An investigation of the range of cervical spine movements incurred during spinal immobilisation procedures.

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CONTENTS

Figures

Tables

1 ABSTRACT

An investigation of the range of cervical spine movements incurred during spinal immobilisation procedures.

Objectives

Safety of out-of-hospital procedures used to manage patients with unstable spinal column injuries has never been effectively evaluated. In particular, literature evaluating the efficacy and safety of the log roll is sparse.

This project evaluated the use of an inertia measurement unit (IMU) system to accurately report neck movement during a log roll manoeuvre. It also investigated the variation encompassed within the technique or associated with the experience of the operator.

Methods

To measure neck movement during a log roll, the IMU system was used to track the orientation of the head in relation to the thorax. Two head supporting techniques were employed during the log roll; the head and the shoulder hold. Thirty six participants performed 216 log rolls using both techniques. Participants were recruited from students, and practicing paramedics, forming novice and experienced groups respectively. Results were analysed using one-way ANOVA, linear regression models and visual examination of the plots. Ethics was obtained from the Flinders Clinical Research Ethics Committee.

Results

The average range of motion across all axes (lateral, flexion and rotation) was found to be 17.4^{o}, which indicates a failure to maintain a neutral alignment, although the clinical significance of this is uncertain.

Comparison of the shoulder hold and the head hold demonstrated the shoulder hold significantly reduced misalignment for rotation over the head hold. Significantly poorer performance by experienced participants compared with novice participants, ,both as lead clinicians directing the performance of the log rolls, was seen in the flexion axis. Linear regression analysis indicated that rotation values were higher than expected when compared with the other axes, with sharp spikes in misalignment at the commencement and conclusion of the manoeuvre.

Conclusions

This study validates the accuracy of the IMU system to use for neck movement studies. It also identified high angles of neck misalignment caused by the log roll which probably relates to participant coordination, spatial awareness and team synchronisation. While this misalignment was evident in all axes, the sharp spikes in rotational misalignment emphasised the problem with team synchronisation. Technique comparison indicated superiority of the shoulder hold over the head hold, but the magnitude of the difference was small. Performance difference between experienced and novice participants indicated

a trend towards degradation of skills in experienced participants, although individual performance as a lead clinician may be influenced by the team's performance.

Further study is required to define an acceptable cervical alignment, determine improvements in techniques and address issues related to skills degradation.

2 ACKNOWLEDGEMENTS

'I certify that this work does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text'

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3 INTRODUCTION

Spinal cord injury (SCI) is a significant and costly burden on the health care system in Australia, with 15new cases per one million population annually (Norton L, 2010). In a report for a Ministerial Meeting on Insurance Issues, Walsh et al (2005) identified the long term care burden of SCI survivors in 2005 to be approaching $500 million annually. With an improved life expectancy of survivors, and a steady rate of SCI, O'Connor (2005) projected the number of Australians living with SCI in 2021 to be 11,871. The importance of research into spinal cord injury cannot be doubted when the personal catastrophe, the social and economic burden and the impact on health care systems is taken into account.

In the report for the Australian Institute for Health and Welfare, Cripps (2006) indicated that 73% of Spinal Cord Injury (SCI) occurs as a result of trauma, with an overrepresentation of cases in the 15-24 age groups. The cervical spine was reported to be the most common spinal level of injury. The majority of these injuries occur as a result of traffic accidents, with other mechanisms including falls, being struck by objects and water related activities (Cripps, 2006).

Spinal column injuries are defined as fractures or dislocation of the vertebrae, together with disruption of the supporting structures of the spine. Spinal column injuries cause damage to the spinal cord (SCI) if parts of the vertebrae or related structures cause narrowing or occlusion of the spinal canal. While many cases of spinal cord injury inevitably occur during the initial insult, it is possible that some cases occur at a later stage due to movement of unstable elements of the spinal column. It is this secondary spinal cord injury that is believed to be preventable with careful application of good spinal care (Ahn et al., 2011; Bernhard, Gries, Kremer, & Böttiger, 2005; R. A. De Lorenzo, 1996; Theodore, Hadley, et al., 2013). Unfortunately, it is impossible for those working in the out-of-hospital setting to know if the trauma victim has a spinal column injury. Consequently, to ensure that further damage to the spinal cord does not occur, care is provided on the assumption that a spinal column injury exists until proven otherwise (Australian and New Zealand Committee on Resuscitation, 2016).

