10234.20)	Administering Pills, Measuring Temperature, Blood glucose, Blood pressure & Heart Rate
Changing IV medication	3535.89 (8742.87)	-
Administering Pills	178.44 (1048.15)	Administering Injections, Setting up IV
Measuring Temperature	-9.66 (47.24)	Administering Injections, Setting up IV
Measuring Blood pressure & Heart Rate	21.81 (111.64)	Administering Injections, Setting up IV
Measuring Blood glucose	192.10 (286.44)	Administering Injections, Setting up IV

For the centre frequency of the high frequency band, no significant differences were established for the tasks. For all of these tasks, the values elicited by the critical tasks were less than those of the reference tasks. This is visible as all the means are negative values and this is depicted in Table XVIII. A significant difference for the high frequency centre frequency component was found for nursing staff-patient ratio (depicted in Table XIX) and a weak positive correlation was calculated at 0.205728.

Table XVIII: The standard deviations and mean percentage of the difference in the centre frequency of the high frequency component from the reference task for the critical tasks in addition to the tasks that are statistically different from each other.

Task	***Mean high frequency: Centre frequency (SD)***
Administering Injections	-2.68 (10.61)
Setting up IV medication	-5.19 (10.40)
Changing IV medication	-3.27 (11.76)
Administering Pills	-5.12 (9.67)
Measuring Temperature	-5.04 (10.09)
Measuring Blood pressure & Heart Rate	-2.84 (8.85)
Measuring Blood glucose	-1.12 (10.19)

Table XIX: The analysis of variance for the effect of nursing staff-patient ratio on high frequency: centre frequency. (significant difference)

Univariate Tests of Significance for high frequency: centre frequency Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 9,644008					
	SS	**Degr. of - Freedom**	**MS**	**F**	**P**
Intercept	3069,66	1	3069,658	33,00463	0,000000
Nursing staff-patient ratio	1348,83	1	1348,831	14,50248	0,000167
Error	30599,27	329	93,007		

Frequency domain: low frequency band

Similar to the high frequency component, significant differences were established for the power of the low frequency band for the various tasks (Table XX). The task with the largest alteration in the power of the low frequency band from the reference task was the task of changing IV medication with a 2080.38 % (SD 4648.55887) increase and this task was significantly different from administering pill medication, measuring temperature, blood glucose, blood pressure and heart rate. The task with smallest percentage difference was the task of measuring temperature with 107.14% (SD 255.99). This task was significantly different from the tasks of administering injections and changing IV medication. These results are depicted in Table XXI.

Table XX: The analysis of variance for heart rate variability (low frequency: power) for the different tasks. (significant difference)

Univariate Tests of Significance for low frequency: power Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1623,449					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	67501810	1	67501810	25,61166	0,000001
Task	83221020	6	13870170	5,26265	0,000034
Error	853930841	324	2635589		

Table XXI: Mean percentage and standard deviations of the difference in the power of the low frequency component from the reference task for the critical tasks in addition to the tasks that are statistically different from each other.

Task	***Mean LF: Power (SD)***	***Tasks that are significantly different from each other***
Administering Injections	1225.65 (3089.07)	Administering Pills, Measuring Temperature, Blood glucose, Blood pressure & Heart Rate
Setting up IV medication	1201.76 (2355.64)	-
Changing IV medication	2080.38 (4648.56)	Administering Pills, Measuring Temperature, Blood glucose, Blood pressure & Heart Rate
Administering Pills	199.21 (277.76)	Administering Injections, Change IV
Measuring Temperature	107.14 (255.99)	Administering Injections, Change IV
Measuring Blood pressure & Heart Rate	141.90 (188.46)	Administering Injections, Change IV
Measuring Blood glucose	222.43 (247.02)	Administering Injections, Change IV

Unlike for the power, the centre frequency of the low frequency band had significant differences between the tasks and this is depicted in Table XXII.

Table XXII: The analysis of variance for the low frequency: centre frequency component for the different tasks. (significant difference)

Univariate Tests of Significance for low frequency: centre frequency Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15,19503					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	55,27	1	55,271	0,239385	0,624982
Task	8416,21	6	1402,702	6,075222	0,000005
Error	74808,05	324	230,889		

The task of administering injections had the highest percentage difference for the centre frequency of the low frequency component with a 7.88% (SD 20.49) increase from the reference task and was significantly different from administering pill medication and all the patient monitoring tasks. The only other task that had significant differences was that of administering pill medication which, in addition to being significantly different from administering injections, was also different from measuring blood pressure and heart rate. For the tasks of administering pill medication, measuring temperature and blood glucose, the values elicited by the critical tasks were less than those of the reference tasks. This is visible as all the means are negative values and this is depicted in Table XXIII.

Table XXIII: The standard deviations and mean percentage of the difference in the centre frequency of the low frequency component from the reference task for the critical tasks.

Task	***Mean percentage of low frequency: Centre frequency (SD)***
Administering Injections	7.88 (20.49)
Setting up IV medication	2.87 (23.12)
Changing IV medication	4.07 (7.18)
Administering Pills	-5.49 (12.93)
Measuring Temperature	-1.93 (13.78)
Measuring Blood pressure & Heart Rate	0.32 (12.77)
Measuring Blood glucose	-3.02 (12.94)

Frequency domain: low frequency power relative to the (LF + HF)

For the low frequency power relative to the sum of the low and high frequency, significant differences between the tasks (depicted in Table XXIV) were also established.

Table XXIV: The analysis of variance for the low frequency power relative to the (LF + HF) (significant difference)

Univariate Tests of Significance for low frequency power relative to (LF+HF) [%] Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 50,86471					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	31987,2	1	31987,17	12,36354	0,000500
Task	111104,2	6	18517,37	7,15725	0,000000
Error	838258,9	324	2587,22		

Table XXV: The mean and standard deviation percentage of the difference in Low Frequency Power relative to the (LF + HF) relative to the reference task.

Task	***Mean percentage of Low Frequency Power relative to the LF + HF (SD)***
Administering Injections	-0.67 (25.13)
Setting up IV medication	6.23 (28.37)
Changing IV medication	21.23 (39.58)
Administering Pills	45.20 (80.89)
Measuring Temperature	17.97 (28.68)
Measuring Blood pressure & Heart Rate	17.63 (21.39)
Measuring Blood glucose	5.14 (16.44)

Using the Post-Hoc LSD Fischer test, it was established that the administering of injections, which had the lowest difference from the reference tasks with -0.67% (SD 25.13), was significantly different from administering pill medication at 45.20% (SD 80.89) and measuring blood pressure and heart rate at 17.63% (SD 21.39). The administering of pill medication, which elicited the largest change in percentage difference, was significantly different from all tasks except changing IV medication which had a difference of 21.23% (SD 39.58). These results are depicted in the Table XXV.

A significant difference was also established for nursing staff-patient ratio and the Product moment correlation was calculated at – 0.184901. This depicted in Table XXVI.

Table XXVI: The analysis of variance for the effect of nursing staff-patient ratio on the low frequency power relative to the (LF + HF). (significant difference)

Univariate Tests of Significance for the low frequency power relative to (LF+HF) [%] Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 53,01040					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	73910,6	1	73910,60	26,30174	0,000000
Nursing staff-patient ratio	24839,2	1	24839,21	8,83925	0,003166
Error	924523,9	329	2810,10		

Subjective measure: NASA-TLX

The NASA-TLX was used after each session of tasks, namely after the administration of medication or patient monitoring in the morning and then again in the afternoon. The calculated workload score was significantly different for the various tasks observed (in Table XXVII).

Table XXVII: The analysis of variance for the NASA-TLX overall workload score and task (significant difference)

Univariate Tests of Significance for Nasa-TLX overall workload score Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 15,23038					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	102922,9	1	102922,9	443,7008	0,000000
Task	20052,4	6	3342,1	14,4077	0,000000
Error	70517,3	304	232,0		

In Figure 21, the mean and standard deviations for the weighted NASA-TLX workload score for the tasks are depicted, indicating which tasks resulted in significantly different workload scores. The task that elicited the highest mean workload score was the task of measuring blood glucose with a score of 47.93 (SD 15.15) and this task was significantly different from all of the other tasks. The lowest workload score was that elicited for changing IV medication with a score of 14.56 (SD 4.74) and this task was significantly different from all other medication administration tasks and measuring blood glucose.

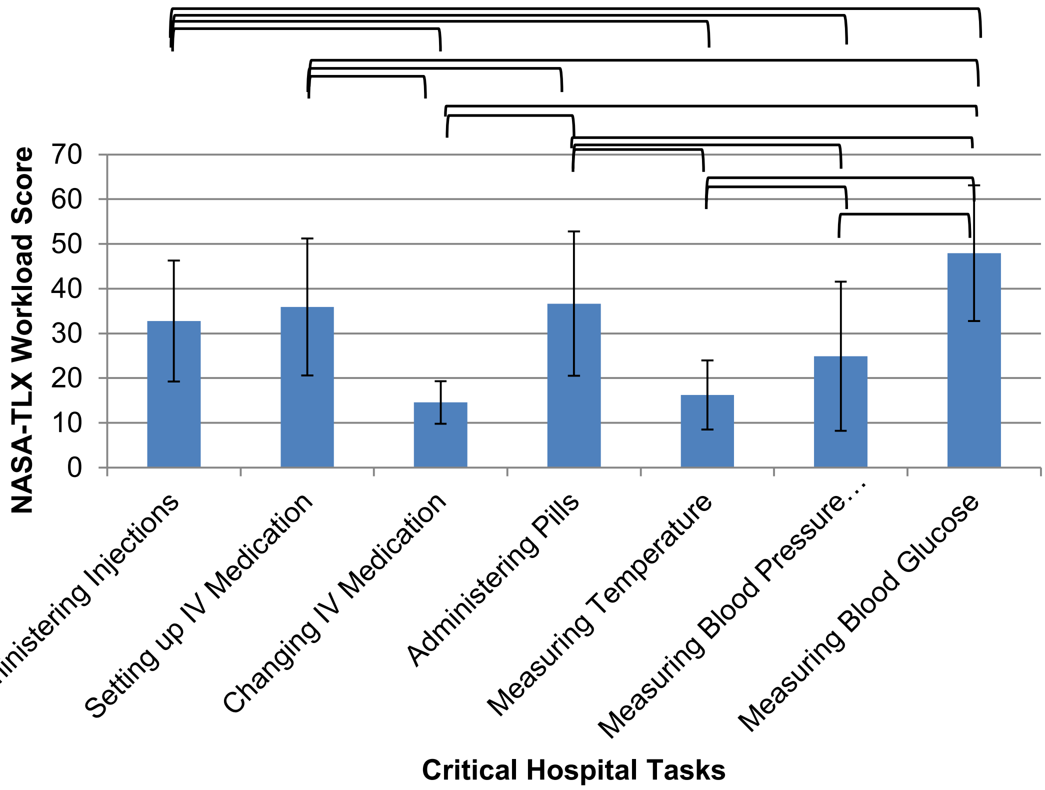


Figure 21: The mean and standard deviation for the weighted workload scores for the critical hospital tasks with brackets indicating significant difference between tasks.

For the remaining medication administration tasks, the mean workload scores were within close proximity of each other in comparison to the other scores. Administering injections had a workload score of 32.76 (SD 13.52), setting up IV medication had a score of 35.92 (SD 15.34) and the administration of pill medication had a score of 36.65 (SD 16.15). Both the tasks of administrating injections and pills were significantly different from the task of changing IV medication and the three patient monitoring tasks. The task of measuring temperature elicited the lowest mean workload score of 16.25 (SD 7.73) and was significantly different from all tasks except changing IV medication. The task of measuring blood pressure and heart rate had a workload score of 24.90 (SD 16.69) and was significantly different from all tasks except setting up and changing IV medication.

A significant difference for the overall NASA workload score was also found for nursing staff-patient ratio (in Table XXVIII) and the Product moment correlation was calculated at – 0.249058.

Table XXVIII: The analysis of variance for the NASA-TLX overall workload score and nurse-patient ratio. (significant difference)

Univariate Tests of Significance for NASA-TLX overall workload score Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 16,58084					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	64648,98	1	64648,98	235,1517	0,000000
Nursing staff-patient ratio	5618,02	1	5618,02	20,4348	0,000009
Error	84951,68	309	274,92		

Weak correlations were established for the individual weighted NASA-TLX scores and the relativised strain indicators. These are depicted in Table XXIX. Weak positive correlations were determined between relativised heart rate and the NASA scale components of mental load, physical load, temporal demand and effort. No significant correlations were established for the high frequency power variable. For both the mental and physical load scales, the majority of the heart rate variability measures elicited negative correlations.

Table XXIX: Product moment correlations for the various strain indicators and the scales of the NASA-TLX.

	Heart Rate	**PNN30**	**HF Power**	**HF Centre Frequency**	**LF Power**	**LF Centre Frequency**	**Relative ratio**
Mental Load	0,177	-0,155	0,0409	-0,147	-0,148	-0,177	0,079
Physical Load	0,191	-0,114	-0,048	-0,054	-0,178	0,004	-0,317
Temporal Demand	-0,131	0,216	0,041	0,162	0,191	-0,078	-0,218
Own Performance	0,247	-0,074	-0,050	-0,230	-0,106	0,129	-0,115
Effort	0,345	-0,236	-0,038	-0,086	-0,257	0,115	-0,260
Frustration	-0,105	0,233	0,074	0,296	0,050	0,076	-0,182

GENERAL OBSERVATIONS

During the task execution analysis numerous influencing factors and additional task characteristics were noted. The researcher observed that numerous tasks overlapped or were performed in parallel. An example of this is the task of measuring temperature which was performed in conjunction with the task of measuring blood pressure and heart rate. As there is a component to the task of measuring temperature that requires the nurse to wait, she then starts measuring the other patients' temperature and blood pressure within that room. Additionally the researcher noted the high demand of verbal communication required of the nurses between other nursing staff, other healthcare staff, patients and visitors. These factors may have had an effect on the physiological responses assessed during the tasks. The time pressure the staff were placed under was observed when tasks were often performed by colleagues who either could not wait for the assigned staff to complete them, or who had to deputise as a result of understaffing.

Some recurring factors that resulted in task interruption or delay, that were not mentioned in the performance section of the results as they did not occur as frequently, were those of visitors, patients and missing patient files. Visitors and other patients often interrupted the nurses during a task in order to ask a question which predominantly occurred outside the specified visiting time. For both task categories, the patient file is required for recording information after the tasks have been done, as well as for providing information regarding the administration of medication. On numerous occasions the patient files were missing and were said to be delayed at the pharmacy where medications are ordered. On these occasions the nurses cannot continue their work routine of administering medication, and nursing assistants record the patient monitoring measures on pieces of scrap paper. Another interruption factor that was observed was that the nurse would interrupt a task to perform a more pressing task. Occasionally the first task would be dependent on the completion of the second task. An example of this would be the nurse identifying that the injection site is no longer functional while attempting to administer medication through it, and this would require the injection site being inserted elsewhere prior to the administration of the medication.

The researcher also observed several consequences as a result of an error identified by another nursing staff member. The errors observed included the administration of the incorrect IV medication, inaccurate recording (or no recording at all) of the medication administered, incorrect blood samples taken, and incorrect tests performed. These were usually the result of an error at the laboratory or the nurse filling in the form incorrectly, and incorrect or incomplete documentation in the patient file for various tasks such as for the administration of IV medication. Additional errors observed were the administration of incorrect medication, incorrect preparation of medication and the incorrect quantity of pills administered. Dangerous behaviour in regards to neglecting safety regulations was also observed. This included a lack of needle safety behaviour being adhered to and protective gear not always being worn. It was also observed that occasional confusion existed about the identity of the patient and that, as a result of not enough stock, patients often did not have their medication administered on time.

CHAPTER V
DISCUSSION

INTRODUCTION

As workload is a multidimensional and complex concept, a multifaceted approach was required to meet the aims of this study. This project set out to identify nursing workload stressors by investigating the strain level associated with specific patient-centered tasks in the South African health care sector. The hypothesis that was to be tested in this section of the research was that different hospital tasks, in conjunction with various contributing factors, elicit different strain levels as a result of work stressors. Furthermore, it was also hypothesised that several of the contributing strain factors that would increase the workload could be identified and would be reflected in an increased strain measure. In order to accurately assess the strain as a result of a work task, the organisational structure within the work environment was considered (Shepherd, 2001) by adopting a top-down approach (Hignett, 2001). The discussion is presented in the same structure as that of the results. There is a degree of overlap in certain areas of this discussion, as this multidimensional concept was required to be studied at different levels in order to obtain a more comprehensive understanding of the concept and its influencing factors.

WORK ENVIRONMENT ANALYSIS

Using a systems theory approach, this analysis first considered the wider context within which the task occurs, as the environment and organisational structure of the system will provide constraints for the task (Shepherd, 2001). By taking into account information regarding the context within which the task occurs, such as related managerial practices, operator knowledge requirements, task cycle times, performance errors, a better understanding of the effect and constraints of the task on the worker can be established (Shepherd and Stammers, 2005).

ORGANISATIONAL STRUCTURE, DIVISION OF LABOUR AND DAILY ROUTINE

As a result of nurses being the main healthcare providers in the South African hospital environment (Van der Walt and Swartz, 2002), they are exposed to high levels of workload and their capabilities need to be maximised. The organisational practice of task-orientated nursing assists in meeting this demand as it has the advantages of maximising the workers' capabilities (Van der Walt and Swartz, 2002). Furthermore, task-orientated nursing is the teaching basis in tertiary education institutes in South Africa, and it is easily transferred to health institutes, assisting with the transfer of students to the workplace (Van der Walt and Swartz, 2002). An additional advantage of this approach is that it allows for routine tasks to be simplified and done more efficiently (Carayon and Friesdorf, 2004). This may result in care being provided more timeously, and consequently the nurses' remaining time can then be allocated to the more complex tasks of patient caring (Carayon and Friesdorf, 2004). The disadvantages associated with this practice, which predominantly affect the patient, are that care is fragmented and lacks continuity, and there is a depersonalising effect on the nursing (Van der Walt and Swartz, 2002). Six criteria have been proposed for care provided by healthcare staff, namely that of being effective, efficient, safe, personalised, equitable and timely (Institute of Medicine Committee on Quality of Health Care in America, 2001). The organisational practice in Settlers Hospital assists in meeting some of these criteria but at the cost of others. As a result of this organisational practice, the nursing workforce is employed more efficiently, and this assists the patient in receiving potentially more effective care. But it comes at the cost of being potentially depersonalised.

The two wards observed had different patient capacities. The medical ward had 52 beds with the approximate daily staff number of twelve nurses, and the surgical ward had 25 beds with an approximate staff number of nine nurses. Despite the medical ward having over twice the patient capacity and morning bed occupancy of 5.68% greater than the surgical ward, it had only a third more staff. Even though Table VI in Chapter IV, indicates that the surgical ward has a greater repertoire of tasks that need to be performed, these include only three additional tasks. All of this data would suggest that the daily workload in the medical ward is greater than that of the surgical ward. The nurse-patient ratio, which is considered an indicator of workload (Carayon and Gurses, 2008), supports this conclusion as both the nursing staff and registered nurse to patient ratios were at all times greater in the medical ward. One of the influencing factors of workload that has not been considered here is the effect of patient status on workload (Carayon and Gurses, 2008). The patient status, which may determine which ward the patient is admitted to, amplifies the task characteristics (Kumashiro, 2005) and as a result affects the workload experienced by the nursing staff (Carayon and Gurses, 2008). During the task execution analysis, the researcher observed that the patients in the medical ward were more bed ridden than those in the surgical ward. The patient's health status and mental capacity also affect how included they can be in their own recovery process (Carayon and Friesdorf, 2006). From observation, it appeared that the patients in the surgical ward caused less workload than the medical ward patients, as most of them were more actively involved in their recovery process (Carayon and Friesdorf, 2006).

From the daily routine gauged through the questionnaire and the observation phase, it was established that, despite being assigned individual tasks, the nurses did not work in isolation and were required to exchange information and co-ordinate resources among themselves and staff from other hospital departments. If the healthcare team does not properly co-ordinate its activities, the performance of these tasks may be impaired (Swezey *et al*., 2000). This was observed during the task execution analysis where missing patient files, which were delayed at the hospital pharmacy regularly, resulted in the delay of the administering of medication on the ward.

More specifically on a ward level, despite individual tasks related to patient care being assigned to different staff members on the ward (Van der Walt and Swartz, 2002), the tasks are interdependent in order to meet the main goal. As a result of this, nurses need to co-ordinate and communicate effectively to work as a team (Bowers and Jentsch, 2005), and consequently the associated task complexity may increase as a result of the required teamwork (Swezey *et al*., 2000). Ineffective communication between staff can result in an increase in workload (Carayon and Gurses, 2008) and may increase the likelihood of an error occurring (Carayon and

Friesdorf, 2004). To ensure the workload was not underestimated, it was determined on a situational level (Carayon and Gurses, 2008), which included the necessary communication and co-ordination needed to ensure the task occurs effective (Hignett, 2001).