Inherent in this management of a trauma victim, there is the need for significant patient movements required for extrication from the scene, transportation in the ambulance and transfer to the hospital barouche within the emergency department. Failure to consider the possibility of an unstable spinal column injury during these movements could lead to adverse outcomes such as secondary spinal cord injury. However, the incidence of this type of secondary injury, in the out-of-hospital setting, is not well elucidated in published literature and remains speculative or confined to observations within the hospital setting (Cloward, 1980; Harrop, Sharan, Vaccaro, & Przybylski, 2001; Lawrence F. Marshall et al., 1987). Intuitively, it is likely that such secondary SCI is avoidable with careful alignment and splinting of the spine to minimise spinal column movement.

Spinal immobilisation techniques have been used since the 1970's to minimise secondary spinal cord injuries in the prehospital setting (R. A. De Lorenzo, 1996). Spinal immobilisation devices are used commonly in prehospital practice; with a wide range of products available for various applications. The recommended spinal immobilisation in Canada and United States of America includes using spinal boards, head restraints, cervical collars and strapping of the body (Canadian Agency for Drugs and Technologies in Health, 2013; Theodore, Hadley, et al., 2013). This model has not been adopted by the Australian and New Zealand Committee on Resuscitation (2016) who warn against the use of spinal boards for transportation and do not mandate any specific method of spinal immobilisation due to the lack of definitive evidence.

Research underpinning spinal immobilisation not only has provided little clear supportive evidence, but also reports a number of adverse findings. The constrictive nature of spinal immobilisation has been shown to cause respiratory compromise in adults and children (Kwan, Bunn, & Roberts, 2001; Schafermeyer et al., 1991; Totten & Sugarman, 1999; Vickery, 2001). Chan, Goldberg, Tascone, Harmon, and Chan (1994) and Chan, Goldberg, Mason, and Chan (1996) examined the discomfort and pain associated with lying on the hard surface of a spinal board, reporting that pain persisted for an extended period after spinal immobilisation. Cordell, Hollingsworth, Olinger, Stroman, and Nelson (1995) and Main and Lovell (1996) developed this issue further by examining the tissue interface pressure at the occiput, shoulders and sacrum of a patient lying on a hard spinal board. They were able to report tissue interface pressure, during tests of volunteers lying on spinal board for 30 to 80 minutes, well in excess of that necessary to impair perfusion to the pressure points, thus risking the development of pressure sores. Cervical collars have received considerable scrutiny, with several studies identifying a lack of effective neck splinting (Horodyski, DiPaola, Conrad, & Rechtine, 2011; McGuire, Degnan, & Amundson, 1990; Podolsky et al., 1983). Furthermore, two studies described serious adverse consequences with investigators reporting raised intracranial pressure and distracting cervical spine injuries (Ben-Galim et al., 2010; Davies, Deakin, & Wilson, 1996).

Highly relevant to the current study, the log roll maneuverer has received a significant amount of criticism for the excessive amount of head and neck movement imposed during the maneuverer. The log roll is used as a method to allow placement of the patient on a spinal board, transfer the patient between stretchers and to examine the patients' back. Motion capture technologies have been used in studies to measure misalignment of the neck during the log rolls (Conrad, Horodyski, Wright, Ruetz, & Rechtine, 2007; Conrad, Rossi, et al., 2012; Del Rossi G, Heffernan TP, Horodyski M, & GR, 2004; Del Rossi, Horodyski, Conrad, Dipaola, et al., 2008; Del Rossi, Horodyski, & Powers, 2003; Horodyski, Conrad, Del Rossi, DiPaola, & Rechtine, 2011; McGuire, Neville, Green, & Watts, 1987; Prasarn, Horodyski, et al., 2012; Rechtine, Conrad, Bearden, & Horodyski, 2007). The investigators found unacceptably high cervical misalignment and recommended that the log roll should be avoided for any trauma cases. A more detailed analysis of these studies is presented in 4.1.1 Evaluation of cervical spine immobilisation.