ROUTINE CRITICAL TASKS

As task analysis can be a lengthy and resource exhaustive process, limitations to the analysis were set (Shepherd, 2001) in the form of the following selection criterion: the task needed to be a routine patient centered task that, as a result of an error, had a potential negative effect on the patient's health status. Through the aid of this criterion, tasks pertaining to medicating patients and monitoring patients' condition were selected. As proposed by Carayon and Friesdorf (2004), the tasks from the administering of patient medication category that were selected for further analysis can be defined as primary work processes, as they are tasks that directly form part of the patient treatment process. The tasks from the patient monitoring category can be defined as secondary work processes, as they contribute to the patient treatment process indirectly by assessing the patient's health. From this definition the patient monitoring tasks can be said to have a lower complexity in comparison to patient medication tasks (Carayon and Friesdorf, 2004).

TASK STRUCTURE ANALYSIS

The task structure analysis aimed at determining the prescribed and theoretical procedure of tasks through the establishment of task goals. This more flexible perspective was adopted as humans have a versatile nature of coping with task demands by employing potentially numerous means to achieve task goals (Shepherd, 2000; Shepherd, 2001). Both task categories were initially analysed using a general information processing model in order to establish the kinds of information processing demands these two task categories placed on the nurses. This was followed by a detailed decomposition of the tasks. Hierarchical task analysis provided a framework for the analysis of the tasks in order to determine the information and task components required for effective performance (Shepherd, 2001), and was selected as it provides the basis for potentially determining cognitive and workload inducing components in a task (Shepherd and Stammers, 2005; Shepherd, 2001; Annett, 2005). From the information processing analysis, it could be determined that the two task categories differed from each other. The task structure analysis alone was not sufficient to determine workload as it is a multidimensional concept (Carayon and Gurses, 2008); however it provided the theoretical foundation for the task execution analysis of the nursing workload on a situational level (Carayon and Gurses, 2008).

INFORMATION PROCESSING

All tasks rely on at least a degree of information processing to allow for effective performance (Carswell and Stephens, 2001; Shepherd, 2001) and the human-task interaction for both task categories was analysed using the general information processing model described in Chapter II. From Figure 9 in Chapter IV, one can determine that information processing required for these two task categories differs slightly. This would have been as a result of the different demands of the two categories namely that the tasks that fell within the patient monitoring category were information acquisitioning tasks, and the tasks that fell within the administering of medication category were prescribed action tasks.

Both tasks used procedural knowledge which is embedded in long-term memory (Bridger, 2009) and, depending on the experience of the nurse, would affect if the tasks occur automatically as a result of a subroutine or not (Bridger, 2009). All the memory stores were used for both task categories, but the order in which the memory stores were required differed as a result of the task demands. The researcher found that numerous tasks had an interruption, and if this interruption occurred when the nurse was processing information in the short-term sensory store, the potential existed that the information might have been forgotten (Carswell and Stephens, 2001). A degree of leeway exists as the information perceived can be temporarily preserved, so that the nurse may turn her attention to the interruption (Wickens, 1985), but the information is only preserved for a short period of time (Carswell and Stephens, 2001; Bridger, 2009). According to Carswell and Stephens

(2001), the number of stages of information processing also affect the workload of a task. The tasks in the patient medication category had four steps, while those in the patient monitoring condition had six, but as the information processing required in each of these steps is undeterminable, one cannot determine the overall effect.

An additional factor that was observed in the task execution analysis that may affect the information processing chain, was that assessing temperature and blood pressure and heart rate often occurred concurrently (Proctor and Read, 2001). For the task of measuring temperature, the nurse assistant was required to wait several minutes for the mercury in the thermometer to rise to provide the temperature reading. In this time the majority of the nursing assistants conducted other tasks such as measuring blood pressure. It was observed that the duration for measuring temperature was an estimate that was not strictly adhered to, with the result that, even though the nurse divided her attention between two tasks, no bottlenecks occurred, as would have been expected for concurrent information processing (Proctor and Read, 2001; Bridger, 2009).

A problem with the majority of psychological models is that the assumption exists that task interface is present (Shepherd and Stammers, 2005). For all tasks observed, the patient can be considered as the task interface. For the tasks of measuring blood glucose and measuring blood pressure and heart rate, there is an additional interface as a result of the required man-machine interaction. As a result, these tasks have different cognitive demands in comparison to the other tasks (Bridger, 2009).

HIERARCHICAL TASK ANALYSIS

Hierarchical task analysis decomposed the task into goals the nurses was required to achieve in order to complete the task. This type of theoretical analysis determines some of the initial task demands or the task-centred workload aspects (Hart and Staveland, 1988) required from the nurse. This can be seen as the first step in a process to determine workload, as it establishes the requirements of the task (Hart and Staveland, 1988; Gaillard and Kramer, 2000). From a hierarchical task analysis perspective, nursing work may be described as being constrained as, by limiting the manner in which the tasks can be performed, error can be minimised. Yet as a result of each patient being unique and responding to treatment differently, nursing work also requires a degree of flexibility (Shepherd, 2001).

The plans indicated in the hierarchical task analysis assisted with capturing the task complexity and provided an indication of the monitoring, judgment and decision-making tasks (Ainsworth, 2001; Shepherd and Stammers, 2005). These processes are difficult to assess and, as such, one can only infer where they may occur in the task (Shepherd, 2001). The comprehensive decomposition of the tasks allowed for the ensuing more in-depth analysis of the effect of workload stress on the nurses. All tasks were found to have cognitive components and, as they were all patient-centred tasks, it can be expected that there is a more psychological component in comparison to tasks revolving around inanimate work objects (Carayon and Friesdorf, 2006; Hignett, 2001).

Various characteristics, relating to necessary skills and posture, that would influence the initial demands were established. For all the tasks, the posture was that of a standing position with the majority of the motor requirements being those of the upper body. Because the posture is similar for the tasks, it would be expected that the resulting physical strain would be similar, and that variations in physical strain would be due to the differences in the upper body movements as well as the compliance of the patient (Boucsein and Backs, 2000). The skills required for both categories of tasks, other than well learned procedural knowledge, included interpersonal and social skills in order to interact not only with the patient but with the various members of the healthcare team (Shepherd, 2001). From the decomposition of the tasks, it was established that all tasks have at least one information communication sub-goal, predominantly in the form of recording the nurse's actions and observations in the patient file. In addition to this, good communication skills in the nursing staff are required (Shepherd, 2001). This sub-goal is not crucial for the individual task but is essential for the main goal of patient treatment and continuity of care, as it is the source of communication between staff and shifts regarding that specific patient (Shepherd, 2001; Swezey *et al*., 2000).

Within the task of administering injection medication, there are more sub-goals that need to be achieved in order to obtain the goals in comparison to the other tasks analysed. According to Leplat's definition of task complexity (1988), this task may be classified as being more complex than the other tasks analysed and may result in a greater cognitive demand on the nurse. In the patient monitoring category, by this same definition, measuring temperature can be described as a less complex task than all the others. But despite this, as numerous factors mitigate the effect of workload, no indication of the workload that may result can be established from the task complexity. This does, however, provide an indication of what trends may result from this factor (Sterud *et al*., 2008; Bridger, 2009). As a result of both an excess and a lack of complexity, errors can occur as a consequence of insufficient vigilance and interaction with the task (Bridger, 2009).

Psychological constraints are not the only consideration needed for task and work analysis (Shepherd and Stammers, 2005). Many tasks entail physical effort, and influences from the external environment can impact on the work performance and execution (shepherd and Stammers, 2005). The task structure analysis allowed for the determination of the theoretical execution and informational processing requirements of the critical tasks. The next applicable step was to assess these tasks within specific contexts to see how the tasks were executed in real situations. The task structure analysis allowed for this as well as determining the effects these tasks within these situations have on the nursing staff.

TASK EXCUTION ANALYSIS

TASK AND WORK ENVIRONMENT CHARACTERISTICS

Task and work environment characteristics were essential to the assessment of workload as the interaction of these two in addition to the worker's abilities affect workload (Hart and Staveland, 1988; Gaillard and Kramer, 2000). The work environment factors in relation to nursing workload are explained by the model of factors which influence manual patient handling described by Hignett and Richardson (1995) depicted in Figure 4, Chapter II. This model suggests that the organisational factors, which were the staff and bed occupancy related results, will have a direct effect on the task the nurse is to perform (Gurses and Carayon, 2009; Hignett, 2001). Similarly the task characteristics would affect the experienced workload (Hart and Staveland, 1988; Gaillard and Kramer, 2000). The first task characteristic assessed was that of task duration which was significantly different for the various tasks.

Task duration

The task of setting up IV medication, which was significantly different from all other tasks, had the greatest duration (10.89 minutes) and variation (SD 10.34). The variation may have been as a result that not enough observations for this task occurred or alternatively, it might be that this task in itself elicits a large amount of variation between nurses. The variation in duration as a result of the task may be caused by patient related factors such as health status and compliance. The effect of the patient's health status on the duration of setting up IV medication was also indicated in the results regarding performance. This task, as a result of a patient in poor health, would require longer and possibly several attempts to be successfully completed. The two tasks with man-machine interaction had the shortest duration and were not significantly different from each other. The short duration is most likely as a result of having a machine to assist with these tasks.

An expected result that was obtained was that the interruptions have a significant effect on the duration of the task. As a result of the nature of the healthcare environment, not all interruptions can be prevented but numerous might be. Even though all the tasks are relatively short in duration, by redesigning the work environment to reduce the number of interruptions, the overall duration of task shift may be reduced and hence have a positive effect on nursing workload.

Interruptions

Interruptions were assessed as either physical or verbal and occurred in 55.89% of the tasks observed. Physical interruptions occurred more than verbal interruptions. The researcher noted that numerous physical interruptions, 6.04% of all the tasks observed, were caused by missing medication and equipment. If equipment and the medication trolleys were checked prior to task shifts starting, these interruptions may be prevented. As no statistical significance for the strain indicators and number of interruptions was established, this would suggest that interruptions do not directly affect strain indicators, and that other task and environment characteristics have a greater influence on strain indicators.

Task performance

Task performance was included in the work analysis as these two concepts are related (Kirschner, 2002) in that low and moderate levels of workload are associated with an acceptable level of performance (Wilson and Eggemeier, 2001). Performance was assessed in the task execution analysis as the number of task failures, machine errors and medication errors. Missing equipment and medication were also assessed as this factor influenced task performance and workload.

Of all the tasks that failed, four instances of setting up IV tasks, one instance of administering injection medication and one instance of administering pill medication were observed. The researcher observed that the failures regarding setting up IV medication were often as a result of the patient-related factors as previously described. This result suggests that a contributing factor to the failure of the task is the complexity as a result of the patient (Hignett and Richardson, 1995). The remaining two instances of task failures were as a result of an organisational factor in that the appropriate medication was not available.

Machine error occurred in 14.04% of the observed tasks that had a man-machine element. All the errors occurred as a result of the failure of the blood pressure and heart rate meter. Failure at this task did not directly jeopardise the patient's health but did increase the nurses' workload, as firstly she was required to establish that the value was inaccurate as a result of machine failure as opposed to an unhealthy patient value, and secondly she needed to repeat the task until an accurate value was returned. Medical equipment needs to be portable and as a result of frequent use, it is not unusual for equipment to become dysfunctional (Bridger, 2009). Not enough machines were available to replace the faulty machines, and so the task shifts were continued with faulty equipment, often requiring values to be reassessed. The result suggests that this is a recurring problem which affects nursing workload, and that it can be easily addressed if the monitors are serviced more regularly.

Values and medication were re-checked a total of 8.46% of all tasks observed, and was included here as it was a safety mechanism to ensure performance was acceptable. Medication errors occurred in 1.51% of all administering medication tasks and all of these errors were timeously corrected by the nursing staff. On one occasion the patient identified that the incorrect number of pills was being administered. This highlights Carayon and Friesdorf's (2006) suggestion that the patient should be an active "co-worker" in the patient treatment process within healthcare systems.

The above factors can be described as workload influencing factors and are reflected through one of the workload assessment perspectives namely either from the subjective, objective and psychophysiological perspectives (Baker, 1985; Kumashiro, 2005). From the above, it has also been established that the task factors such as duration and interruptions not only affect workload but also influence the performance of the task (Kirschner, 2002). Both of the above-mentioned factors did not have an effect on the strain indicators, but they are definite task characteristics or influencing factors and may contribute more to the qualitative experience of workload which is no less important than the physical counterpart (Hart and Staveland, 1988; Kumashiro, 2005).

Staff assistance, staff capacity, and bed occupancy

Very few tasks, only 2.72% of the tasks observed, were tasks where fellow nurses assisted each other in completing the task. This emphasises how independent the nurses' work is on an individual task level (Shepherd, 2001), as previously mentioned. This variable also highlighted how, if the workload or task complexity became too great for one individual, it was approached by a team of nurses (Bowers and Jentsch, 2005). In the specific case of the observed instance of setting up IV medication, the nurses needed assistance with correctly placing the needle within the vein. As a result of the patient's frail condition, several staff members attempted to complete this task, which eventually was not completed successfully and was left to be completed at a later point in time.

The bed occupancy was calculated as a percentage of the number of beds occupied within that ward. This is one of the ward properties that directly influenced the nurses' workload as the number was equivalent to the number of patients per task shift, whether it was for administrating medication or for monitoring patient condition (Hignett and Richardson, 1995; Gurses and Carayon, 2009; Hignett, 2001).). Both wards had a greater bed occupancy percentage in the morning than in the afternoon. From this one can conclude that, in the morning, more patients are present requiring medication administering and patient monitoring per task shift than in the afternoon. This would also suggest that the workload was greater in the morning but as the staff numbers were higher in the morning, this would have mitigated the workload effect. From the results, one can determine that there is greater variability in the bed occupancy percentage between days for the surgical ward, and this may be as a result of the nature of cases that are treated in this ward (Hignett and Richardson, 1995; Carayon and Gurses, 2008).).

From the organisational analysis, it was determined that nurses had one of two day shifts that either started at 7:00 am or 1:00 pm, and both shifts ended at 7:00 pm. The bed occupancy percentage suggests that this appeared to be considered when the shift structure was developed in that, as a result of a lower bed occupancy percentage in the afternoon, less nursing staff would be required. However, the shift workload reflected by the nurse-patient ratio suggests that this may have only been considered superficially, and the consequences of this type of shift system may not have been considered.

Nurse-patient ratio

The nurse-patient ratio was calculated by determining the number of patients per nursing staff and the number of patients per registered nurse. This measure has been reported to assess nursing workload on a unit level (Carayon and Gurses, 2008). From the results, it was concluded that, irrespective of the time of day, both ratios were higher for the medical ward than for the surgical ward. This would suggest that the nurses in the medical ward are exposed to higher workload levels as there are more patients per nursing staff member needing care in the medical ward than in the surgical ward. This may indicate that, as a result of the nurse-patient ratio, the patients in the medical ward are at a greater risk, as a higher nurse-patient ratio has been associated with having a negative impact on patient outcomes (Carayon and Gurses, 2008).

This research found that the medical ward had a nursing staff-patient ratio of 4.25 patients (SD 0.59) in the morning and 5.30 (SD 1.66) in the afternoon. For the surgical ward, the ratio was 2.19 (SD 1.15) in the morning and 3.08 (SD 1.47) for the afternoon. The registered nurse-patient ratio for the medical ward in the morning was 9.15 (SD 1.75) and in the afternoon was 11.66 (SD 4.69), while for the surgical ward in the morning this ratio was 5.28 (SD 1.58) and 8.08 in the afternoon (SD 5.28). All of these results differed from the nurse-patient ratios identified in the literature. Bateman (2009) states that in 2009, the national nurse-patient ratios in the public health sector were approximately 1 nurse to 18 patients, while the public health sector in the Eastern Cape had 1 nurse to 50 patients. An explanation for these differences could be that the ratios were calculated on a provincial level or on an institutional level as opposed to the ward level for which it was calculated for this research (Joubert, 2009). The nurse-patient ratio calculated on the ward level is said to be a more accurate reflection of nursing workload (Joubert, 2009). Literature suggests that the probability of risks increases as the nurse-patient ratio increases and, as a result of this, one can conclude that the patients are at higher risk in the afternoon as opposed to the morning for both wards (Carayon and Gurses, 2008).

STRAIN ANALYSIS

For the strain analysis, the different strain levels for the seven tasks observed was determined in the field through the use of the psychophysiological methods of heart rate frequency and heart rate variability. All of the heart rate measures assessed were relativised as the difference from the reference task as a percentage of the reference task. In addition to this, the subjective workload was assessed using the NASA-TLX.

Heart rate

Heart rate was significantly different for several of the tasks observed, as was to be expected. The task of measuring temperature elicited the greatest positive deviation from the reference task. From this one can conclude that the elevated heart rate indicates an increased demand on the body (McArdle *et al*., 2007). With the information regarding the task structure and through observation, the researcher proposes that it was predominantly the other influences and activities performed during the waiting period within the task of measuring temeperature that caused this elevated heart rate, as this constituted the greatest portion of the task. In the task structure analysis, the task of measuring temperature was identified as having a lower complexity compared to the other tasks (Leplat, 1988) and, during the observation phases in this research, it was established to be predominantly performed as a secondary task to the measuring of blood pressure and heart rate.

For the other tasks, no observations relating to the variability in heart rate as a result of extraneous factors were noted. As the tasks had different sub-goals that needed to be obtained, it was expected that the different sub-goals and demands of the tasks would elicit unique strain reactions compared to the other tasks (Noakes, 2001; Schubert *et al*., 2009; Boucsein, 2001). For all the tasks, heart rate was established not to be significant for duration of the task and the occurrence of interruptions. This suggests that other task and work related factors play a more determining role in heart rate. The result of a lack of significant findings for duration and heart rate has important implications as even though the duration of the individual task does not show to have a significant effect on heart rate, the accumulative effect of tasks and task shifts with a longer duration might have severe effects such as fatigue (Luczak and Göbel, 2000). A workload factor that was found to have a significant effect on heart rate was that of nursing staff-patient ratio, which had a relatively weak negative correlation of – 0.397739. This suggests that, as the nursing staff-patient ratio increases, heart rate decreases. This finding contradicts the literature which suggests that, as the nurse-patient ratio increases, so workload increases.

Heart rate variability

Time domain analysis: pNN30

This time domain variable determined the percentage of differences between successive N-N intervals that were greater than 30 milliseconds (Kim *et al*., 2009; Mietus *et al*., 2002). Significant results were established for this heart rate variability measure and the various tasks observed. All the tasks observed except one, namely measuring temperature, had a positive increase in heart rate variability from the reference task. This would suggest that, in comparison to the reference task, which was a reading task, all tasks except measuring temperature had greater variability, thus inferring that these tasks had less of a cognitive demand than the reference task (Boucsein, 2000). This is contradictory to the results expected, based on the previous analyses, as, according to the task structure analysis and the defining criterion for task complexity by Leplat (1988), this would suggest that all the hospital tasks have greater complexity than the reference task and so too have greater cognitive demands than the reference task. Potentially, as a result of experience and automation (Matthews, 2001; Bridger, 2009), these demands may have been reduced.

The remaining results also produced conflicting information with regards to the literature studied. The task with smallest positive increase in percentage from the reference task was the task of measuring blood pressure and heart rate , while the task with the greatest increase was that of setting up IV medication. According to the literature this would indicate that the task of measuring blood pressure and heart rate was more cognitively demanding than the task of setting up IV medication, which contradicts the results from the previous analyses of task complexity based on the defining criterion by Leplat (1988). Similarly, the significant results for nursing staff-patient ratio and pNN30 did not follow the expected trends. A positive correlation was determined, when a negative correlation was expected, as a decrease in heart rate variability reflects an increase in cognitive workload (Mulder *et al*., 1981; Rowe *et al*., 1998).

Frequency domain: high frequency band

Significant differences were established only for the power and not the centre frequency of the high frequency band for the various tasks. For these heart rate variability measures, similar results were established as with the pNN30 measure. For the power of the high frequency component, once again the task of measuring temperature had a negative difference from the reference task's measure, and this the researcher has previously attempted to explain.

The tasks with the highest alteration in power of the high frequency band were setting up IV medication and administering injection medication. The tasks with the smallest difference from the reference task were the tasks of measuring temperature, blood pressure and heart rate, followed by the task of administering pill medication. With regards to current literature (Boucsein, 2000), these results suggest that these three tasks have a greater cognitive demand than the tasks of setting up IV medication and administering injection medication. The qualitative results previously established contradict this finding.

Frequency domain: low frequency band

Significant differences were established for the power and centre frequency of the low frequency band for the various tasks. For both measures, the three tasks that elicited the largest alteration in the power from the reference task were the tasks of changing IV medication, administering injection medication and setting up IV medication. The tasks with smallest percentage difference for the variable of power were the task of measuring temperature and the task of measuring blood pressure and heart rate, while for centre frequency it was the tasks of administering pill medication and measuring blood glucose. Similar to the previously discussed results, these also did not follow the expected trends. From the qualitative analysis, it was expected that the administering patient medication tasks would be more demanding than the patient monitoring tasks but, according to the majority of the literature, the lower heart rate variability values suggest the greater cognitive demand.

Frequency domain: low frequency power relative to the (LF + HF)

For the low frequency power relative to the sum of the low and high frequency, significant differences between the tasks were also established. Of all the heart rate variability measures, this measure elicited results most supported by the majority of the literature. The task of administering injection medication had a lower heart rate variability measure than the reference task for this variable. This suggests that this task was more cognitively demanding than the reference task as well as all the other tasks. The qualitative results showed similar findings in that this task was categorised as the most complex task as a result of the number of task elements, and therefore it elicited the greatest workload (Leplat, 1988). This same result and conclusion hold true for the task of setting up IV medication, as this task had the second largest number of task elements and the third lowest heart rate variability measure. For the tasks of changing IV medication and measuring temperature, blood pressure and heart rate, the results depicted the expected trend. These tasks had relatively few task elements and therefore could be defined as simpler tasks which result in a lower workload, reflected by a higher heart rate variability measure compared to the tasks previously discussed (Wickens, 1985; Hart and Staveland, 1988; Mulder *et al*., 1981; Rowe *et al*., 1998). This would suggest that these tasks have less of a cognitive demand in comparison to the tasks of administering injection medication and setting up IV medication. For the tasks of administering pill medication and measuring blood glucose levels, the results do not correspond with the trends proposed by the literature. For the nursing staff-patient ratio, a statistical significance was established with a negative correlation. This finding is supported by the literature in that when the nursing staff-patient ratio increases, so does the physical and cognitive workload of the nurse, reflected by a decrease in heart rate variability (Mulder *et al*., 1981; Rowe *et al*., 1998).

Heart rate variability: conclusion

For the heart rate variability measures of pNN30, the high frequency and the low frequency component, this research found contradicting results compared to the majority of the literature. The rapid response of the short-term heart rate variability measures (Rowe *et al*., 1998), a reason why they are useful cognitive workload indicators (Kumashiro, 2005), may also be the reason for the incomprehensible results of the above mentioned discussion. As this research was a field study, the lack of control over the extraneous variables may have contributed to the responses in heart rate variability, one these being the combination and overlapping nature of the tasks.

The results relating to the high and low frequency components, with the exception of the low frequency power relative to the (LF + HF), might be explained by the associated regulators for these two frequency bands. The high frequency band reflects parasympathetic activity (Acharya *et al*., 2006; Karim *et al*., 2011; Redondo and Del Valle-Inclán, 1992) and respiration (Gaillard and Kramer, 2000; Schubert *et al*., 2009). As numerous factors affect respiration, for example talking (Weintjies and Grossman, 2005) and parasympathetic activity, and as these could not be controlled during the testing, these in turn might have had a greater effect on the high frequency component (Gaillard and Kramer, 2000; Schubert *et al*., 2009) than the demands of the task. Similarly, for the low frequency components, the results may be explained by the fact that these components reflect blood pressure regulation and body temperature control (Karim *et al*., 2011; Gaillard and Kramer, 2000), and other factors may have been responsible for the variability in the results.

As the variable of low frequency power relative to the (LF + HF) considers more than just one heart rate variability measure, it provides a more sensitive measure. The low frequency component is said by some researchers to provide the greatest indication of cognitive workload (Rowe *et al*., 1998), as well as to reflect task situation (Karim *et al*., 2011; Gaillard and Kramer, 2000). These facts, in addition to using a base relativised form of this variable, may provide a possible explanation for why the results for this variable were similar to the expected trends discussed in literature.

Subjective measure: NASA-TLX

The NASA-TLX weighted overall workload score was significantly different for the various tasks observed. The lowest workload scores were for the tasks of changing IV medication and measuring temperature. As previously discussed, these tasks can be defined as less complex tasks, using Leplat's description (1988), compared to the other tasks analysed. A significant difference was also determined for the overall NASA workload score and nursing staff-patient ratio. A weak negative product moment correlation was calculated for the overall score. This suggests that, as the workload in the form of the nursing staff-patient ratio increased, the subjective overall workload decreased. These results cannot be adequately explained by the literature and may be the outcome of insufficient data due to the constraints of the work environment; therefore no definitive conclusions can be drawn. Further research using this tool in the specific environment would be required.

Despite these variants, conclusions supported by the literature were drawn for the individual scales of the NASA-TLX and the different strain indicators. Weak correlations were established between these two sets of variables. Very weak positive correlations were determined between heart rate frequency and the NASA-TLX scale components of mental load, physical load, temporal demand and effort. The literature supports these findings as an increase in heart rate results from an increase in mental, physical and overall effort (Kumashiro, 2005; Boucsein and Backs, 2000; McArdle *et al*., 2007). Similarly, heart rate increases as a result of stressors such as time pressure, measured as a temporal demand for the NASA-TLX (Kapitaniak, 2001). For the scale of mental load, weak negative correlations were drawn for all heart rate variability measures, except for the high frequency power and for the low frequency power relative to the (LF + HF). Literature suggests that, as a result of an increase in mental workload, all heart rate variability measures should decrease (Mulder *et al*., 1981; Rowe *et al*., 1998).

CONCLUSION

In this discussion, the researcher attempted to draw conclusions using both qualitative and quantitative data in relation to the expected trends discussed in current literature. As workload and work stress are complex interrelated concepts, a multidimensional approach was required to assess these and related factors. These results reflect the interrelated nature of the influencing factors for workload, work stress and resulting strain. The work environment analysis was used to establish the wider context that would affect the task and therefore the resulting workload, while the task structure analysis was used to determine initial task demands. The workload assessed in the task execution analysis is affected by numerous factors, including the result of the interactional effect of the factors identified in the first two analyses.

Using a systems theory approach for the work environment analysis, the researcher considered the wider context within which the task occurs, as the environment and organisational structure of the system will provide constraints for the task (Shepherd, 2001). As a result of this, it was established that the underlying teamwork component of all of the tasks analysed was more complex than when considered in isolation. From the work organisational analysis, it was concluded that, as a result of the different ward capacities and functions, the medical ward may have a higher workload demand due to the increased number of patients related to available staff in comparison to the surgical ward. Using the work process categorisation provided by Carayon and Friesdorf (2004), the researcher suggested that, as administering patient medication tasks constituted a more primary work process in comparison to the tasks associated with monitoring the patient's condition, these tasks had a greater complexity, which would affect workload (Hart and Staveland, 1988).

The task structure analysis aimed at determining the prescribed and theoretical procedure of tasks through the establishment of task goals. The factors found to influence the information processing required for these tasks, and therefore the cognitive demands required, were the number and stages of information processing (Carswell and Stephens, 2001), and concurrent execution of tasks (Proctor and Read, 2001), with the patient being the main task interface (Bridger, 2009). From the information processing analysis, it could be determined that the two task categories differed from one another. This would have been as a result of the different demands of the two categories, namely, that the tasks that fell within the patient monitoring category were information acquisitioning tasks, and the tasks that fell within the administering of medication category were prescribed action tasks.

As a result of all tasks being patient-centred, it can be expected that there is a more psychological component in comparison to tasks revolving around inanimate work objects (Carayon and Friesdorf, 2006; Hignett, 2001). This analysis determined that the variations in workload were as a result of the differences in the upper body movements as well as the compliance of the patient (Boucsein and Backs, 2000). The necessary skills required for the tasks that were analysed included interpersonal and social skills, good communication skills, and being able to perform constrained tasks while being flexible enough to adapt the task to the specific patient-task scenario. From the theoretical analysis of the task, it was determined that the tasks within the administering patient medication category had a greater inherent theoretical complexity than those within the patient monitoring category (Leplat, 1988).

The task and work environment characteristics that were assessed included duration, interruptions and task performance and can be described as workload influencing factors. From this research, duration was shown to be significantly different for the tasks and may influence the more qualitative aspect of workload as opposed to the more quantitative strain measures. Interruptions, which occur as a result of the surrounding environment, also influenced duration, but these factors did not affect immediate strain. Task performance has been shown to influence workload as well as the objective task characteristics. Workload was also assessed on a unit level by determining nurse-patient ratios.

For the strain analysis, significant results for the tasks were determined for heart rate frequency and the heart rate variability measures. Expected results were determined for heart rate frequency, whereas for heart rate variability contradictory results were obtained. Only the results for the low frequency power relative to the (LF + HF) indicated the same trends as determined by the qualitative data with regards to workload and work stress. For the results regarding subjective workload, as determined by the NASA-TLX, the results produced were similar to the conclusions drawn from the qualitative data. Contradicting data was determined for the correlation of the overall workload score, but the results from the individual scales followed the expected trends from the current literature.

SECTION TWO

REPORTED ERROR AND PREDICTIVE ERROR PROBABILITY ANALYSIS

CHAPTER VI

INTRODUCTION

AIMS AND OBJECTIVES

Most error models and techniques focus on the man-machine interaction (Bridger, 2009) but as errors in the healthcare environment revolve around the patient and may not involve a machine and with the consequences such as loss of life (Bridger, 2009), more suitable models and assessment techniques need to be investigated and developed. This second smaller section in this research aimed to assess the error protocols and predictive error probability within the healthcare environment.

As work analysis is linked to error identification in that task analysis aims at identifying problems in the work system (Shepherd and Stammers, 2005), Section two was based on the results of Section one. This section of the research, through the achievement of three objectives contributed to the overall aim of assessing workload in relation to error probability. The first objective was to determine the relevant error protocols, the second objective was to determine which type of errors were reported, and commented on the errors observed during the task execution analysis. Finally the third objective of this section in this research was to determine the predicted human error probability of the critical tasks.

RESEARCH DESIGN

Similar to Section one, the results of this section took the form of a top-down approach (Hignett, 2001). Initially an analysis was performed at the organisational or work environment level and as a result of the findings, the second analysis was performed at a task structure level. From the results of the error reporting and error procedure analysis (Chapter VIII), it was determined that the errors observed by the researcher during the task execution analysis performed in Section one, were not reported. As a result of this the researcher focused on identifying the human error probability at the ward level for these specific tasks. Error probability at a task execution level was not included as it fell outside the scope of this research, but drawing on the conclusions of the previous sections recommendations were made. A diagrammatic representation of the approach adopted and the structure of the results presented are featured in Figure 22.

Chapter VIII: Work environment level

Error Procedure and Error Reporting Analysis

- What errors are reported?
- What error protocols are in place?

↓

Chapter IX: Task structure level:

Predictive Error Analysis

- On a task level, what errors are likely to occur?

Figure 22: The experimental design and structure of section two: reported error and predictive error probability analysis.

This section of the research was predominantly based on the information provided by subject matter experts. For the error procedure and error reporting analysis, senior nursing staff were consulted to determine error protocol, while adverse event records for Settlers Hospital were obtained. Similarly to determine the predicted human error probability of the tasks, senior registered nurses were asked to assist with determining the probability and criticality of certain errors.

CHAPTER VII

REVIEW OF RELATED LITERATURE

INTRODUCTION

Various factors that affect workload or work stress (Hart and Staveland, 1988; Sterud *et al*., 2008) also affect the performance of the task (Kirschner, 2002). Not only do high workloads but also low workloads may result in operator stress (Gaillard and Kramer, 2000; Wilson and Eggemeier, 2001; Bridger, 2009) and poor performance, which may manifest as human errors (OGP, 2010; Brookhuis, 2005). Error can be defined as the deviation of human performance from the task's intended action, and may or may not result in a negative consequence (Reason, 2001). Intrinsically errors are not bad as they may assist with the learning and adaptation process, but the resulting consequence can be devastating depending on the context (Reason, 2001). In the hospital context, human error may have negative implications such as a delay in treatment (Berguer, 1999) and a lack of patient safety (Carayon and Friesdorf, 2006) that may even result in patient death (Bridger, 2009). Human errors in the healthcare system are difficult to detect and this may be as a result of numerous factors including that the patient is a form of task interface (Carayon and Friesdorf, 2006), that the effect of the mistake may not be immediately visible, and that there is not a system in place for the detection of errors (Narumi *et al*., 1999). One ergonomic intervention with regards to human error would be to redesign the work environment so that measures are in place to prevent the occurrence of errors (Bridger, 2009).

For complex systems such as health care, it can be said to have a blunt and sharp end. At the blunt end are the managers and system regulators while at the sharp end in this context are the nurses and doctors (Woods *et al*., 2010). Similarly from a systems perspective, two error conditions can occur based on this practice structure (Reason, 2001). The first is that of active failures which refer to errors made at the level of the human-system interface, which have a brief but immediate effect (Reason, 2001) that occur at the sharp end of a complex system (Woods *et al*., 2010). The second is the latent conditions which, as a result of managerial and organizational influences, lead to error-provoking behaviour in the workplace

(Reason, 2001). These conditions occur at the blunt end of a complex system (Woods *et al*., 2010). As the class or type of error is dependent on the underlying psychological processes, in order to better understand the occurrence of error, it needs to be understood in the terms of information processing and behaviour (Reason, 2001). One of these most prominent theories related to error and behaviour is that of Rasmussen’s theory of skill-, rule- and knowledge-based behaviour (Reason, 2001).

SKILL-, RULE- AND KNOWLEDGE-BASED BEHAVIOUR

This model assesses performance of tasks or classifies behaviour as being skill-, rule- and knowledge-based (Sanderson and Harwood, 1988; Shepherd and Stammers, 2005; Bridger, 2009). This model suggests that if a worker is confronted with a task requiring a response, the worker will most likely first try an acquainted response before adopting a more novel approach in order to complete the task (Shepherd and Stammers, 2005). This model provides a framework which gives rise to different patterns of errors (Shepherd and Stammers, 2005; Sanderson and Harwood, 1988) and was designed to attempt to reduce human error in the control of complex systems, while being predominantly aimed at functioning as a guide for the design of display coding (Sanderson and Harwood, 1988).

Rasmussen’s skill-, rule- and knowledge classification has four levels (Sanderson and Harwood, 1988). The first level, the skill-based level, corresponds with behaviour that consists predominantly of automated routines (Rasmussen, 1983) and is described as being ‘signal’ driven (Shepherd and Stammers, 2005;). The second level, namely the ‘rule’ based level is concerned with the behaviour regarding the perception of familiar but peculiar situations (Shepherd and Stammers, 2005; Rasmussen, 1983). This level is concerned with the behaviours as a result of past experience and is driven by ‘signs’ (Sanderson and Harwood, 1988). The third level refers to the situation an individual finds themselves in that is completely unfamiliar. This level is referred to as the ‘knowledge-based’ category and is mediated by ‘symbols’ (Shepherd and Stammers, 2005). The fourth level occurs as a result of unforeseen conditions and also corresponds to the ‘knowledge-based’ category (Rasmussen, 1983).

Based on the above model, errors are classified into three categories as a result of the type of deviation that occurs (Reason, 2006). The first category is that of trips and stumbles which specifically refers to the unintended alteration in the upright posture (Reason, 2001). The nervous system automatically detects and corrects these types of errors (Reason, 2001). The second category of errors is that of slips and lapses (Reason, 2001), which refer to the unintended deviation of action from the planned response (Reason, 2001) and occur at a skill-based level (Bridger, 2009; Reason, 2006). Slips specifically refer to the deployment of an inappropriate level of attention while lapses are rather associated with memory failure (Reason, 2001; Carayon and Friesdorf, 2006). Slips or lapses usually occur within well-learnt behaviours and are commonly referred to as absent-minded actions (Bridger, 2009). For slips to occur the task needs to be a routine task in a familiar setting, an alteration in either the plan or circumstance needs to have occurred and a distraction either by an external stimulus or internal preoccupation needs to occur. All three of these conditions need to be present simultaneously for a slip to occur (Reason, 2001). The third category of errors is that of mistakes which occurs on a higher level of information processing in comparison to the other two (Reason, 2001; Carayon and Friesdorf, 2006). Two types of errors exist in this category, namely that of rule-based mistakes and that of knowledge-based mistakes (Reason, 2006; Bridger, 2009). The deviation occurs at the selection of the action rather than on the level of the action itself (Reason, 2001). This third category is extremely hard to detect and recover, and usually the system has regulations in place for their prevention (Reason, 2001).

ERROR ASSESSMENT TECHNIQUES

Numerous methods are available to assess, predict and reduce errors; these include probabilistic risk assessment, human reliability assessments and error prediction techniques (Reason, 2006). One such technique that aims at predicting and reducing error, which was utilised in this research, is the Systematic Human Error Reduction and Prediction Approach (SHERPA) developed by Embrey (1986, as citied by

Stanton, 2005). This technique is a development of hierarchical task analysis (Stanton and Young, 1999; Stanton, 2005) and by identifying the psychological mechanism associated with error, analyses tasks and identifies potential solutions (Stanton, 2005). Once the task has been decomposed via hierarchical task analysis, credible errors modes for appropriate sub-tasks are established and these error modes are then classified using the taxonomy of credible errors featured in Table XXX (Stanton and Young, 1999). This technique categorises tasks according to a predetermined taxonomy and classifies the tasks into five error types. This tool provides a structured and comprehensive assessment means of error but can be tedious and time-consuming for complex tasks (Stanton and Young, 1999).

Table XXX: Taxonomy of Credible Errors used for SHERPA (Stanton, 2005).

Action errors	**Checking Errors**	**Retrieval errors**	**Communication errors**	**Selection errors**
A1. Operation too long/short	C1. Check omitted	R1. Information not obtained	I1. Information not communicated	S1. Selection omitted
A2. Operation mistimed	C2. Check incomplete	R2. Wrong information obtained	I2. Wrong information communicated	S2. Wrong selection made
A3. Operation in wrong direction	C3. Right check on wrong object	R3. Information retrieval incomplete	I3. Information communication incomplete	
A4. Operation too little/much	C4. Wrong check on right object			
A5. Misalign	C5. Check mistimed			
A6. Right operation on wrong object	C6. Wrong check on wrong object			
A7. Wrong operation on right object				
A8. Operation omitted				
A9. Operation incomplete				
A10. Wrong operation on wrong object				

An additional method that may be used in conjunction with SHERPA is that of task analysis for error identification (TAFEI) (Stanton, 2005). This error analysis method allows for the prediction of errors predominantly for user-device interaction (Baber, 2001; Stanton and Baber, 2005). Similarly this method also utilizes hierarchical task analysis as the foundation for the analysis (Baber, 2001; Stanton and Baber, 2005). This error prediction analysis aims to identify all illegal actions and so develop the device so it is impossible for these errors to occur, and thus improves usability (Stanton and Baber, 2005).

Alternative techniques that need consideration with regards to human error are the human reliability analyses (Hollnagel, 2001; Reason 2006). These analyses consider the probability that a worker will correctly perform a task within the given time allocation (Hollnagel, 2001). These analyses determine the human error probability for a specific task or node and then alter the score using performance shaping factors (Hollnagel, 2001). This is based on the assumption that failure can be determined from specific types of action regardless of the context (Hollnagel, 2001). As a result of excluding the influencing factor of context, the usability of these analyses is limited as the accuracy is debatable for non-routine tasks (Hollnagel, 2001). To overcome this limitation human reliability methods have recently been adapted to include an operator model either in the form of a behavioural, information processing or a cognitive model (Hollnagel, 2001).

HOSPITAL CONTEXT

Healthcare, as previously mentioned, is a complex system as it has the properties of being dynamic and rapidly changing (Carayon and Friesdorf, 2006). These are important considerations when attempting to determine error probability (Bridger, 2009). As the main goal of healthcare is patient-centred, consequently the hazards in this field are predominantly patient-related and may manifest in the form of a lack of patient safety and medical errors (Carayon and Friesdorf, 2006, Buckle *et al*., 2006). Patient-centred errors may also occur as a result of faulty medical equipment. As a result that medical equipment is portable and frequently used; it often becomes malfunctional (Bridger, 2009). Hospitals usually lack formal quality control systems with regards to equipment (Bridger, 2009) and then it is the nurse or healthcare staff using the equipment who need to serve as an error detection system. Factors that have been shown to affect the probability of errors occurring include ineffective communication, the number of hours worked by nursing staff (Gurses and Carayon; 2009), time pressure and frequent interruptions (Hallin and Danielson, 2007).