Clearly there is doubt and controversy related to spinal immobilisation, which has not yet been resolved. The link between good neurological status outcomes in patients with spinal column injury and spinal immobilisation cannot be easily authenticated by the available evidence. Much of the effort made by the health care provider to ensure good acute management of suspected SCI may be misguided or unnecessary. It is often the fear of causing further damage, and an understanding of the devastating consequences of SCI, that mandates strict splinting of the spine, without those implementing the care having a sound evidence base to support their work.

3.1 Project Aims

In order to provide evidence that effectively evaluates spinal immobilisation, this study was designed as a pilot project to validate a biomechanical measuring system to provide data on cervical spine movement. It addresses the current lack of a system that verifies the effectiveness of spinal immobilisation systems in limiting head movement relative to the body.

The primary aim of the study is:

> *To investigate the feasibility of measuring movement of the head relative to the torso with an inertia measurement unit (IMU) system.*

This will be tested using a simple patient manoeuvre; the log roll as a test case. To contextualise the testing to the pre-hospital setting, these log rolls will be performed by paramedics and paramedic students in a simulated setting on a healthy participant. It has been conjectured that variations in techniques of performing the log roll may also impact on cervical alignment. Two commonly employed techniques include the head-only hold; where the patients head is grasped on both sides and the head-shoulder hold; where the shoulders are grasped and the head is supported on the forearms. Variations in the experience of the operators may also have an impact on cervical alignment where the time since training and skill decay may impact on the effectiveness of the log roll.

These factors have been taken into account with the secondary aims of the study, which are:

1. *To measure the amount of relative head movement in three dimensions that is caused by the log roll.*
2. *To test for differences in relative head movement between two techniques of supporting the head; the head-only hold and the head-shoulders hold, during the log roll manoeuvre.*
3. *To test for differences in relative head movement between novice operators and experienced operators acting as the lead clinician holding the head and directing the procedure.*

4 LITERATURE REVIEW

4.1 Anatomy of the cervical spine column

The cervical spine column is a complex collective of seven vertebrae (C1 to C7), intervertebral discs and ligaments which protect the spinal cord from injury and allow a high degree of flexibility. Together with the muscles of the neck the cervical spine supports the head and allows flexion and extension in the sagittal plane, axial rotation and lateral bending in the coronal plane (Bogduk & Mercer, 2000). Flexibility is enabled by articulation of joints between each vertebra and between the uppermost vertebrae and the skull.

Each vertebra, except C1, has the general form of an anterior vertebral body and a posterior vertebral arch, which forms the canal through which the spinal cord passes (Pimentel & Diegelmann, 2010). The vertebral arch is composed of pedicles forming the anterior segments of the arch and laminae forming the posterior segment of the ring (figure 4-1). A thickening of the bone at the junctions of the pedicles and laminae form the lateral masses. Articulation surfaces on the superior and inferior aspects of these lateral masses form the facet joints of the vertebrae. Between each vertebra, excluding the C1-C2 joint, are intervertebral discs. These intervertebral discs have an inner core of the gelatinous Nucleus Pulposus, which provides a cushioning between the vertebrae, and an outer ring of fibrous cartilage; the Annulus Fibrosus, which acts as a ligament between the vertebrae. The facet joints on either side of the vertebral arch slope downwards posteriorly at approximately 45 degrees and allows primarily a sagittal flexion and extension movement (Radcliff et al., 2011).

Projecting from the lateral aspects of the vertebral arch are the transverse processes, which provide sites for ligament and tendon attachment. There is a foramen within the transverse process through which the vertebral artery passes. Projecting posteriorly from the midline of the vertebral arch lie the spinous processes, which form attachment points for the interspinous ligaments (Bogduk & Mercer, 2000).