As a result of healthcare being a complex system that predominantly revolves around a task object that is human, a holistic ergonomic approach needs to be adopted in order to assess and improve the system for all, healthcare worker and patient alike (Buckle *et al*., 2006). Ergonomic analyses within this context can assist with improving human performance which in turn would then reduce the risk of error and injury to not only the worker but the patient as well (Berguer, 1999). Currently the error prevention structures that are utilised in some hospitals is that of a self-reporting systems to record human errors in nursing care. These systems hope that through reporting, incidents may be detected earlier and the necessary corrective procedures implemented (Narumi *et al*., 1999). Alternatively, many hospitals have rules and protocols in pace to prevent errors such as confirming the patient's identity prior to administering medication, and recording the types and number of adverse events that occur (Bridger, 2009). Despite the large amount of information available regarding human error, there are still shortcomings regarding human error in the healthcare field with specific regard to nursing workload and working conditions (Narumi *et al*., 1999).

CHAPTER VIII

WORK ENVIRONMENT ASSESSMENT: REPORTED ERROR ANALYSIS

AIM AND PROCEDURE

This study contributed to the aim of assessing the error protocols and predictive error probability within the healthcare environment by achieving two objectives. The first objective was to ascertain the protocols in place for error prevention and the procedure for reporting errors, and the second objective was to assess the types and number of errors reported in Settlers Hospital.

The first objective was assessed at an organisational level in both the form of required prevention protocols and errors reported. Error prevention protocols and error reporting procedure was determined through the questionnaire done in the work environment analysis (Appendix A) in Section one. This questionnaire was directed at the senior professional nurses as they assist the chief professional nurse in the management of the wards. For the second objective, after receiving permission from the hospital, the adverse event reports from January 2009 to October 2011 were obtained to determine the number of errors reported. These reports listed per month the number of occurrences of adverse events. To supplement the data, the number of in-patient admissions was obtained, in order to have a perspective from which to analyse the number of adverse events. Unfortunately for the months of October 2010 to December 2010, no adverse event reports were archived and therefore this data is missing.

RESULTS

ERROR PREVENTION PROTOCOLS AND ERROR REPORTING PROCEDURE

The error prevention protocols determined during the questionnaire were either ethical guidelines or specific protocols the hospital had defined. The answers from the questionnaire regarding error prevention protocols also often provided information regarding safety guidelines as opposed to only specific guidelines relating to error prevention.

Error prevention protocols that were of an ethical nature included specific regulations regarding patients' privacy, and included the Bathu Pele principles, which is the principle that the patient's needs come first, and the Nurses' oath. Error prevention protocols that were defined and set by this specific hospital included rules and regulations regarding nurses' actions during tasks. These regulations to guide nurses' actions included continuous recording and reporting of their actions regarding patient treatment to supervisors, thorough identification of the patient prior to any procedure was required and sharp instruments need to be disposed of properly to prevent injuries. With regards to medication, the room containing medication needed to remain locked at all times and the key was to be kept by registered personnel only. Furthermore schedule 5 and 6 drugs were to only be administered by professional nurses and the stock of these drugs was to be checked daily. Additional regulations included staff needing to wash their hands before treating the next patient in order to prevent cross infection, protective clothing such as gloves was to be worn at all times, no needles or syringes were to be recapped, in order to prevent needle prick injuries and finally the rail on patients' bed needed to be maintained up at all times to prevent the patient from falling out of the bed.

With regards to error reporting procedures, also established during the questionnaire, when an error has occurred or the patient has had an unexpected negative reaction, a record needs to be entered in the patient file and an adverse event report needs to be completed. The senior registered nurses stated that the adverse event report should state exactly what happened, the condition of the injury if any and be submitted to the management where the incident would be further investigated if necessary. Furthermore the immediate supervisor of the nurses needed to be notified and the doctor of the patient. Depending on the severity and nature of the incident, once it had been reported to management, a disciplinary committee might issue a written warning to the nurse regarding the incident. If the event has had a negative effect on the patient's health, then family members would need to be informed as well. The more specific procedures for adverse events depend on the event that occurred. Some examples of this include if a patient develops bedsores which may result from insufficient turning of the patient done by nursing staff, an incident report would need to be written and reported to the matron's office, while with a needle prick event, blood would need to be taken from both patients involved, the necessary forms need to be filled in and the incident would need to be reported to the health safety representative. In event of missing drugs, the involved nurses would be required to write a statement regarding the situation to the matron.

ADVERSE EVENTS

From the adverse event data of the last three years, it can be concluded the number of adverse events at Settlers Hospital has increased. Despite the adverse event data being incomplete, with data regarding the number of admissions various conclusions can be drawn. The number of patients admitted in 2009 was 7779, in 2010 there were 7796 patients, and in 2011 up to the end of October there were 6470 patients. If one extrapolates the data for 2011, it is expected that by the end of the year approximately 7764 patients will have been admitted. From this one can conclude that the number of patients admitted has remained fairly constant over the time span of three years. Even though 3 months of adverse event reports are missing for 2010, the number of adverse events had increased from 29 events in 2009 to 36 in 2010. For 2011, by the end of October, 76 events had already been reported, the largest number of adverse events over the three year period. The number of adverse events and patient admissions for the time frame of January to September for the year 2009, 2010 and 2011 are depicted in Figure 23. The data was presented in this form as a result of the missing data for the months October to December 2010 and November to December 2011.

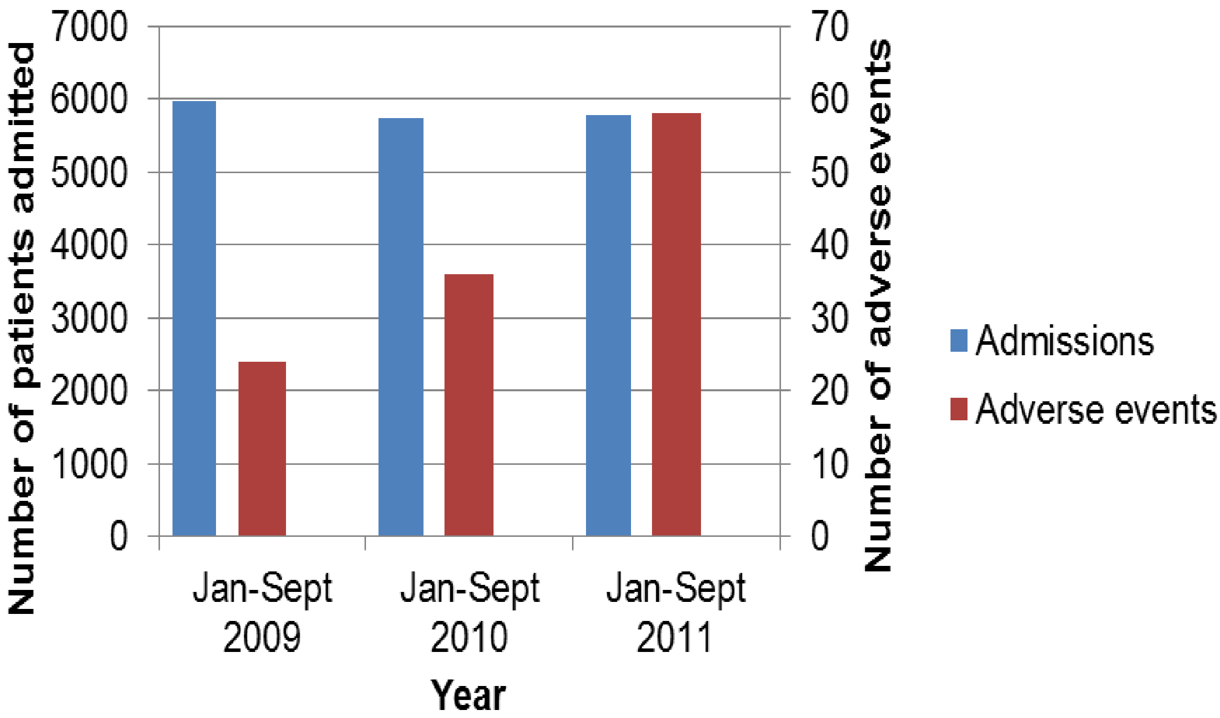


Figure 23: The number of adverse events and patient admissions for the years 2009, 2010 and 2011.

This graph allows for the emphasis of the differences in the data irrespective of the missing months and indicates that that the number of errors is increasing regardless of the number of patients admitted as this appears to be remaining constant.

The event with the highest incident count in 2009 was that of stillbirths which accounted for 50.00% of the total number of events. In 2010, the highest incident count resulted from the unavailability of medication at 25% of all events reported that year. In 2011, the event of an adverse reaction had the highest number of incidences at 44.83% of all events reported. In Table XXXI, the various reported adverse events are listed in addition to the number of reported occurrences for each event for the months of January to September 2009, 2010 and 2011.

Table XXXI: The number and types of adverse events for the years 2009, 2010 and 2011.

	Number of Adverse Events		
	2009	**2010**	**2011**
Maternal deaths	3	0	1
Neonatal deaths	6	7	6
Stillbirths	12	4	11
Unavailability of medicine	2	9	0
Water outages in hospital	1	1	0
Snake in hospital	0	1	0
Abscondment	0	5	4
RHT	0	2	1
Length of stay longer than 30 days	0	2	0
Malfunction detected/faulty	0	2	0
Electrodes stock out	0	1	0
Late submission of HIV statistics by ward	0	1	0
Nursing assistant assaulted by patient	0	1	0
Development of bedsores	0	0	1
Bladder injury as a result of a catheter	0	0	1
Wheelchairs	0	0	1
Bedfall	0	0	3
Swab or instrument left behind	0	0	1
Adverse reaction to drugs	0	0	26
Other: mentally ill patient fell and broke leg in hospital	0	0	2
Total number of advents	**24**	**36**	**58**

DISCUSION

The first step in improving a system, whether it is to reduce workload or improve performance within the system, is to identify if a problem within the system exists. These results as depicted in Figure 23 have identified that there is a problem within this specific hospital as a result of the number of adverse events is increasing annually irrespective of the number of patients admitted.

Following this it is necessary to establish the potential root cause of the problem. This research attempted this by establishing for which tasks the adverse events occurred as depicted in Table XXXI. Ideally with these results one would have considered the number of staff in addition to the adverse events reported and the number of patients admitted. Unfortunately this data was not available and as a result no conclusions could have been drawn regarding the number of adverse events with regards to staffing capacity. Another factor that complicates the analysis of this form of data is the inherent problem associated with errors in that it is not easy to determine where they originate as most errors are unobservable and it is rather the consequence of the error that is recognizable (Reason, 2006; Bridger, 2009). Rasmussen (2000, as cited by Carayon and Friesdorf, 2006) suggested that human error at various different levels can contribute to incidents and accidents. As a result of this, the researcher attempted to estimate all the levels at which these errors could have occurred for these tasks.

In 2009, the highest incident count at 50.00% was that of stillbirths. This may have been a result of numerous factors of which many the patient herself would have been responsible for. A large degree of control related to this task falls outside the range of the nurses and doctors in this context. Without context specific information regarding these adverse events, one cannot determine all the possible levels on which an error could have occurred. In 2010, the unavailability of medication at 25% had the highest incident account. Once again the degree of control falls outside the range of the direct healthcare providers in this context as this adverse event is as result of failure within the organisational structure or in the supply chain. In 2011, the event of an adverse reaction had the highest incident count at 44.83% of all events reported. This adverse event may be as a result of an error occurring at numerous different levels. The first level is that of the patient and this adverse event may have occurred as a result that the patient did not reveal all necessary information to the healthcare staff. The second level this error may have occurred is the level of the healthcare staff, as they may have not prescribe or admit the correct medication. Finally the last level where the error may have occurred is that of the pharmaceutical supplier.

From these results, one can determine that in order to provide high-quality safe care, a comprehensive idea of the errors and their causes is needed in order to ensure that they do not occur (Carayon and Friesdorf, 2006). As a result of this, for errors occurring in the healthcare field, a more comprehensive determination of the level at which errors within tasks can occur is needed at a situational level considering the specific context (Reason, 2006). Furthermore, as a result of the observations regarding errors made during the task execution analysis performed in Section one, the researcher found that these errors and incidents were not reported. The errors were identified and corrected by other staff timeously and without a great effect on the patient and thus may not have been reported. That said, the accumulative effect of these types or errors may have a more significant long-term effect in the form of increased workload for nursing staff, an extended patient stay as well as the additional economic cost to the hospital. As a result of this finding the researcher then attempted to determine the predicted human error probability for critical tasks for which the majority of the observed occurrences of these unreported errors occurred. These results are featured in the next chapter.

CHAPTER IX
TASK STRUCTURE ASSESSMENT

AIM

From the results of the Chapter VIII and the observations regarding errors made during the task execution analysis performed in Section one, the researcher found that these errors and incidents were not reported. As a result of this the researcher focused on identifying the human error probability at the ward level for specific tasks. The objective of this study within this research was to ascertain the predicted human error probability for the critical tasks assessed in Section one. By determining which task components were at greater risk of an error occurring, the researcher hoped to have a better understanding of the errors that occur that are not report, and identify where potential solutions could be implemented. This analysis used the SHERPA technique aimed at senior professional nurses in conjunction with the hierarchical task analysis performed in Section one to determine which sub-tasks are error prone and what the resulting consequence may be.

PROCEDURE

The systematic human error reduction and prediction approach (SHERPA) was used to analyse the seven critical tasks that were the focus of Section one. The first step in SHERPA was to decompose the task into components using hierarchical task analysis (Stanton, 2005). This was completed for the workload assessment in Section one (see Appendix B), and then used to analyse human error probability in Section two. The sub-tasks kept their original numbering in the SHERPA analysis so that the position of the sub-tasks within the hierarchical structure of the whole task could be easily identified. Each subtask was classified from the error taxonomy as an action, retrieval, checking, selection or information communication subtask (Stanton, 2005). Following this, possible error forms of these subtasks were established and classified according to the taxonomy of credible errors (Stanton, 2005) featured in Table XXX, in Chapter VII. Thereafter the potential consequences of these errors were determined (Stanton, 2005).

Four subject matter experts were asked to rate the criticality and the probability of the error occurring either as low, medium or high (Stanton, 2005) using the SHERPA forms created using the above mentioned technique, which is attached in Appendix F. A low probability was defined as the error that seemed never to have occurred before; medium probability was defined as the error that had occurred on previous occasions; and a high probability was defined as the error occurring frequently (Stanton, 2005). The criticality of that error was defined by what type of incident would result from this error: low criticality referred to minimal or no effect on the patient, medium criticality referred to a moderate effect on the patient, while high criticality was defined as a serious effect on the patient (Stanton, 2005). For each criticality and probability rating, the average rating was determined. This was done by assigning a low rating with the value of 1, medium with the value of 2 and high with the value of 3. This was followed by determining the average number of all the ratings which is featured in the brackets below the probability or criticality level in the SHERPA tables featured below.

RESULTS

For each of the tasks' sub-tasks that were identified as resulting in a credible error, the criticality and probability of an error was assessed. These operations (or subtasks) are featured in red in each of the SHERPA tables below. In addition to the calculated criticality for specific operations, criticality was determined in the case of specific operations as being case-dependent for example the severity of the effect as a result of an error would be dependent on the medication being administered, the patient's health status, and the patient's reaction.

Administering medication tasks

Setting up IV medication

For the task of setting up IV medication, the majority of credible errors that can result within this task have a medium probability of occurring. All the SHERPA results for this task are featured in Table XXXII. The only two operations that had a high probability of an error occurring were the sub-tasks of writing up and attaching the necessary label for the IV medication; with the consequence that the wrong information would be transferred between staff regarding IV medication.

Table XXXII: The predictive error analysis for the task of *Setting up IV medication*

Administering Patient Medication: Setting up intravenous (IV) medication					
Operations	**Task Classification**	**Human-error Identification**	**Consequence**	**Probability**	**Criticality**
1.2 Determine if medication is required	Retrieval	Fail to identify if medication is required	No medication administered	Medium (2.00)	Medium (1.75)
1.3 Determine what medication is required	Retrieval	Incorrectly determine required medication	Wrong medication selected	Medium (2.00)	High (2.50) **Depends*
1.4 Record in patient's file	Information Communication	Information not accurately recorded, incompletely recorded or not recorded at all		Medium (2.33)	Medium (2.33)
2.1 Obtain correct IV bag, unwrap and prepare	Selection/ Action	Incorrect IV medication obtained and prepared	Patient receives wrong IV medication, medication is inaccurately prepared	Low (1.00)	Medium (2.00)
2.2 Write up label	Action	Label not written up correctly or at all	IV medication not accurately recorded	High (2.50)	Medium (1.50)
2.3 Attach label to bag	Action	Label not attached	Information about medication not transmitted between staff	High (3.00)	Medium (3.00)
3.2 Identify correct vein	Selection	Incorrect vein identified	IV does not flow into the body as it should. Flows into artery. Results in swelling	Medium (1.75)	Medium (2.33)
3.5 Correctly Insert needle into body	Action	Needle not correctly placed	IV medication does not enter the body	Low (1.00)	High (3.00)
3.6 Check needle placement is correct	Checking	Check not performed	IV medication does not enter the body, IV medication does not enter the body as it should	Low (1.00)	Low (1.00)
4.3 Remove air from tubing	Action	Air is not removed from tubing	Air enters the vein of the patient. Drip does not run.	Medium (1.75)	Medium (2.25)
4.7 Check drip flow	Checking	Check not performed	IV medication administered at a too fast or too slow rate.	Medium (2.00)	Medium (1.83)

The criticality was rated as high for an error for the operations of determining the required IV medication, but this criticality is dependent on the medication, the patient's condition, and on correctly inserting the needle into the body. The consequence of these errors is that the wrong medication is administered or that the medication does not enter the body. An additional consequence of an error occurring for the task of placing the needle in the body is that the patient experiences swelling and pain, if the needle is incorrectly inserted.

Changing IV medication

Similar to the task of setting up IV medication, changing IV medication had a medium probability of errors occurring for the majority of the operations, and a high probability of an error occurring was selected for the same two operations that had a high probability in the task of setting up IV medication. These results are featured in Table XXXIII.

Table XXXIII: The predictive error analysis for the task of *Changing IV medication.*

Administering Patient Medication: Changing IV medication					
Operations	**Task Classification**	**Human-error Identification**	**Consequence**	**Probability**	**Criticality**
1.2 Determine if more IV medication is required	Retrieval	Fail to identify if medication is required	No medication administered	Medium (2.00)	Low (1.33)
1.3 Determine what IV medication is required	Retrieval	Incorrectly determine required medication	Wrong medication selected	Medium (1.67)	High (2.83) **Depends*
1.4 Record in patient's file	Information Communication	Information not accurately recorded, incompletely recorded or not recorded at all	Information is not adequately transmitted between staff	Medium (2.33)	Medium (2.00)
2.1 Obtain IV bag, unwrap and prepare	Action	Incorrect IV medication obtained and prepared	Patient receives wrong IV medication, medication is inaccurately prepared	Medium (1.75)	High (2.67) **Depends*
2.2 Write up label	Action	Label not written up correctly or at all	IV medication not accurately recorded	High (2.75)	Medium (1.75)
2.3 Attach label to bag	Action	Label not attached	Information about medication not transmitted between staff	High (3.00)	High (2.50)
4.6 Check drip flow	Checking	Check not performed	IV medication administered at an inaccurate rate.	Medium (2.00)	Medium (1.83)

Two operations had a high criticality regarding an error occurring, and were the sub-tasks of determining the required medication, and obtaining the new IV medication. These two operations are related in that an error occurring at the stage of determining the required medication will only manifest itself at the stage of obtaining the new IV medication. The criticality for both these operations is dependent on the patient and medication. Despite similar task operations for setting up IV medication and changing IV medication, the subject matter experts assessed these operations slightly differently and as such, between the two tasks, the probability for the operations was not identical.

Administering injection medication

For the task of administering injection medication, none of the operations had greater than a medium occurrence probability. Similar to the tasks of setting up and changing IV medication, a high error criticality, dependent on patient and medication related factors, was rated for the tasks of determining and selecting medication. As previously explained, these two operations are related in that an error occurring at the stage of determining the required medication will only manifest itself at the stage of selecting the medication. These results are depicted in Table XXXIV.

Table XXXIV: The predictive error analysis for the task of *Administering injection medication.*

Administering Patient Medication: Injections					
Operations	**Task Classification**	**Human-error Identification**	**Consequence**	**Probability**	**Criticality**
1.1 Determine if medication is required	Retrieval	Fail to identify if medication is required	Medication not administered	Medium (2.00)	Medium (1.75)
1.2 Determine required medication	Retrieval	Incorrectly determines required medication	Wrong medication selected	Medium (1.50)	High (2.88) **Depends*
1.4 Record in patient's file	Information Communication	Information not accurately recorded, incompletely recorded or not recorded at all	Information is not adequately transmitted between staff	Medium (2.33)	Medium (2.00)
2.2.1 Select correct medication	Selection	Select incorrect medication	Wrong medication selected and prepared	Medium (2.00)	High (3.00)
2.2.6 Withdraw fluid A from vial A	Action	Medication inaccurately prepared	Medication administered not in correct form	Low (1.25)	Medium (1.63) **Depends*

During the completion of the SHERPA analysis, the subject matter experts consulted highlighted that for the task component of checking drip flow, the patients often would adjust the drip rate themselves, and thus eliminating the check the nurses performed. The result of this would be that the IV medication is not administered at the correct rate and would be caused as a result of an inaccurate action performed by the patients and not by the nurses.

Administering pill medication

Depicted in Table XXXV is the SHERPA analysis for the task of administering pill medication. For the task of administering pill medication, none of the operations had greater than a medium criticality of which all operations but one were dependent on the medication and the patient's condition. The only task component that was rated as having a high probability was that of recording the information in the patient file. The consequence of errors occurring at this task component are a loss in communication between the other staff, especially when there are shift changes.

Table XXXV: The predictive error analysis for the task of *Administering pill medication.*

Administering Patient Medication: Pills					
Operations	**Task Classification**	**Human-error Identification**	**Consequence**	**Probability**	**Criticality**
1.4 Determine if medication is required	Retrieval	Fail to identify if medication is required	Medication not administered	Medium (2.00)	Medium (1.75) **Depends*
1.5 Determine required medication	Retrieval	Incorrectly determine required medication	Wrong medication selected	Medium (1.50)	Medium (2.00)
2.1 Select correct medication and quantity	Selection	Select incorrect pills. Select incorrect quantity	Wrong medication selected. Wrong quantity selected.	Low (1.33)	Medium (2.00) **Depends*
2.3 Prepare pills	Action	Medication inaccurately prepared	Medication not correctly prepared	Medium (2.00)	Medium (2.00) **Depends*
2.4 Record in patient's file	Information communication	Information not accurately recorded, incompletely recorded or not recorded at all	Information not accurately transferred	High (2.5)	Medium (2.00) **Depends*

Monitoring patient condition tasks

Measuring blood glucose level

For the task of measuring blood glucose the highest probability was that of a medium probability for the task component of administering the appropriate medication towards the end of the task after having determined the blood glucose level. This task component also had the highest criticality, as the effect of the incorrect or lack of blood glucose medication can have severe immediate health implications for the patient. These results are depicted in Table XXXVI

Table XXXVI: The predictive error analysis for the task of *Measuring blood glucose level.*

Patient monitoring: Measuring blood glucose					
Operations	**Task Classification**	**Human-error Identification**	**Consequence**	**Probability**	**Criticality**
3.1 Read off blood glucose level from machine	Retrieval	Value read off inaccurately	Results in inaccurate actions	Low (1.33)	Medium (2.25)
3.2 Record in patient's file	Action/ Information communication	Value recorded inaccurately, value not recorded	Inaccurate information transmitted	Low (1.00)	Medium (2.33)
3.4 Administer appropriate medication	Selection/ Action	Medication not administered, incorrect medication administered	Patient's condition will not improve and may become worse	Medium (1.75)	High (2.63)

Measuring temperature

For measuring temperature, none of the task components were rated as having a high probability or criticality. All the task components were rated as having a medium criticality, while the only medium rated probability was that for the task of reporting the increased temperature to the staff nurse. The SHERPA results for the task of measuring temperature are featured in Table XXXVII.

Table XXXVII: The predictive error analysis for the task of *Measuring temperature.*

Patient monitoring: Measuring temperature					
Operations	**Task Classification**	**Human-error Identification**	**Consequence**	**Probability**	**Criticality**
1. Read thermometer	Retrieval	Value is read inaccurately	Following action is incorrect and incorrect information is recorded	Low (1.33)	Medium (2.00)
2. Record in patient's file	Information communication	Value is recorded inaccurately	Following action is incorrect and incorrect information is recorded	Low (1.00)	Medium (2.00)
3. Report to staff nurse	Information communication	Not reported to nurse in order to take necessary action	Patient's vital signs do not return to the normal range as soon as possible	Medium (2.00)	Medium (2.00)

Measuring blood pressure and heart rate

The task of measuring blood pressure and heart had the operations of recording the systolic blood pressure and reporting the value to registered nurses if above 120mmHG, rated as having a high criticality with a medium probability. These two operations are potentially related in that an error occurring at the stage of recording the systolic blood pressure may result in the error of not being reported to the registered nurse at a later stage. These results are featured in Table XXXVIII.

Table XXXVIII: The predictive error analysis for the task of *Measuring blood pressure and heart rate.*

Patient monitoring: Measuring blood pressure and heart rate					
Operations	**Task Classification**	**Human-error Identification**	**Consequence**	**Probability**	**Criticality**
6.1 Record systolic blood pressure	Retrieval/ Information communication	Value is recorded inaccurately	Resulting actions are incorrect, and wrong information is transmitted	Medium (2.00)	High (2.50) **Depends*
6.2 Record diastolic blood pressure in patient's file			Wrong information is transmitted	Low (1.00)	Low (1.00)
6.3 Record heart rate in patient's file			Resulting actions are incorrect, and wrong information is transmitted	Low (1.00)	Low (1.00)
6.4 Report to registered nurse	Information communication	Not reported to nurse in order to take necessary action	Patient's vital signs do not return to the normal range as soon as possible	Medium (2.25)	High (2.63)

DISCUSSION

All the errors identified in the above analysis are that of active errors as they have a fairly immediate effect and occur at the level of nurse and patient interaction (Carayon and Friesdorf, 2006). Similar forms of errors were established within the two task categories. For the administering of patient medication, retrieval, information communication and action errors were identified (Stanton, 2005). While the main types of errors for the monitoring of patient condition category were identified as retrieval and information communication errors with the exception of one action error being identified in the task of measuring blood glucose (Stanton, 2005). These results highlight sub-tasks that may be prone to errors and through the insertion of checks at these critical sub-tasks may be avoided. These results would all predominantly occur in the error form of a slip (Bridger, 2009; Reason, 2006).

Using the above results in conjunction with the general observations made during the task execution analysis, the researcher was able to draw further conclusions for errors within these tasks. A recurring factor involved in the execution of these tasks was the occurrence of interuptions. These interruptions were caused by visitors, other patients, nursing and healthcare staff and as a result of organisational factors. Based on a similar conclusion by Hallin and Danielson (2007), from the above discussion it can be concluded that the probability of errors occurring in the analysed tasks increases as a result of interruptions. The reason for this is that these interruptions can be identified as the first condition needed in order for lapses to occur and as a result of the nurses' work being routine in nature, the second condition namely that of the task being a routine task in a familiar setting is also met (Reason, 2001). As a result of this, it can be concluded that in numerous instances nurses are only one condition away from the possibility of a slip occurring. From this one could conclude that by reducing the number of interruptions one should be able to reduce the probability of an error occurring in these tasks. Unfortunately not all the interruptions are preventable as the researcher also observed numerous interruptions that resulted in a task of greater priority needing to be completed prior to the interrupted task was completed.

For all the tasks analysed, the component of information communication regarding recording medication or patient condition in the patient file was revealed as a sub-task that had the potential of an error occurring at this operation. During the observation phase in Section one, it was determined that on numerous occasions the patient files were missing and were said to be delayed at the pharmacy. As a result of this, not only was occasionally the nurses' work interrupted but the potential exists from this situation for an error to occur. The error could occur in that the information would not be recorded as the file was not present. From the observation, it was determined that occasionally the information was then recorded elsewhere but as a result of this, the nurse may forget to update the file when it has been relocated. An alternative error that can arise from missing patient files is that the wrong medication is administered as the nurse may decide to administer the medication despite the patient file being missing unaware that the medication orders might have been changed.

The researcher also observed several consequences as a result of an error identified by another staff member during the task execution analysis that was related to the above featured SHERPA analysis and as a result was able to draw further conclusions from the data obtained. These observed errors included the administration of the incorrect IV medication, the incorrect quantity of pill medication administered and inaccurate recording of information regarding patient condition and administered medication. For the administration of incorrect IV medication, according to the SHERPA analysis this operation had a medium probability and a high criticality depending on the medication and the patient. From the observed scenario, the criticality appeared low as no immediate effects were observed but this error my result in longer lasting effects such as an increased hospital stay for the patient. For the task of administering pill medication, the task component of determining the required number of pills was rated with a low probability and a medium criticality that is dependent on the patient and medication. In the observed case related to the error regarding administration of pill medication, as the error was caught timeously, the patient suffered no effects. For the error observed of inaccurately recording patient information, the majority of the tasks analysed using SHERPA indicated that there was a medium probability and a medium criticality associated with errors at this subtask. From the above observations, it can be conclude that SHERPA can assist in identifying problem areas but a more specific context of the tasks needs to be included. In the context of the hospital environment, for many errors the criticality is dependent on the medication or the patient. Furthermore the above mentioned instances indicates that even though these errors are not reported, they do occur, and SHERPA analysis is one means of identify at which task components these type of low effect errors can occur.

The complete eradication of error from a system is not possible but the more timeously the errors in the healthcare field are identified, the better the potential for correcting the situation is (Reason, 2006). Examples of this are that during the task execution analysis, it was determined that of all the tasks observed, medication errors occurred on three occasions (1.51% of all the tasks observed) and all of these errors were timeously corrected by the nursing staff and no negative effects were observed. To assist with error management, one can potentially identify the working conditions in which these low effect errors are most likely to occur. By determining this, one can implement various structural or organisational safety mechanisms in order to prevent as many of these slips from occurring as possible or identify these error as soon as possible in order to correct them.

CHAPTER X

SUMMARY, CONCLUSION AND RECOMMENDATIONS

South African hospitals have unique challenges and demands, and in conjunction with a diminishing nursing workforce (Vujicic *et al*., 2004) the staff that remain are placed under increasing demands. These demands not only affect the healthcare worker but also the patients in that treatment quality is affect (Carayon and Friesdorf, 2006). This project aimed at addressing patient treatment quality from the perspective of worker capabilities. It did so by investigating the strain level and predicted human error probability associated with specific patient-centered tasks in the South African health care sector.

SUMMARY OF PROCEDURES

This research aimed at determining the strain and the predicted human error probability of various hospital tasks in conjunction with establishing probable contributing factors such as work organization through two independent yet interlinked studies.

In order to examine the effect of workload on the strain experienced by nurses, a work environment and workload analysis was performed in Settlers Hospital for seven patient-centred tasks. The tasks considered in this analysis were the tasks of setting up and changing IV medication, administering injection and pill medication, measuring blood glucose, temperature and heart rate and blood pressure. This analysis consisted of three smaller analyses where different aspects related to workload were assessed. The first analysis assessed the organisational structure within the wards investigated. The second analysis determined the structural components of the seven patient-centred tasks. The third analysis determined the strain level and influencing factors of these tasks. For the third analysis, fourteen nurses participated in this field study, and each participant was observed on two different weekdays during the day shift. During these observations, the detailed analysis of the seven pre-defined tasks was performed in conjunction with heart rate measures and subjective workload ratings assessed by the NASA-TLX.

In order to determine the error protocols and predictive error probability within the healthcare environment, two additional analyses were performed. The first analysis determined the protocols in place for error prevention, procedure for reporting errors, as well as the types and number of errors reported in the hospital. The second analysis as a consequence of the previously found results analysed human error probability at a task structure level.

SUMMARY OF RESULTS

WORKLOAD ENVIRONMENT AND WORLOAD ANALYSIS

As workload and work stress are complex interrelated concepts, a multidimensional approach was required to assess these and related factors. From these results it was established that different organizational and environment factors could affect task complexity and workload. One of these factors identified was that of the effect of different ward capacities and functions. As a result of this it was determined that the medical ward may have a higher workload demand in comparison to the surgical ward.

On a task structure level, the tasks that were the focus of this research were analysed to determine the different information processing demands and task components. Potential workload factors were investigated at this level and based on the theoretical analysis, the task complexity was determined as a potential influencing workload factor. The skills required for these tasks were also determined which included interpersonal and social skills, good communication skills, and being able to perform constrained tasks while being flexible enough to adapt the task to the specific patient-task scenario. The task that was identified as having the greatest inherent theoretical complexity was the task of administering injection medication that fell within the administering patient medication category (Leplat, 1988).

The third analysis in this section aimed at determining the strain level in addition to task and work environment characteristics. The task and work environment characteristics that were assessed included duration, interruptions and task performance and from these results, despite not directly affecting strain, these measures can still be conclude as workload influencing factors. For the strain analysis, significant results for the tasks were determined for heart rate frequency and the heart rate variability measures. Expected results were determined for heart rate frequency, whereas for heart rate variability predominantly contradictory results were obtained. Only the results for the low frequency power relative to the (LF + HF) indicated the same trends as determined by the qualitative data with regards to workload and work stress. Subjective workload, as determined by the NASA-TLX, was also assessed and the results produced were similar to the conclusions drawn from the qualitative data.

REPORTED ERROR AND PREDICTIVE ERROR PROBABILITY ANALYSIS

Error protocols and predictive error probability within Settlers Hospital was determined through two different analyses. From the first analysis, it was determined that the number of adverse events is increasing annually irrespective of the number of patients admitted within the researched hospital. The types of adverse events were identified and potential causes were discussed. But it was also established using the observations made during the first section that the errors observed by the researcher during the task execution analysis, were not reported. As a result of this, the researcher focused on identifying the human error probability at the ward level for specific tasks in the second analysis. The SHERPA analysis allowed for the identification of the credible errors, their probability and criticality and found similar types of errors within the two task categories. For both task categories, retrieval, information communication and action errors were identified. From the general observations, it was determined that the SHERPA analysis is useful tool in determining some of the potential errors that may occur within the studied tasks.

RESEARCH HYPOTHESIS

The overall research hypothesis was to determine the strain and the predicted human error probability of various hospital tasks in conjunction with establishing probable contributing factors.

The first section of this research hypothesised that different hospital tasks elicit different strain levels which can be determined in conjunction with determining several of the contributing strain factors. The results obtain from this study tentatively proved this hypothesis as the different tasks elicited different strain measures. Furthermore certain factors were found to have a significant effect on the strain level experienced, for example the nurse-patient ratio. Similarly the second section, which hypothesised that the predicted error probability of the tasks could be determined, was tentatively proven. Through the various analyses the overall hypothesis was tentatively proven that strain and predicted human error probability could be analysed in the field.

CONCLUSIONS

Despite the seemly simple hypothesis, the value of this research lies in the foundation that the gathered information provides and the numerous potential applications of this data. Numerous conclusions with regards to workload and error probability can be drawn from this data but it needs to be considered that as this research was explorative in nature and as a result of the large amount of qualitative data, majority of these conclusions will require further investigation.

From the first section, it can be concluded that strain as a result of task workload can be determined in the field. To do this though, a multifaceted approach is required to establish all the influencing factors. Through systematic analysis, one should be able to determine which factors have a greater effect on task strain than others. This approach allows for the determination of work environment and task factors resulting in the workload becoming excessive which could have the consequence of resulting in fatigue or errors. This then provides a starting point for an intervention as it reveals the problem areas within a work system.

Numerous factors are related to workload and in order to understand them, the specific workload for the researched system first needs to be determined. This research provides one possible way of analyzing workload and its related factors. As workload is a complex concept both qualitative and quantitative data were required to draw the necessary conclusions. In addition to this, by collecting several forms of data, the results and conclusion become more reliable. With specific regard to the measures used in this research, the researcher concludes that potentially heart rate variability can be used in the field but it needs to be used in conjunction with other measures and tentatively analysed with the consideration that numerous factors may have influenced the variable. More rigourous testing of heart rate variability in the field is required though. From the results obtained, several influencing factors of the complex interrelated concepts of workload and work stress were identified.

Similarly for the second section in this research, the results provided a starting point for intervention strategies. The first analysis in the second section highlighted that using hospital records, only some potential problems in the work system can be identified. Furthermore it was concluded that established protocols are not always adhered to and to improve a work system with this regard the protocols and procedures need to be enforced. The results from the second analysis indicated that even if errors are not reported, this does not mean they have not occurred. The second analysis also assisted in establishing where possible errors could occur. The combined results from this section however provide more specific starting points for interventions relating to error reduction. A final conclusion for the second section is that similar to workload, error probability is context dependent, and this needs to be considered when analyzing tasks and work environments.

This combined approach and collective results indicate that in order to understand complex systems, analyses need to be performed on various levels using various measures in order to understand how the system functions as a whole. If analysis is only performed from one perspective, the results will be superficial and interventions based on these results may not be effective.

RECOMMENDATIONS

Several recommendations can be made using the information gathered during this research. These recommendations are aimed at how the nursing work environment can be improved with regards to workload, how patient treatment can be improved as a result of a reduction in errors and the potential direction of the research that is to follow.

A very important component of the healthcare work system is that of the patient. But this factor cannot be forcefully controlled or altered to reduce the workload but rather depending on the specific situation can assist in reducing workload through receiving cooperation from the patient. But this is very dependent on the patient's health status, and if the scenario allows one can get them actively involved in their own recovery by making them aware of the medication they require as well as ensuring they do not hinder their own recovery. Examples of this would include ensuring patients are aware that they should not alter their own drip rate as this would not achieve the patient's desired effect of being released from hospital sooner. Also if patients are aware of the medication that they require, if a slip occurs and nurse provides the patient with the wrong quantity or type of medication, the patient may assist in preventing the consequence of this error.

A workload-related factor that can be potentially altered, even if only partially, to improve workload, is that of interruptions. Significant differences were not determined for the strain indicators but as interruptions have an effect on the duration, the potential exists that interruptions have an accumulative effect on the overall workload experienced by the nurse and affect error probability and fatigue. Further research regarding this is required to determine if interruptions have an overall detrimental effect on workload and error probability. As a result of the nature of the healthcare environment, not all interruptions can be prevented but those that can, may be eliminated through potential alterations in the organisational structure of the ward.

This researcher hypothesizes that by reducing interruptions, this would reduce time on task, as well as time on task shift which may reduce the workload of the task shift.

A more specific recommendation based on the results established in Section one, is that a maintenance check should be included in the organisational structure in the ward. If the blood pressure and heart rate meters were more reliable, nurses would not have to repeat tasks in order to determine the blood pressure and heart rate. This would reduce the time on task and therefore potentially the workload experienced over the entire day. This recommendation can be applied to any other machines that are used within the hospital context, as faulty machines provide an opportunity for an error to occur.

A general recommendation for the reduction of errors in this context is that the proposed safety procedures should be adhered to and enforced. This research discovered that even though safety procedures were stated by the senior registered nurses, a majority did not adhere or enforce them.

A final recommendation would be to extend this research and determine the effect of different strain levels on error probability. This may require intensive laboratory tests that are followed by comprehensive analyses of error reports and numerous observation phases in the field. Using this research as a foundation, the researcher proposes the next step would be to determine a base strain level in a laboratory setting for specific tasks followed by determining the error probability or error trends for strain levels. This would assist in providing information regarding the effect of the work environment on the strain elicited by the task done in the field as well as providing information regarding the effect of stress on error probability.

This research has highlighted that task and work environment characteristics affect workload which in turn may affect error probability. As a result of this, this research has provided a foundation not only for potential workload and error management improvements but also for future research regarding these two concepts.

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APPENDICES

<u>Appendix A: Work Environment Analysis</u>

General questionnaire
Interview guidelines

<u>Appendix B: Task Structure and Execution Analysis</u>

Hierarchical task analysis procedure and task decomposition tables
Subject questionnaire

<u>Appendix C: Ethical Considerations</u>

Department of Health of the Eastern Cape Ethical Approval
Research Information Letter for Interview
Research Information Letter for Task Analysis
Informed Consent Form

<u>Appendix D: Daily routine of the nurses</u>

<u>Appendix E: Statistical Tables for the Task Execution Analysis</u>

<u>Appendix F: SHERPA Analysis Forms</u>

Appendix A: Work Environment Analysis

General questionnaire

Interview guidelines

Human Kinetics and Ergonomics Masters Research Project:

The analysis of the strain level and the predicted error probability for critical hospital tasks

General Questionnaire for Nurses

This questionnaire aims to establish the daily routine of this ward as well as which tasks can be defined as 'critical'. A task can be defined as 'critical' if an error in this task has a potential negative effect on the patient's health status. This questionnaire also aims at establishing who performs which tasks in the ward and what error protocols are in place.

Ward:

Date:

1. Please list the usual routine of a normal weekday below. Please include how long that task takes you and what other staff members are also responsible for completing that task.