The uppermost vertebra (C1) is named the Atlas and has a distinctly different structure form the other vertebrae. It is a ring-shaped bone without a vertebral body. The Atlas articulates above with the Occipital Bone through a joint that allows primarily a flexion-extension motion. This occipito-atlantal (OA) junction is firmly secured by the Alar, Apical and Anterior-axial Ligaments which span between the Occipital bone and C2. The Axis (C2) has a vertebral body with an upward projecting process; the Odontoid Process. The anterior part of C1 rotates about this bony projection from C2; and is secured in position by the Transverse Ligament which passes posteriorly around the odontoid process and attaches to the lateral masses of C1. This structure allows a great range of movement in axial rotation (Bogduk & Mercer, 2000).

In addition to the upper cervical spine ligaments described above the spine is securely supported by a longitudinal system of ligaments provided by the anterior and posterior longitudinal ligaments and the lingamenta flava (Pimentel & Diegelmann, 2010). The anterior and posterior longitudinal ligaments lie on the anterior and posterior aspects of the vertebral body respectively, while the ligamenta flava lies on the inner aspect of the posterior part of the vertebral arch. Further support of the vertebrae is provided by the facet joint capsule and the intervertebral discs, both of which firmly anchor adjacent vertebrae. Finally, the interspinal ligaments and the intertransverse ligaments span between spinous process and transverse processes respectively providing further support for the spinal column (K. L. Moore, Dalley, & Agur, 2013).

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Figure 4-1: General structure of the cervical spine

The major components of the cervical spine showing the vertebrae, the intervertebral discs, the ligamenta and the facet joint (zygapophyseal joint) capsules. Image from K. L. Moore et al. (2013)

Articulation of the cervical spine is a summation of many smaller movements at each vertebral level. While rotation of the head is largely achieved by the rotation of the atlas around a superiorly projecting bony process of C2, the odontoid process, it is also supplemented by sliding of the facet joints throughout the sub-axial cervical spine. Similarly, the nodding motion of the head predominantly occurs at the occipito-atlantal junction, but further flexion and extension is achieved at each vertebral level through the facet joints. Lateral bending is a more complex motion, involving both rotation and flexion at each facet joint, giving an overall movement to the side (Radcliff et al., 2011). The normal range of motion in each axis for a healthy individual is provided in table 4-1. Crucial to the normal articulation of the cervical spine are the limitations to the range of motion imposed by the ligaments and facet joint capsules (Bogduk & Mercer, 2000). Forceful movements beyond the normal range of motion would contribute to a significant number of spinal column injuries which involve flexion, extension rotation and lateral bending.

Table 4-1: Normal range of motion of the cervical spine

divided into contribution from the component parts; the Occipito-atlantal junction, the Atlas –axis junction and the Sub- axial Cervical Spine, from Bogduk & Mercer (2000).

Joint	Flexion-extension	Axial Rotation	Lateral Bending
Occipito-atlantal junction	14°-15°	0°	0°
Atlas-axis junction	10°	47°	5°
Sub-axial cervical spine	2°-3°	2-7°	3°-6°

The structure of the cervical spine relates to several important factors when considering spinal column injury. Firstly, the range of movement demonstrates a highly degree of flexibility. The robust system of ligaments, facet joint capsules and intervertebral discs ensure that the spine has the ability to move freely while retaining a high level of innate strength. However, the cervical spine has an inherent vulnerability due to its the weight of the head, the relatively small size of the cervical vertebrae and the morphology of the angled facet joints that could shear under axial loads (Bland & Boushey, 1990). Damage to anterior or posterior elements of the cervical column allows instability which may result in SCI (White, Johnson, Panjabi, & Southwick, 1975). Consequently, the spinal trauma victim can have an injury that is a highly unpredictable in terms of column stability and neurological outcome. It is this unpredictability which creates challenges for workers in the out-of-hospital setting where the stability and severity of the column damage cannot be determined.

4.2 Injury patterns

The classification of cervical spine injuries has received much attention during the last two decades, with numerous schemes proposed. While these schemes do not impact greatly on the out-of-hospital care of trauma victims, the understanding does have significance for the paramedic. A scheme which links the mechanism of injury to the likely spinal column injuries, provides the paramedic with an appreciation of the probability of a patient having a spinal column injury, and thus prompts the paramedic to take appropriate actions to protect the spine. An exhaustive account of the classification systems will not be presented here, but relevant key findings will be briefly described.