Time	Duration	Task	Staff

2. Which tasks do you classify as critical and why? Critical in this sense is defined as tasks where if a mistake is made, the patient's health will be negatively affect in some way.

Task	Importance

3. What rules and protocols are in place to prevent errors from occurring?

4. What procedure must be followed if an error occurs?

INTERVIEW GUIDELINES

The purpose of the interview is to verify the information gathered that was used to create the task templates during the observation phase and from information from the questionnaire prior to data collection.

Ward:

Date:

1. Is the following general information about your ward correct?

Medical ward function: Treats patients with medical disorders and diseases such as diabetes, psychological disorders, etc.

Surgical ward function: Treats patients with pre-operative and post-operative care.

Division of tasks:

Nursing staff	
Registered nurses	**Nursing assistant**
Take reports	
Wash patients	
Feed patients	
Admission of patients	
Blood glucose checks	Monitor vital signs
Phone for blood test results	Change patients
Prepare medication trolleys	
Doctors rounds	
Intravenous medication	
Administered medication and injections	
Discharging patient	
Ordering drugs and medication	

2. Do you consider these tasks as being critical (Critical implying that an error in this task would result in negative health implications for the patient)? What are the potential negative implications of errors occurring in these tasks?

For the Medical Ward

Patient Medication

Tasks	Staff	Approximate time of occurrence
Pill medication	Professional nurses	10:00, 14:00, 18:00
Injection medication	Professional nurses	10:00, 14:00, 18:00
Intravenous medication	Professional nurses	10:00, 14:00, 18:00

Monitoring patient condition (measuring vital signs)

Tasks	Staff	Approximate time of occurrence
Measuring blood glucose	Staff nurses	8:00, 11:00
Measuring temperature	Nursing assistants	10:00, 13:00
Measuring blood pressure & heart rate	Nursing assistants	10:00, 13:00

For the Surgical Ward

Patient Medication

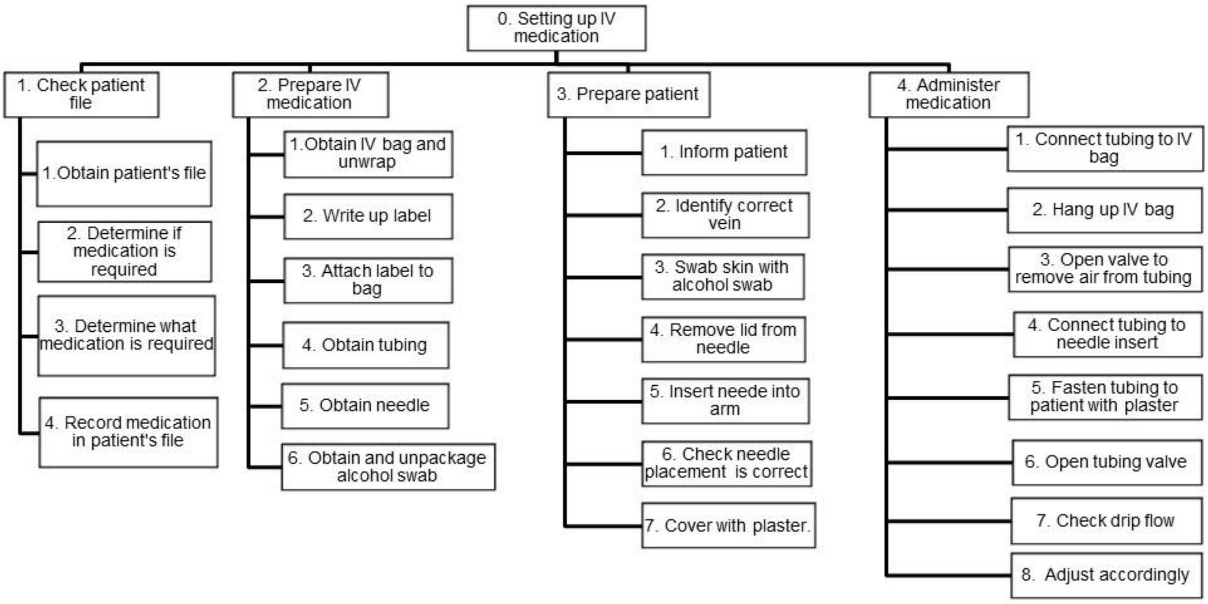
Tasks	Staff	Approximate time of occurrence
Pill medication	Professional nurses	10:00, 14:00, 17:00
Injection medication	Professional nurses	10:00, 14:00, 17:00
Intravenous medication	Professional nurses	10:00, 14:00, 17:00

Monitoring patient condition (measuring vital signs)

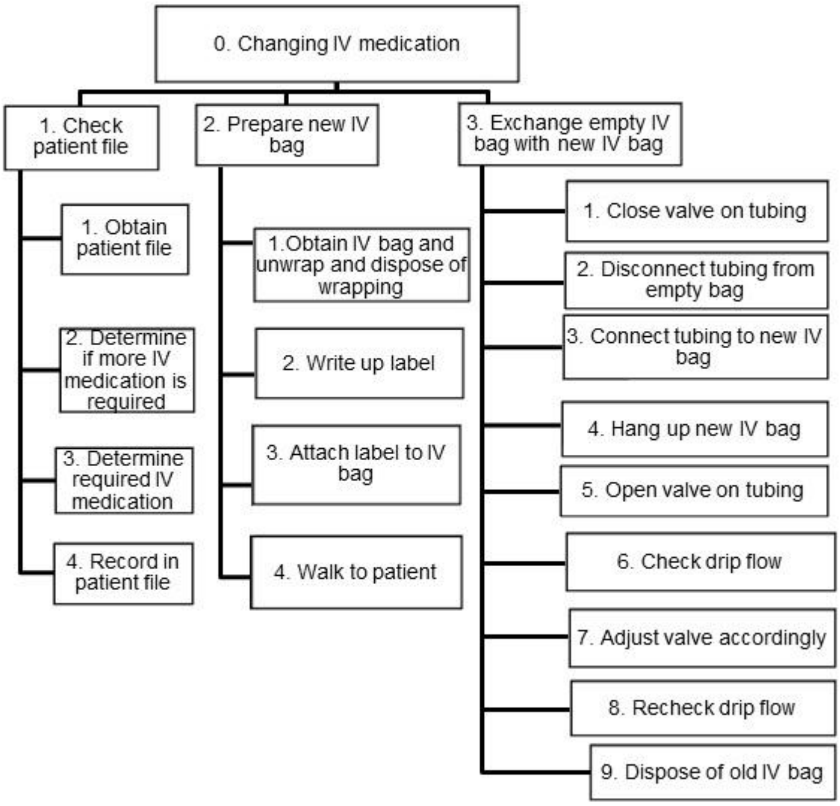
Tasks	Staff	Approximate time of occurrence
Measuring blood glucose	Staff nurses	8:00, 11:00
Measuring temperature	Nursing assistants	09:00, 10:00, 14:00
Measuring blood pressure & heart rate	Nursing assistants	09:00, 10:00, 14:00

3. Is the flow diagram of these specific routine critical tasks accurate? If not, please explain why not.

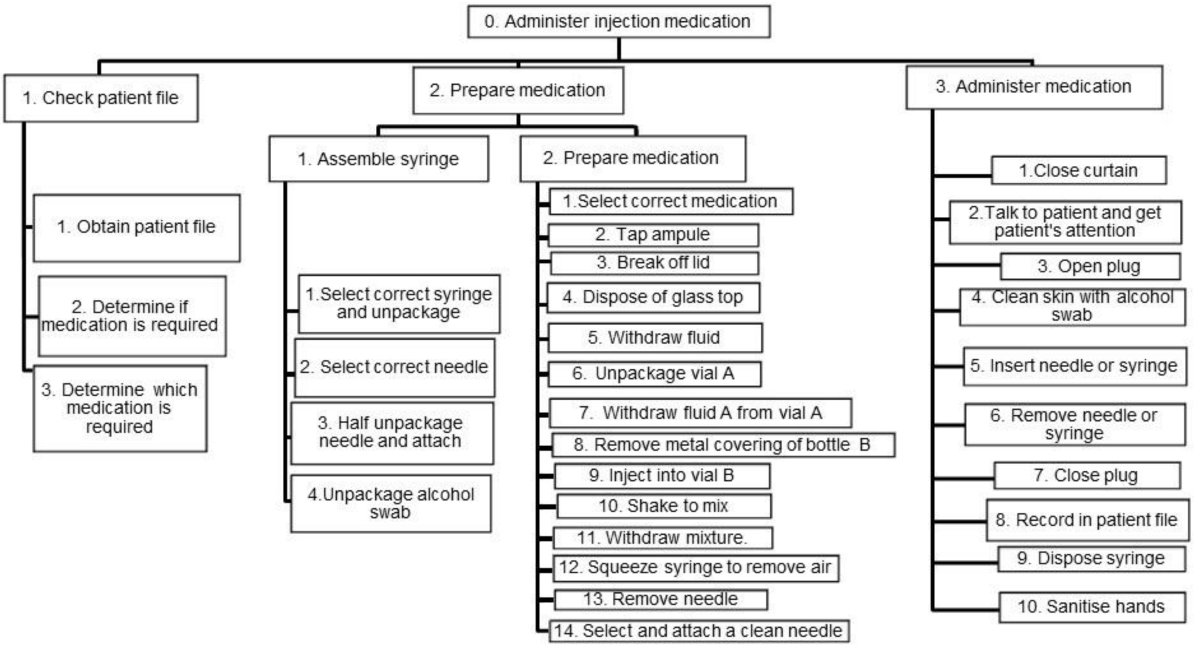
Setting up IV medication



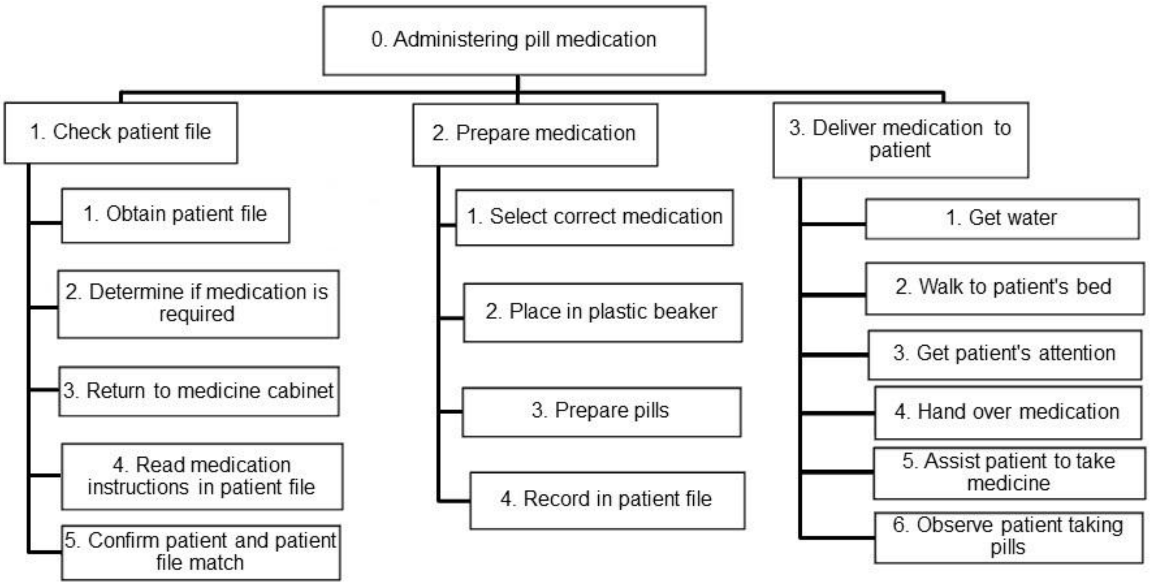
Changing IV medication



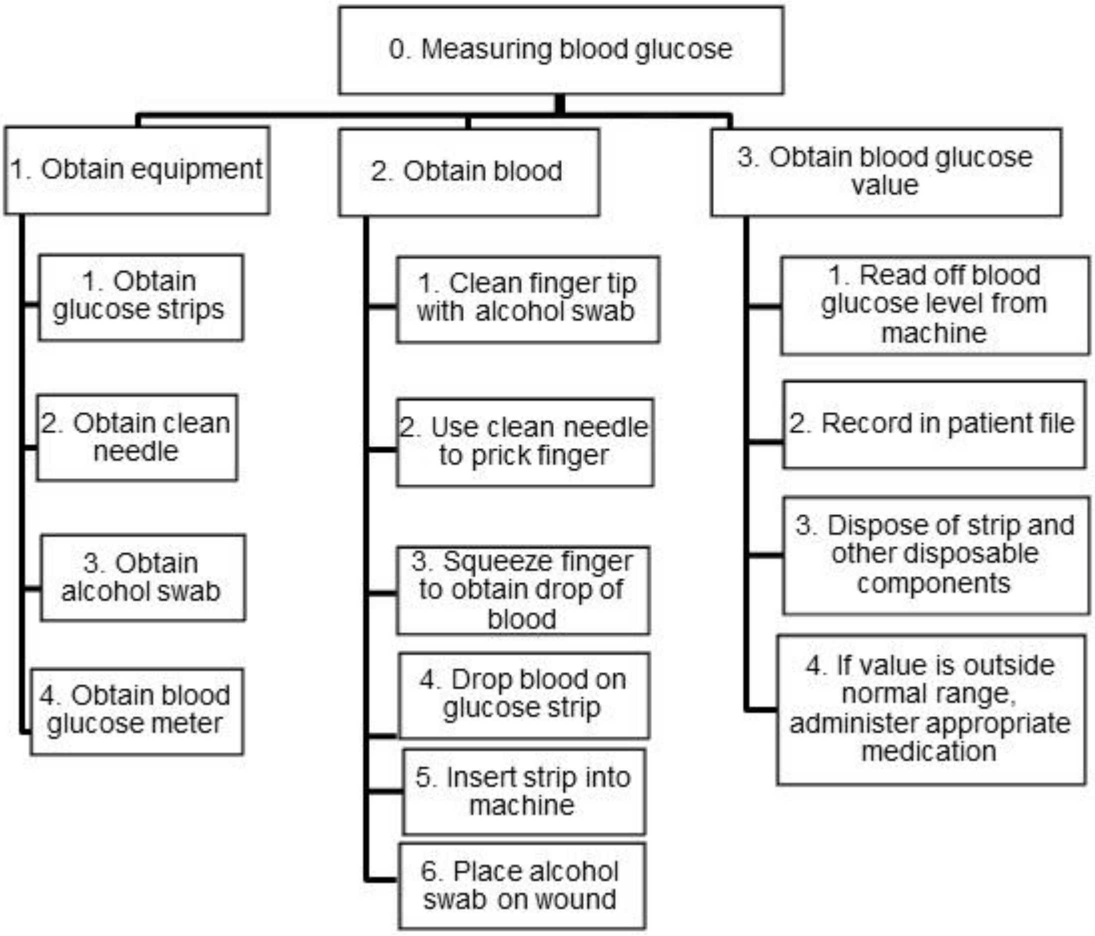
Administer injection medication



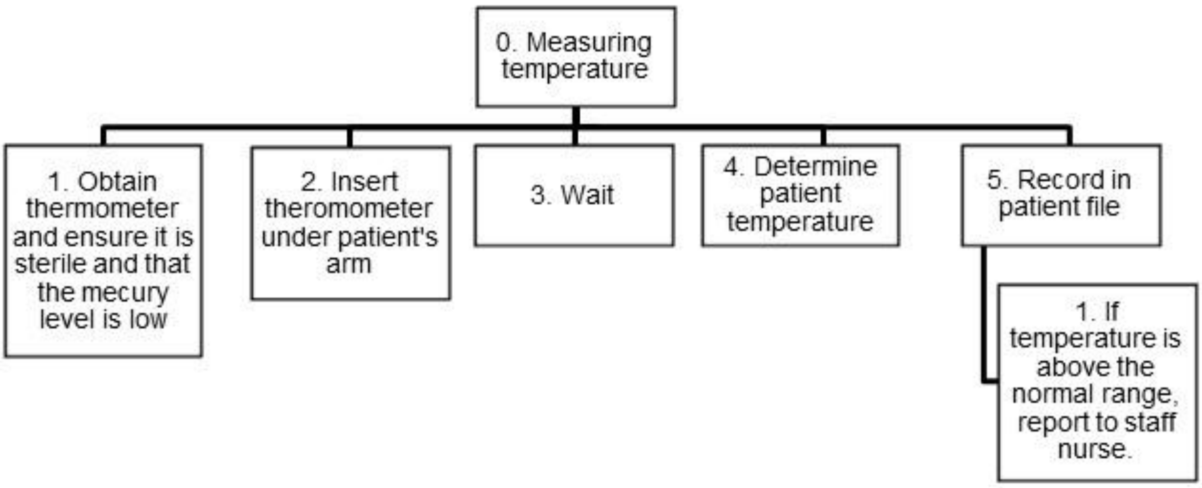
Administering pill medication



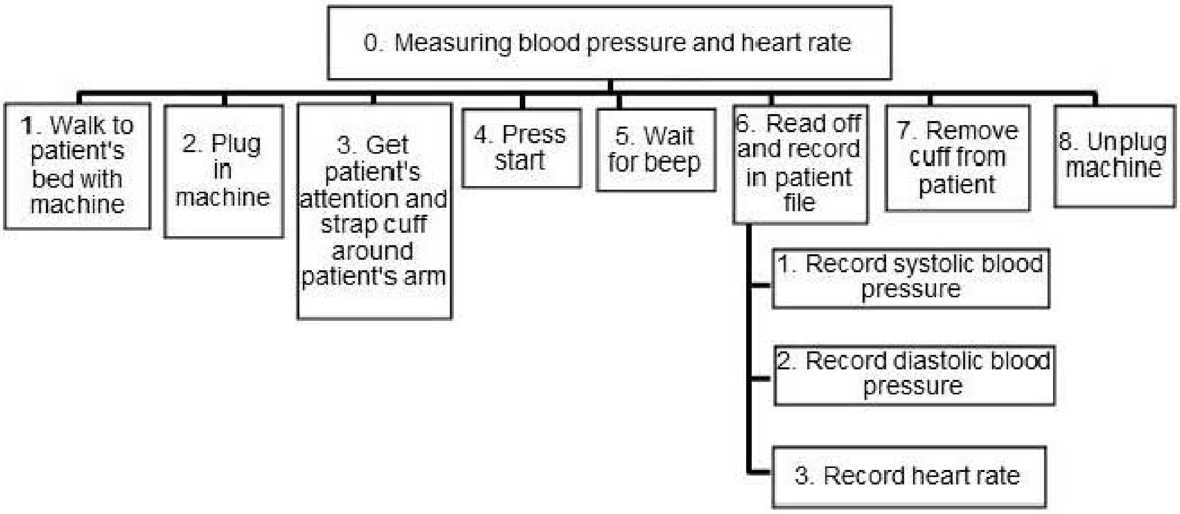
Measuring blood glucose



Measuring temperature



Measuring blood pressure and heart rate



Appendix B: Task Structure and Execution Analysis

Hierarchical task analysis procedure and task decomposition tables

Subject questionnaire

Human Kinetics and Ergonomics Masters Research Project:

The analysis of the strain level and the predicted error probability for critical hospital tasks

Hierarchical Task Analysis Tables

1. Please mark order of events.
2. Cross out if task component does not occur.
3. Please include repetition cycles within various task components.
4. Notes need to include interruptions, duration of interruptions and talking.

   Interruptions are defined as an incident, whether it is a verbal interruption or an interruption requiring the nurse to change position, which results in her having to cease the current task she is doing. If the nurse is interrupted as a result of a colleague enquiring something but she continues the task through these discussion this is classified as a Verbal 1 interruption. If the nurse ceases the activity to communicate with another colleague this is classified as a verbal 2 interruption. A physical interruption is where the nurse ceases the task to perform some alternative task (for example resetting up an IV site).
5. Record the durations for the various task segments.
6. Include all necessary data on table on reverse side of page.
7. Include a **NASA TLX** score after nurse completes round in that specific room
8. For each task analysis, please record the following data at for that specific task.

Additional Task Information

Ward:	
Date:	
Nurse code:	
Task:	
Time of day: Task start time:	
Time of day: Task end time:	
Previous task:	
Duration:	

Organisational Analysis

Number of staff assisting on task:	
Number of interruptions:	
Percentage of beds occupied (whole ward):	
Percentage of beds occupied (that room):	
Total day staff capacity:	

Administering Medication: Injections			
Order of Occurrence (& duration)	**Operations and Plans**	**RD**	**Notes (talking/ interruptions)**
   Total **Time:**	**0. Administer injection medication** *Plan: Do 1 then 2 then 3.* 1. Check patient file 2. Prepare medication 3. Deliver medication to patient	 No Yes Yes	
    Time:	**1. Check patient file** *Plan: Do 1and 2 then if necessary 3.* 1. Obtain patient file. 2. Determine if medication is required. 3. Determine required medication	 No No No	
	2. Prepare medication *Plan: Do 1 then 2* 1. Assemble syringe 2. Prepare medication	 Yes Yes	
      Time:	**2.1. Assemble syringe** *Plan: Do 1 and 2 before proceeding to 3.Do 4 if necessary.* 1. Select correct syringe and unpack 2. Select correct needle 3. Unpack and attach needle 4. Unpack alcohol swab	 No No No No	
                Time:	**2.2. Prepare medication** *Plan: Do 1 then proceed to 2 or 5. If 2 is selected do up to 4. If 5 is selected do up to 9. Then do 10 to 12 in order. Do 13 if required.* 1. Select correct medication 2. Flick ampule. 3. Break lid off 4. Dispose of glass top 5. Unpack vile A 6. Withdraw fluid A from vile A 7. Remove metal covering opening of bottle B 8. Inject into bottle B containing powder B 9. Shake to mix 10. Withdraw mixture/liquid 11. Squeeze syringe to remove air 12. Remove needle 13. Select and attach a new clean needle	 No No No No No No No No No No No No No	
            Time:	**3. Deliver medication to patient** *Plan: Do 1 if necessary. Do 2, then 3 or 4. Then do 5. If necessary 7.Do 8 to 10.* 1. Close curtain 2. Talk to patient and gets patient's attention 3. Open plug 4. Clean skin with alcohol swab 5. Insert needle of syringe 6. Remove needle 7. Close plug 8. Record in patient file 9. Dispose in appropriate bins 10. Sanitise hands	 No No No No No No No No No No	

Administering Medication: Pills			
Order of Occurrence (& duration)	**Operations and Plans**	**RD**	**Notes (talking/interruptions)**
Total Time:	**0. Administer pill medication** *Plan:Do 1, then 2 then 3.* 1. Obtain patient file 2. Prepare medication 3. Deliver medication	 Yes Yes Yes	
Time:	**1. Obtain patient file** *Plan: Do 1, then 2, then 3 and 4.* 1. Walk to patient bed to collect file 2. Return to medicine cabinet 3. Read patient file 4. Confirm patient and patient file match	 No No No No	
Time:	**2. Prepare medication** *Plan: Do 1 then 2 or 3, followed by 4.* 1. Select correct pill 2. Place in plastic beaker 3. Prepare pill (e.g. crush pill) 4. Write in patient file	 No No No No	
Time:	**3. Deliver to patient** *Plan: Do 1- when necessary. Do 2, 3 4 then 5 or 6 in order.* 1. Get water 2. Walk to patient's bed with pills and file 3. Get patient's attention 4. Hand over medication 5. Assist patient to take medicine 6. Observe patient taking pills	 No No No No No No	

Administering Medication: Setting up intravenous (IV) medication			
Order of Occurrence (& duration)	**Operations and Plans**	**RD**	**Notes (talking/interruptions)**
Total Time:	**0. Setting up intravenous medication** *Plan: Do 1, 2, 3, 4 in order.* 1. Check patient file 2. Prepare IV medication 3. Prepare patient 4. Administer medication	 Yes Yes Yes Yes	
Time:	**1. Check patient file** *Plan: Do1, 2, 3, 4 in order.* 1. Walk to patient bed to collect file 2. Determine if medication is required 3. Determine what medication is required 4. Record in patient's file	 No No No No	
Time:	**2. Prepare IV medication** *Plan: Do 1, 2, 4, 5 and 6 in any order. Do 3 after 1 and 2.* 1. Obtain IV bag and unwrap 2. Write up label 3. Attach label to bag 4. Obtain and unwrap tubing 5. Obtain needle 6. Obtain and unwrap alcohol swab	 No No No No No No	
Time:	**3. Prepare patient** *Plan: Do 1 to 7 in order.* 1. Inform patient and get their attention and cooperation 2. Identify correct vein 3. Swab skin with alcohol swab 4. Remove lid from needle 5. Insert needle into body 6. Check needle placement is correct 7. Cover with plaster	 No No No No No No No	
Time:	**4. Administer medication** *Plan: Do 1 to 8 in order.* 1. Connect tubing to IV bag 2. Hang up IV bag 3. Open valve to remove air from tubing 4. Connect tubing to needle inserted in patient 5. Fasten tubing to patient with plaster 6. Open tubing valve 7. Check drip flow 8. Adjust accordingly	 No No No No No No No No	

Administering Medication: Changing intravenous (IV) medication			
Order of Occurrence (& duration)	**Operations and Plans**	**RD**	**Notes (talking/ interruptions)**
Total Time:	**0. Changing intravenous (IV) medication** *Plan: Do 1 then 2 then 3.* 1. Check patient file 2. Prepare new IV medication 3. Exchange empty IV bag with new IV bag	No Yes Yes	
Time:	**1. Check patient file** *Plan: Do 1, 2 then if necessary 3 and then 4.* 1. Obtain patient file. 2. Determine if more IV medication is required. 3. Determine required IV medication 4. Record in patient file	No No No	
	2. Prepare new IV medication *Plan: Do 1, 2, in any order followed by 3 and 4 in order.* 1. Obtain IV bag, unwrap and dispose of wrapping 2. Write up label 3. Attach label to new IV bag 4. Walk to patient	Yes Yes	
Time:	**3. Exchange empty IV bag with new IV bag** *Plan: Do 1 to 7 in order. Repeat 7 and 8 if necessary. Then do 9.* 1. Close valve on tubing 2. Disconnect tubing from empty IV bag 3. Connect tubing to new IV bag 4. Hang up new IV bag 5. Open valve on tubing 6. Check drip flow 7. Adjust valve accordingly 8. Recheck drip flow 9. Dispose of old IV bag in red bin	No No No No No No No No No No	

Patient monitoring: Measuring blood glucose			
Order of Occurrence (& duration)	**Operations and Plans**	**RD**	**Notes (talking/ interruptions)**
   Total time:	**0. Measuring blood glucose** *Plan: Do 1 then 2 then 3.* 1. Obtain equipment 2. Obtain blood 3. Obtain blood glucose reading	 Yes Yes Yes	
     Time:	**1. Obtain equipment** *Plan: Do 1, 2, 3 and 4 in any order.* 1. Obtain glucose strips 2. Obtain blood glucose machine 3. Obtain cotton wool 4. Obtain alcohol swab	 No No No	
         Time:	**2. Obtain blood** *Plan: Do 1 to 8 in order.* 1. Clean fingertip with alcohol swab 2. Use clean needle to prick finger 3. Squeeze finger to obtain drop of blood 4. Drop blood on glucose strip 5. Insert strip into machine 6. Place cotton wool on wound 7. Press button 8. Wait	 No No No No No No No No	
     Time:	**3. Obtain blood glucose reading** *Plan: Do 1 to 3 in order.* 1. Read off blood glucose level from machine 2. Record in patient file 3. Dispose of strip and other disposable components in appropriate bins	 No No No No	

Patient monitoring: Measuring blood pressure and heart rate			
Order of Occurrence (& duration)	**Operations and Plans**	**RD**	**Notes (talking/ interruptions)**
Total Time:	**0. Measuring blood pressure and heart rate** *Plan: Do 1 to 8 in order.* 1. Walk to patient's bed with machine 2. Plug in machine 3. Get patient's attention and strap cuff around patient's arm 4. Press start 5. Wait for beep 6. Record in patient file 7. Remove cuff from patient 8. Unplug machine	 No No No No Yes No No No	
Time:	**6. Record in patient file** *Plan: Do 1, 2 and 3 in any order.* 1. Record systolic blood pressure 2. Record diastolic blood pressure 3. Record heart rate	 No No No	

Patient monitoring: Measuring temperature			
Order of Occurrence (& duration)	**Operations and Plans**	**RD**	**Notes (talking/ interruptions)**
Total Time:	**0. Measuring temperature** *Plan: Do 1 to 5 in order.* 1. Obtain thermometer 2. Place thermometer underneath arm 3. Wait 4. Read thermometer 5. Record in patient file	 No No No No No	

Human Kinetics and Ergonomics Masters Research Project:

The analysis of the strain level and the predicted error probability for critical hospital tasks

Questionnaire for Task Execution Analysis

Subject code:

1. Ward: ____.
2. Birth date: ____.
3. Stature (mm):____.
4. Weight (kg):____.
5. Sex:____.
6. What qualification do you hold, and how long did you study to obtain this qualification? During your studies were you able to work already as a nurse and for how long?

   ____.
7. How long have you been working as a qualified registered nurse/staff nurse/nursing assistant?
8. How long have you worked at Settlers Hospital?

   ____.
9. Out of the pairs below, please indicate which one you found more important in completing that specific task. Please cross through the block if you do not perform this task.

<u>Medication</u>

Giving pill medication

Physical demand/mental demand	Temporal demand/physical demand	Temporal demand/ frustration level
Temporal demand/mental demand	Own performance/physical demand	Temporal demand/ effort
Own Performance/mental demand	Frustration level/physical demand	Own performance/ frustration level
Frustration level/mental demand	Effort/physical demand	Own performance/ effort
Effort/mental demand	Temporal demand/own performance	Effort/ frustration level

Giving injection medication

Physical demand/mental demand	Temporal demand/physical demand	Temporal demand/ frustration level
Temporal demand/mental demand	Own performance/physical demand	Temporal demand/ effort
Own Performance/mental demand	Frustration level/physical demand	Own performance/ frustration level
Frustration level/mental demand	Effort/physical demand	Own performance/ effort
Effort/mental demand	Temporal demand/own performance	Effort/ frustration level

Setting up intravenous medication

Physical demand/mental demand	Temporal demand/physical demand	Temporal demand/ frustration level
Temporal demand/mental demand	Own performance/physical demand	Temporal demand/ effort
Own Performance/mental demand	Frustration level/physical demand	Own performance/ frustration level
Frustration level/mental demand	Effort/physical demand	Own performance/ effort
Effort/mental demand	Temporal demand/own performance	Effort/ frustration level

Changing intravenous medication

Physical demand/mental demand	Temporal demand/physical demand	Temporal demand/ frustration level
Temporal demand/mental demand	Own performance/physical demand	Temporal demand/ effort
Own Performance/mental demand	Frustration level/physical demand	Own performance/ frustration level
Frustration level/mental demand	Effort/physical demand	Own performance/ effort
Effort/mental demand	Temporal demand/own performance	Effort/ frustration level

Monitoring patient's condition

Measuring patient's blood glucose levels

Physical demand/mental demand	Temporal demand/physical demand	Temporal demand/ frustration level
Temporal demand/mental demand	Own performance/physical demand	Temporal demand/ effort
Own Performance/mental demand	Frustration level/physical demand	Own performance/ frustration level
Frustration level/mental demand	Effort/physical demand	Own performance/ effort
Effort/mental demand	Temporal demand/own performance	Effort/ frustration level

Measuring patient's temperature

Physical demand/mental demand	Temporal demand/physical demand	Temporal demand/ frustration level
Temporal demand/mental demand	Own performance/physical demand	Temporal demand/ effort
Own Performance/mental demand	Frustration level/physical demand	Own performance/ frustration level
Frustration level/mental demand	Effort/physical demand	Own performance/ effort
Effort/mental demand	Temporal demand/own performance	Effort/ frustration level

Measuring patient's blood pressure and heart rate

Physical demand/mental demand	Temporal demand/physical demand	Temporal demand/ frustration level
Temporal demand/mental demand	Own performance/physical demand	Temporal demand/ effort
Own Performance/mental demand	Frustration level/physical demand	Own performance/ frustration level
Frustration level/mental demand	Effort/physical demand	Own performance/ effort
Effort/mental demand	Temporal demand/own performance	Effort/ frustration level

Appendix C: Ethical Considerations

Department of Health of the Eastern Cape Ethical Approval

Research Information Letter for Interview

Research Information Letter for Task Analysis

Informed Consent Form

Department of Health of the Eastern Cape Ethical Approval

From: To: 0466033934 25/05/2011 11:25 #000 P.001/001

Eastern Cape Department of Health

Enquiries	Zonwabele Merile	Tel No	040 608 0830
Date	23rd May 2011	Fax No	043 642 1409
e-mail address	zonwabele.merile@imp.ecprov.gov.za		

Dear Ms E. Burford

Re: The analysis of the strain level of critical hospital tasks and their effect on error probability

The Department of Health would like to inform you that your application for conducting a research on the abovementioned topic has been approved based on the following conditions:

1. During your study, you will follow the submitted protocol with ethical approval and can only deviate from it after having a written approval from the Department of Health.
2. You are advised to ensure, observe and respect the rights and culture of your research participants and maintain confidentiality of their identities and shall remove or not collect any information which can be used to link the participants.
3. The Department of Health expects you to provide a progress on your study every 3 months (from date you received this letter) in writing.
4. At the end of your study, you will be expected to send a full written report with your findings and implementable recommendations to the Epidemiological Research & Surveillance Management. You may be invited to the department to come and present your research findings with your implementable recommendations.
5. Your results on the Eastern Cape will not be presented anywhere unless you have shared them with the Department of Health as indicated above.

Your compliance in this regard will be highly appreciated.

DEPUTY DIRECTOR: EPIDEMIOLOGICAL RESEARCH & SURVEILLANCE MANAGEMENT

PGDP EASTERN CAPE

RHODES UNIVERSITY

Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS

PROJECT INFORMATION: INTERVIEW

The Department of Human Kinetics and Ergonomics at Rhodes University is interested in observing and analyzing the strain levels associated with various tasks performed by the nurses in Settlers Hospital. A second focus of this project is to examine the effect of strain level on probability of error. This research is undertaken at a Master of Science Degree level.
The title of the project is:

The analysis of the strain level and the predicted error probability for critical hospital tasks

Procedure:
Initially information regarding the daily routine, error protocols and identify which tasks may be defined as 'critical' were collected via a general questionnaire and an observation phase. This information was used to establish a task breakdown of the 'critical' task in the form of a hierarchical task analysis diagram.

In this interview you will then be required to confirm the general information, gathered during the observation phase and from the questionnaires, are correct and complete. Furthermore you will be required to confirm if the task breakdown in the diagrams provided is correct and contains all necessary tasks components.

Thank you for your assistance and time. This information gathered will assist with the next phase of this project, which is a comprehensive task analysis.

RHODES UNIVERSITY
Grahamstown • 6140 • South Africa
HUMAN KINETICS & ERGONOMICS

PROJECT INFORMATION: TASK ANALYSIS

The Department of Human Kinetics and Ergonomics at Rhodes University is interested in observing and analyzing the strain levels associated with various tasks performed by the nurses in Settlers Hospital. A second focus of this project is to examine the effect of strain level on probability of error. This research is undertaken at a Master of Science Degree level.
The title of the project is:

The analysis of the strain level and the predicted error probability for critical hospital tasks

Procedure:
The testing will be carried out in your workplace and will not interfere with your daily work requirements. Several weeks in advance, during a habituation session I will come to the hospital to explain the purpose of this research, what is required of you and the procedure.

On the testing days, at the start of your shift, you will be fitted with a heart rate monitor chest strap, which will record your heart rate over the duration of your shift. At the end of your tea or lunch break, you will be required to sit quietly for a couple of minutes so that the heart rate monitor can record a reference heart rate. After this you will be required to read a short text in order to record a "cognitive" reference heart rate variability value. You will then be observed during the performance of the most important tasks as determined from a previous questionnaire and interview. After these tasks you will be asked how strenuous you thought the tasks were, for this you will be required to indicate on the rating scales shown to you during the habituation session. At some point in the course of the day you will be required to fill in a questionnaire to determine you current experience level and the subjective weightings for the rating scales to be used.

For this research, it is very important that your behaviour and routine do not change as a result of the researcher’s presence. We wish to observe your work the way you normally do it and are not there to evaluate your performance in any way.

If at any point during the testing you feel the need to withdraw from this study for whatever reason, and giving no reasons, you are free to do so. No matter at what point in the testing, you are free to withdraw by simply telling the researcher you wish to no longer participate. If you wish to withdraw, you do not have to provide a reason and there will be no consequences to you. Your anonymity will be ensured and all information will be stored confidentially by ensuring that there is no link between the data and your name. The researcher will use codes to store all the data as opposed to your name. None of your individual results will be made available at any time, and only the aggregated data will be included in the thesis, the presentation of the final results and published for academic purposes.

I will also explain to the patient’s that I am not there to observe them but rather to observe you and the other nurses perform your routine tasks. Furthermore I will explain to the patients that no data will be recorded pertaining to their medical condition or existing medical records. If any of the patients have a problem with this, I will then leave the room until that task with that patient is complete.

The patients may potentially feel uncomfortable with the observation and if so, I can wait outside the ward and complete the data collection through discussions with you on what tasks that were performed while you were in the ward. If you feel uncomfortable being observed, you can ask me to leave the room and the data for those tasks will not be collected.

The benefit of this study is that it may provide insight into which tasks are strenuous and may constitute a potential area for errors by nurses. This may be useful when it comes to error prevention as there is the potential to identify tasks that are error-prone due to the stress level. By identify these tasks, one can determine which areas need attention and not only will this assist in addressing patient needs better, but should also assist your workload by altering the procedures for these stressful tasks.

SUBJECT CONSENT FORM (Interview & Task analysis)

I, ___________________________, have been fully informed of the research project entitled: "**The analysis of the strain level and the resulting error probability for critical hospital tasks",** and hereby give my consent to participate in the above mentioned research and to allow for the aggregated form of the data to appear in the form of an academic article or report.

I am fully aware of the procedures involved as well as the potential risks and benefits associated with my participation, as explained to me verbally and in writing. In agreeing to participate in this research I waive any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries or offense experienced whilst partaking in this investigation. The waiver shall be binding upon my heirs and representatives.

I understand that I may express any concerns about my participation in this study to the researcher. I am aware that I may withdraw my consent and may withdraw from participation in this research at any time without giving reason and without any consequences. I am aware that my anonymity will be protected at all times, and agree that all the information collected may be used and published for statistical or scientific purposes.

I have read the information sheet accompanying this form and understand it. Any questions which may have occurred to me have been answered to my satisfaction.

PARTICIPANT

_______________	_______________	_______________
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

_______________	_______________	_______________
(Print name)	(Signed)	(Date)

WITNESS 1:

_______________	_______________	_______________
(Print name)	(Signed)	(Date)

WITNESS 2:

_______________	_______________	_______________
(Print name)	(Signed)	(Date)

Appendix D: Daily routine of the nurses

Table 1: Daily Routine for nursing staff in the medical ward:

Time	Tasks	Staff
07:00	Taking reports Stock taking Make beds & wash patients	All Professional nurses Professional nurses & nursing assistants
08:00	Check patient files Check medication trolleys Phone calls regarding blood tests Blood glucose checks Patient's breakfast (feed some patients)	Professional nurses & nursing assistants Professional nurses Professional nurses Staff nurses All
09:00	Doctors rounds (several hours)	Professional nurses (2)
10:00	Medical rounds (IV, injections and pills) Administration (includes paperwork, discharges phone calls) Measure vital signs	Professional nurses & staff nurses (2 each) Professional nurses & nursing assistants Nursing assistants
11:00	Blood glucose checks	Staff nurses (2)
12:00		
13:00	Measuring vital signs Change patients	Nursing assistants Nursing assistants
14:00	Administration (includes paperwork, discharges, phone calls) Following doctor's orders Medical rounds Patient-related tasks (x-ray stc.)	Professional nurses Professional nurses Professional nurses & nursing assistants Nursing assistants
15:00		
16:00		
17:00		
18.00	Administration (includes paperwork and discharges) Medical rounds	Professional nurses Professional nurses
19:00	Handover	Professional nurses

Table 2: Daily Routine for nursing staff in the surgical ward:

Time	Tasks	Staff
07:00	Make beds Wash patients Stock taking & drug ordering Check emergency trolleys Prepare patients for theatre (include give drugs)	Professional nurse & nursing assistants Nursing assistants Professional nurse Professional nurses Professional nurses
08:00	*Patient breakfast* Check patient files Doctors rounds (several hours)	 Professional nurse & nursing assistants Professional nurse
09:00	Medical rounds Measure vital signs	Professional nurse Nursing assistants
10:00	Administration Patient related tasks Medical rounds Dressing of wounds Check vitals of patients	Professional nurse & nursing assistants Professional nurse & nursing assistants Professional nurse Professional nurses (staff & registered) Nursing assistants
11:00 **11:30**	Check patient files Assess patients' conditions *Patient visitor time (30min)*	Nursing assistants Professional nurses (staff & registered)
12:00	Staff lunch (first half)	
13:00	Staff lunch (second half) Measure vital signs (Monitor patient condition)	 Nursing assistants
14:00	Administration (admissions & discharges) Medical rounds Patient related tasks Measure vital signs Patient changes	Professional nurse Professional nurse Nursing assistants Nursing assistants Nursing assistants
15:00	*Patient visiting time (30min)* Admissions	
16:00	Check on patients	Nursing assistants
17:00	*Patient dinner* Patient changes Medication round	 Profession & staff nurses
18.00		
19:00	Handover	Professional nurse

Appendix E: Statistical Tables for the Task Execution Analysis

Table 1: The Post Hoc results for the different tasks and duration.