In a retrospective study of 165 cases, Allen, Ferguson, Lehmann, and O'Brien (1982) identified a need for a system which used the mechanism of injury to predict the likelihood of neurological damage**.** The authors identified that the force vector was important in the injury type, which led to the classification of cervical injuries into the six categories of; compressive flexion, vertical compression, distractive flexion, compressive extension, distractive extension and lateral flexion. The force vector predicts which of the six fracture categories may have occurred.

Moore *et al.* (2006) proposed a new classification system for lower cervical spine injuries; the Cervical Spine Injury Severity Score (CSISS) which takes into account the mechanism of injury (force vector), a morphological system to describe injury and a severity score. While a useful way of describing spinal injuries, it was not universally adopted. It was further tested in a review by Zehnder *et al.* (2009) who found the system to be clinically relevant, reliable and reproducible.

Vaccaro *et al.* (2007) introduced a scheme which recognised three major components of subaxial cervical spine injuries; the injury morphology, the extent of disruption to the disco-ligamentous complex and the neurological status. This scheme was described as the Subaxial Injury Classification (SLIC) system. The investigators were able to allocate severity scores to each category to calculate a total injury severity.

A systematic review by Aarabi *et al.* (2013) recommended the adoption of the both the Cervical Spine Injury Severity Score (CSISS) and the Sub-axial Injury Classification (SLIC) systems, although they note that both systems can be complicated and need further validation. The importance of understanding the degree of instability, the need for surgical intervention and the benefit of being able to communicate the severity of injury was identified as positive features of the combination (Aarabi *et al.* 2013). Hadley *et al.* (2013) also conducted a systematic review of the classification schemes that report neurological examination, functional outcomes and pain following SCI. In a thorough analysis, the investigators reported that the 2000 American Spinal Association (ASIA) Standards were the *"most consistent, reliable, valid, and responsive scoring system"* for the acute assessment of neurological function. This standard does not address the types or mechanisms of injury, but focusses only the consequent neurological disability. The authors also made recommendations related to the functional capacity of patients after SCI and the management of pain.

Vaccaro *et al.* (2015) furthered the classification of cervical spine as part of the "AOSpine Injury Classification System" with the goal of providing a "comprehensive yet simple classification system with high intra- and inter-observer reliability to be used for clinical and research purposes." This system categorised injuries according to four key criteria; compression injuries, tension band disruption (i.e. damage to vertebral bodies, longitudinal ligaments, ligamentum flavum and intervertebral discs) translational injuries and facet injuries. This system also accounted for patient specific modifiers and neurological status.

The studies outlined above (Allen *et al.* 1982, Moore *et al.* 2006, Vaccaro *et al.* 2007, Vaccaro *et al.* 2015) indicate that key factors which influence neurological damage are; the direction of the impact (either compression or tension), the integrity of the disco-ligamentous complex and dislocation (or subluxation) of the intervertebral joint. It is evident in the schemes used to describe cervical spine injuries, that there is a high variability in the injury that can result from any particular mechanism of injury. While forces exerted in a specific direction on the head can result in a predictable range of injuries; the severity of the injury, degree of instability and the chance of neurological damage is difficult to predict. This unpredictable nature of cervical spine injuries creates challenges for paramedics working in the prehospital setting.

4.2.1 Prehospital context of injury patterns

The type of injury does have significant bearing on the stability of the cervical spine and the potential chance of developing a SCI. While paramedics are well placed to identify the mechanism of injury at the accident scene, they do not have the advantage of knowing how the spine is injured. Consequently they are unable to definitely determine the stability of the injury and must treat all suspected spinal column injuries with the assumption of instability.