LSD test; variable Duration Probabilities for Post Hoc Tests Error: Between MSE = 10,207, df = 324,00								
	Task	**{1} - 4,3676**	**{2} - 4,3196**	**{3} - 10,889**	**{4} - 3,9500**	**{5} - 7,6620**	**{6} - 3,3014**	**{7} - 2,7640**
1	Injection		0,920621	0,000000	0,758440	0,000109	0,040625	0,015165
2	Pills	0,920621		0,000000	0,782712	0,000049	0,031114	0,012500
3	Set up IV	0,000000	0,000000		0,000048	0,013869	0,000000	0,000000
4	Change IV	0,758440	0,782712	0,000048		0,014230	0,631992	0,401441
5	Temp	0,000109	0,000049	0,013869	0,014230		0,000000	0,000000
6	BP&HR	0,040625	0,031114	0,000000	0,631992	0,000000		0,407999
7	BG	0,015165	0,012500	0,000000	0,401441	0,000000	0,407999	

Table 2: The Post Hoc results for the different tasks and heart rate frequency.

LSD test; variable Heart rate Probabilities for Post Hoc Tests Error: Between MSE = 85,265, df = 324,00								
	Task	**{1} - 10,250**	**{2} - 13,454**	**{3} - 13,375**	**{4} - 7,4220**	**{5} - 18,683**	**{6} - 14,460**	**{7} - 11,810**
1	Injection		0,021933	0,338764	0,471400	0,000590	0,005275	0,411749
2	Pills	0,021933		0,980380	0,120099	0,026520	0,459504	0,359170
3	Set up IV	0,338764	0,980380		0,222145	0,160077	0,738525	0,650516
4	Change IV	0,471400	0,120099	0,222145		0,010118	0,072800	0,282968
5	Temp	0,000590	0,026520	0,160077	0,010118		0,080910	0,010732
6	BP&HR	0,005275	0,459504	0,738525	0,072800	0,080910		0,158463
7	BG	0,411749	0,359170	0,650516	0,282968	0,010732	0,158463	

Table 3: The Post Hoc results for the different tasks and the heart rate variability measure of pNN30.

	LSD test; variable HRV: PNN30 Probabilities for Post Hoc Tests Error: Between MSE = 11614,, df = 300,00							
	Task	**{1} - 65,539**	**{2} - ,90821**	**{3} - 116,17**	**{4} - 30,551**	**{5} - - 21,55**	**{6} - 6,5452**	**{7} - 53,160**
1	Injection		0,000455	0,217622	0,488980	0,003452	0,002513	0,601147
2	Pills	0,000455		0,003746	0,547854	0,412688	0,722578	0,012914
3	Set up IV	0,217622	0,003746		0,164471	0,002856	0,006479	0,136754
4	Change IV	0,488980	0,547854	0,164471		0,339621	0,629412	0,661115
5	Temp	0,003452	0,412688	0,002856	0,339621		0,318917	0,017452
6	BP&HR	0,002513	0,722578	0,006479	0,629412	0,318917		0,033964
7	BG	0,601147	0,012914	0,136754	0,661115	0,017452	0,033964	

Table 4: The Post Hoc results for the different tasks and the power of the high frequency component of heart rate variability.

	LSD test; variable HF (0.15-0.4Hz): Power Probabilities for Post Hoc Tests Error: Between MSE = 4608E4, df = 324,00							
	Task	**{1} - 5512,8**	**{2} - 178,44**	**{3} - 5685,5**	**{4} - 3535,9**	**{5} - - 9,657**	**{6} - 21,814**	**{7} - 192,10**
1	Injection		0,000000	0,942648	0,493365	0,002165	0,000001	0,000165
2	Pills	0,000000		0,019849	0,238839	0,913227	0,875535	0,991723
3	Set up IV	0,942648	0,019849		0,548370	0,040671	0,018295	0,031094
4	Change IV	0,493365	0,238839	0,548370		0,268680	0,222412	0,265748
5	Temp	0,002165	0,913227	0,040671	0,268680		0,985848	0,918442
6	BP&HR	0,000001	0,875535	0,018295	0,222412	0,985848		0,901750
7	BG	0,000165	0,991723	0,031094	0,265748	0,918442	0,901750	

Table 5: The Post Hoc results for the different tasks and the power of the low frequency component of heart rate variability.

LSD test; variable LF (0.04-0.15Hz): Power Probabilities for Post Hoc Tests Error: Between MSE = 2636E3, df = 324,00								
	Task	**{1} - 1225,6**	**{2} - 199,21**	**{3} - 1201,8**	**{4} - 2080,4**	**{5} - 107,14**	**{6} - 141,90**	**{7} - 222,43**
1	Injection		0,000035	0,966813	0,215985	0,009259	0,000050	0,002857
2	Pills	0,000035		0,075717	0,006026	0,823522	0,810600	0,941240
3	Set up IV	0,966813	0,075717		0,305253	0,099587	0,064405	0,107486
4	Change IV	0,215985	0,006026	0,305253		0,010368	0,005103	0,010029
5	Temp	0,009259	0,823522	0,099587	0,010368		0,934722	0,806738
6	BP&HR	0,000050	0,810600	0,064405	0,005103	0,934722		0,807152
7	BG	0,002857	0,941240	0,107486	0,010029	0,806738	0,807152	

Table 6: The Post Hoc results for the different tasks and the centre frequency of the low frequency component of heart rate variability.

LSD test; variable LF (0.04-0.15Hz): Center Frequency Probabilities for Post Hoc Tests Error: Between MSE = 230,89, df = 324,00								
	Task	**{1} - 7,8772**	**{2} - - 5,492**	**{3} - 2,8652**	**{4} - 4,0707**	**{5} - - 1,929**	**{6} - ,31795**	**{7} - - 3,024**
1	Injection		0,000000	0,351179	0,555696	0,014721	0,002365	0,000551
2	Pills	0,000000		0,113495	0,134190	0,356751	0,009813	0,402621
3	Set up IV	0,351179	0,113495		0,880443	0,440175	0,634039	0,300527
4	Change IV	0,555696	0,134190	0,880443		0,402872	0,560157	0,291458
5	Temp	0,014721	0,356751	0,440175	0,402872		0,571653	0,804000
6	BP&HR	0,002365	0,009813	0,634039	0,560157	0,571653		0,279582
7	BG	0,000551	0,402621	0,300527	0,291458	0,804000	0,279582	

Table 7: The Post Hoc results for the different tasks and the low frequency power relative to (LF+HF)

LSD test; variable LF power relative to (LF+HF) [%] Probabilities for Post Hoc Tests Error: Between MSE = 2587,2, df = 324,00								
	Task	**{1} - -,6733**	**{2} - 45,202**	**{3} - 6,2288**	**{4} - 21,233**	**{5} - 17,965**	**{6} - 17,629**	**{7} - 5,1437**
1	Injection		0,000000	0,701159	0,311292	0,164747	0,027364	0,578426
2	Pills	0,000000		0,027752	0,261736	0,035856	0,000270	0,000061
3	Set up IV	0,701159	0,027752		0,576071	0,572334	0,524543	0,954518
4	Change IV	0,311292	0,261736	0,576071		0,891676	0,867198	0,474577
5	Temp	0,164747	0,035856	0,572334	0,891676		0,979795	0,385451
6	BP&HR	0,027364	0,000270	0,524543	0,867198	0,979795		0,227614
7	BG	0,578426	0,000061	0,954518	0,474577	0,385451	0,227614	

Table 8: The Post Hoc results for the different tasks and the overall NASA-TLX workload score.

LSD test; variable Nasa-TLX Overall Workload Score Probabilities for Post Hoc Tests Error: Between MSE = 231,96, df = 304,00								
	Task	**{1} - 32,758**	**{2} - 36,649**	**{3} - 35,916**	**{4} - 14,557**	**{5} - 16,247**	**{6} - 24,901**	**{7} - 47,925**
1	Injection		0,108101	0,581013	0,005485	0,000132	0,002458	0,000008
2	Pills	0,108101		0,895626	0,000621	0,000001	0,000000	0,000328
3	Set up IV	0,581013	0,895626		0,009867	0,003091	0,052185	0,047673
4	Change IV	0,005485	0,000621	0,009867		0,816833	0,109766	0,000001
5	Temp	0,000132	0,000001	0,003091	0,816833		0,039039	0,000000
6	BP&HR	0,002458	0,000000	0,052185	0,109766	0,039039		0,000000
7	BG	0,000008	0,000328	0,047673	0,000001	0,000000	0,000000	

Appendix F: SHERPA Analysis Forms

Human Kinetics and Ergonomics Masters Research Project:

The analysis of the strain level and the predicted human error probability for critical hospital tasks

Systematic Human Error Reduction and Prediction Approach

SHERPA tables

1. Please mark the probability of that error occurring:
    a. ***Low = error has never known to occur***
    b. ***Medium = error has occurred on previous occasions***
    c. ***High = error occurs frequently***
2. Please mark the criticality of that error, by defining what type of incident would result from this error:
    a. ***Low = minimal or no effect on the patient***
    b. ***Medium = moderate effect on the patient***
    c. ***High = serious effect on the patient***
3. Finally please suggest how these errors could be reduced.

Administering Medication: Injections				
Operations and Plans	**Human-error Identification**	**Consequence**	**Probability (L, M, H)**	**Criticality (L, M, H)**
0. Administer medication *Plan: Do 1 then 2 then 3.* 1. Check patient file 2. Prepare medication 3. Deliver medication to patient				
1. Check patient file *Plan: Do 1 then if necessary*				
1.1 Determine if medication is required	Fail to identify if medication is required	Medication not administered		
1.2 Determine required medication	Incorrectly determines required medication	Wrong medication selected		
2. Prepare medication *Plan: Do 1 then 2*				
2.1 Assemble syringe				
2.2 Prepare medication				
2.1. Assemble syringe *Plan: Do 1 and 2 before proceeding to 3. Do 4 when necessary.*				
2.1.1 Select correct syringe and unpackage				
2.1.2 Select correct needle				
2.1.3 Unpackage and attach needle				
2.1.4 Unpackage alcohol swab				
2.2. Prepare medication *Plan: Do 1 to 4 if necessary. Do 5t to9 if necessary. Then do 9 to 12 in order. Do 13 if required.*				
2.2.1 Select correct medication	Select incorrect medication	Wrong medication selected and prepared		
2.2.2 Flick ampule.				
2.2.3 Break lid off				
2.2.4 Dispose of glass top				
2.2.5 Unpackage vile A				
2.2.6 Withdraw fluid A from vile A	Medication inaccurately prepared	Medication administered not in correct form		
2.2.7 Remove metal covering opening of bottle B				
2.2.8 Inject into bottle B containing powder B				

2.2.9 Shake to mix				
2.2.10 Withdraw mixture				
2.2.11 Remove air from syringe				
2.2.12 Remove needle				
2.2.13 Select and attach a clean needle				
3. Deliver medication to patient *Plan: Do 1 if necessary. Then do 2. Do 3 or 4. Then do 5. If necessary 7.Do 8 to 10.*				
3.1 Close curtain				
3.2 Talk to patient and gets patient's attention				
3.3 Open plug				
3.4 Clean skin with alcohol swab				
3.5 Insert needle of syringe				
3.6 Remove needle				
3.7 Close plug				
3.8 Record in patient file				
3.9 Dispose of appropriately				
3.10 Sanitise hands				

Administering Medication: Pills				
Operations and Plans	**Human-error Identification**	**Consequence**	**Probability (L, M, H)**	**Criticality (L, M, H)**
0. Administer medication *Plan: Do 1, then 2 then 3.* 1. Obtain patient file 2. Prepare medication 3. Deliver medication				
1. Obtain patient file *Plan: Do 1, then 2, then 3.*				
1.1 Walk to patient bed to collect file				
1.2 Return to medicine cabinet				
1.3 Read patient file				
1.4 Determine if medication is required	Fail to identify if medication is required	Medication not administered		
1.5 Determine required medication	Incorrectly determines required medication	Wrong medication selected		
2. Prepare medication *Plan: Do 1 then 2 or 3, followed by 4.*				
2.1 Select correct medication and quantity	Select incorrect pills. Select incorrect quantity	Wrong medication selected. Wrong quantity selected.		
2.2 Place in plastic beaker				
2.3 Prepare pill	Medication inaccurately prepared	Medication not correctly prepared		
2.4 Write in patient file	Information not accurately recorded, incompletely recorded or not recorded at all			
3. Deliver to patient *Plan: Do 1- when possible. Do 2, 3 the 4 or 5 in order.*				
3.1 Get water				
3.2 Walk to patient's bed with pills and file				
3.3 Get patient's attention				
3.4 Assist patient to take medicine				
3.5 Observe patient taking pills				

Administering Medication: Setting up intravenous (IV) medication				
Operations and Plans	**Human-error Identification**	**Consequence**	**Probability (L, M, H)**	**Criticality (L, M, H)**
0. Setting up intravenous medication *Plan: Do 1, 2, 3, 4 in order.* 1. Check patient file 2. Prepare IV medication 3. Prepare patient 4. Administer medication				
1. Check patient file *Plan: Do1, 2, 3, 4 in order.*				
1.1 Obtain patient file				
1.2 Determine if medication is required	Fail to identify if medication is required	No medication administered		
1.3 Determine what medication is required	Incorrectly determines required medication	Wrong medication selected		
1.4 Record in patient's file	Information not accurately recorded, incompletely recorded or not recorded at all			
2. Prepare IV medication *Plan: Do 1, 2, 4, 5 and 6 in any order. Do 3 after 1 and 2.*				
2.1 Obtain correct IV bag, unwrap and prepare	Incorrect IV medication obtained and prepared	Patient receives wrong IV medication, medication is inaccurately prepared		
2.2 Write up label	Label not written up correctly or at all	IV medication not accurately recorded		
2.3 Attach label to bag	Label not attached	Information about medication not transmitted between staff		
2.4 Obtain and unwrap tubing				
2.5 Obtain needle				
2.6 Obtain and unwrap alcohol swab				
3. Prepare patient *Plan: Do 1 to 7 in order.*				
3.1 Inform patient and get their attention and cooperation				
3.2 Identify correct vein	Incorrect vein identified	IV does not flow into the body as it should.		
3.3 Swab skin with alcohol swab				
3.4 Remove lid from needle				
3.5 Correctly Insert needle into body	Needle not correctly placed	IV medication does not enter the body		
3.6 Check needle placement is correct	Check not performed	IV medication does		

		not enter the body, IV medication does not enter the body as it should		
3.7 Cover with plaster				
4. Administer medication *Plan: Do 1 to 8 in order.*				
4.1 Connect tubing to IV bag				
4.2 Hang up IV bag				
4.3 Remove air from tubing	Air is not removed from tubing	Air enters the vein of the patient		
4.4 Connect tubing to needle inserted in patient				
4.5 Secure tubing with plaster				
4.6 Open tubing valve				
4.7 Check drip flow	Check not performed	IV medication administered at a too fast or too slow rate.		
4.8 Adjust accordingly				

Administering Medication: Changing intravenous (IV) medication				
Operations and Plans	**Human-error Identification**	**Consequence**	**Probability (L, M, H)**	**Criticality (L, M, H)**
0. Changing intravenous (IV) medication *Plan: Do 1 then 2 then 3.* 1. Check patient file 2. Prepare new IV medication 3. Exchange empty IV bag with new IV bag				
1. Check patient file *Plan: Do 1 then if necessary 2. Then if necessary 3and then 4*				
1.1 Obtain patient file				
1.2 Determine if more IV medication is required	Fail to identify if medication is required	No medication administered		
1.3 Determine what IV medication is required	Incorrectly determine required medication	Wrong medication selected		
1.4 Record in patient's file	Information not accurately recorded, incompletely recorded or not recorded at all	Information is not adequately transmitted between staff		
2. Prepare new IV medication *Plan: Do 1, 2, and 3 in order. Then do 4.*				
2.1 Obtain IV bag, unwrap and prepare	Incorrect IV medication obtained and prepared	Patient receives wrong IV medication, medication is inaccurately prepared		
2.2 Write up label	Label not written up correctly or at all	IV does not flow into the body as it should.		
2.3 Attach label to bag	Label not attached	Information about medication not transmitted between staff		
2.4 Approach patient				
3. Administer medication *Plan: Do 1 to 7 in order. Repeat 6 and 7 if necessary. Then do 8.*				
3.1 Close valve on tubing				
3.2 Disconnect tubing from empty IV bag				
3.3 Connect tubing to new IV bag				
3.4 Hang up new IV bag				
3.5 Open tubing valve				
3.6 Check drip flow	Check not performed	IV medication administered at a too fast or too slow rate.		
3.7 Adjust accordingly	Not adjusted	IV medication administered at a too fast or too slow rate.		
3.8 Appropriately dispose of old IV bag				

Patient monitoring: Measuring blood glucose				
Operations and Plans	**Human-error Identification**	**Consequence**	**Probability (L, M, H)**	**Criticality (L, M, H)**
0. Measuring blood glucose *Plan: Do 1 then 2 then 3.* 1. Obtain equipment 2. Obtain blood 3. Obtain blood glucose reading				
1. Obtain equipment *Plan: Do 1, 2, 3 and 4 in any order.*				
1.1 Obtain glucose strips				
1.2 Obtain blood glucose machine				
1.3 Obtain blood glucose needle				
1.4 Obtain alcohol swab				
2. Obtain blood *Plan: Do 1 to 8 in order.*				
2.1 Clean fingertip with alcohol swab	Not perform action task	Blood maybe contaminated and affect reading		
2.2 Use clean needle to prick finger				
2.3 Squeeze finger to obtain drop of blood				
2.4 Drop blood on glucose strip				
2.5 Insert strip into machine				
2.6 Place alcohol swab on wound				
2.7 Press button				
2.8 Wait				
3. Obtain blood glucose reading *Plan: Do 1 to 3 in order. If value is outside the normal range, do 4.*				
3.1 Read off blood glucose level from machine	Value read off inaccurately	Results in inaccurate actions		
3.2 Record in patient file	Value recorded inaccurately, value not recorded	Inaccurate information transmitted		
3.3 Dispose of strip and other disposable components in appropriate bins				
3.4 Administer appropriate medication	Medication not administered, incorrect medication administered	Patient's condition will not improve and may become worse		

Patient monitoring: Measuring blood pressure and heart rate				
Operations and Plans	**Human-error Identification**	**Consequence**	**Probability (L, M, H)**	**Criticality (L, M, H)**
0. Measuring blood pressure and heart rate *Plan: Do 1 to 8 in order.*				
1. Walk to patient's bed with machine				
2. Plug in machine				
3. Get patient's attention and strap cuff around patient's arm				
4. Press start				
5. Wait for beep				
6. Read off and record in patient file	Value is read off and recorded inaccurately	Resulting actions are incorrect, and wrong information is transmitted		
7. Remove cuff from patient				
8. Unplug machine				
6. Record in patient file *Plan: Do 1, 2 and 3 in any order*				
6.1 Record systolic blood pressure	Value is recorded inaccurately	Resulting actions are incorrect, and wrong information is transmitted		
6.2 Record diastolic blood pressure	Value is recorded inaccurately	Wrong information is transmitted		
6.3 Record heart rate	Value is recorded inaccurately	Resulting actions are incorrect, and wrong information is transmitted		
6.4 Report to registered nurse	Not reported to nurse in order to take necessary action	Patient's vital signs do not return to the normal range as soon as possible		

Patient monitoring: Measuring temperature				
Operations and Plans	**Human-error Identification**	**Consequence**	**Probability (L, M, H)**	**Criticality (L, M, H)**
0. Measuring temperature *Plan: Do 1 to 5 in order. If 5 is above 'normal' do 6.*				
1. Obtain thermometer				
2. Place thermometer underneath arm				
3. Wait				
4. Read thermometer	Value is read inaccurately	Following action is incorrect and incorrect information is recorded		
5. Record in patient file	Value is recorded inaccurately	Following action is incorrect and incorrect information is recorded		
6. Report to staff nurse	Not reported to nurse in order to take necessary action	Patient's vital signs do not return to the normal range as soon as possible		