While it is intuitively possible for unstable elements of the cervical spinal column to move into the spinal canal hours or days after the initial impact, causing mechanical compression of the spinal cord, it is not well reported in the literature. Oto *et al.* (2015). Harrop *et al.* (2001), Marshall *et al.* (1987b) and Farmer *et al.* (1998) provide case series of deterioration in neurological outcomes linked to specific events in hospital, while Toscano (1988) reported some prehospital deteriorations. These deteriorations in some cases appear directly related to mechanical movements, although in many cases could simply be the result of other secondary processes occurring coincidentally. Consequently the role of poor cervical spine alignment or lack of splinting in contributing to SCI is not well understood. This lack of clarity of the role of mechanical disturbance causing or exacerbating a SCI in an already unstable spinal column injury, has led to the assumption that any neck movement is detrimental. Therefore, it is thought necessary to take all possible precautions to limit head movement if a cervical spine injury is suspected.

However, this presumption that minimising head movements will limit the formation of SCI is not well linked to any evidence. Furthermore, the common methods of trauma patient handling have not been evaluated to ascertain the amount of head movement caused by this handling. Consequently, paramedics are attempting to manage complex cervical injuries without knowing either the stability of the injury or the effectiveness of the handling methods employed. While it may be impossible to improve the prehospital assessment of cervical stability in the foreseeable future, the prehospital techniques of spinal injury management are capable of improvement.

4.3 Incidence of cervical spinal column injury

Spinal cord injury (SCI) throughout the world is a devastating event for the patient, leading to severe disability. Survivors of SCI, in many cases, face a lifetime of living with their disability, a limited employment capacity and heavy reliance on health care and welfare systems. To gain a perspective of the impact of SCI on population health, it is useful to examine the extent, cause and distribution of the problem. Many nations maintain registers of injuries which detail the incidence and causes.

In Australia, SCI are reported to the Australian Spinal Cord Injury Register (ASCIR). O'Connor (2005) reported trends in SCI in Australia from 1986-1997. During this period, there appeared to be a steady incidence rate of approximately 247 new cases annually. Life expectancy following SCI was 40.35 years and there were 681 people living with SCI per million population. In a complex analysis which takes into account a forecast incident rate; which is somewhat dependent on changes to transport safety, improvements in life expectancy following SCI and the impact of an aging population, O'Connor (2005) forecast the number of people living with SCI in 2021 to be between 10,450 and 11, 870.

Data is reported to the National Injury Surveillance Unit of the Australian Institute of Health and Welfare and published in the Injury Research and Statistics Series (Norton L 2010). These publications detail an incidence of reported SCI from July to the following June each year. Data is collected from the six spinal units around Australia who receive all spinal injured patients. In the year 2007-2008, there were 362 new cases, of which 285 had traumatic causes. This represents 15.0 new cases per million population in 2007-08. Interestingly, the incidence rate increased with remoteness of the accident, with the very remote category reporting 8 times the incidence of major cities. The author cautions that the incidence in the more remote areas was low, so the data should be interpreted with care. However, the remoteness of the incidence does have some relevance to out-of-hospital providers, who must manage the trauma victim for much longer than in a major city.

Incidence of persisting SCI was greatest in the 15-24 years age group and males were 5.3 time more likely to have a SCI than females. A breakdown of cause of SCI showed that transport related injuries and falls represented the greatest type at 46% and 28% respectively. Within the falls category, 64% were from greater than one metre and 36% were from less than one metre. Those over 65 years were more likely to incur a SCI from a low fall than a high fall. Survival to 90 days following SCI (with or without neurological deficit) was 98% with an average stay in hospital after the initial event of 133 days. The level of injury shows a clear predominance of cervical spine involvement, which accounts for 53% of all cases, followed by the thoraco-lumbar junction at 11% and 32% distributed along the thoracic spine. This is highly relevant to those providing initial care in the out-of-hospital setting who need to remain alert for injuries to the spine in all trauma cases.

4.3.1 Prehospital context of spinal cord injury

Middleton *et al.* (2012) published findings from a review of traumatic spinal cord injury cases managed by the Ambulance Service New South Wales (ASNSW) between January 2004 and June 2008 with the aim of evaluating if SCI were accurately identified and expediently transferred to a spinal cord injury unit (SCIU). This retrospective study linked data from ASNSW with clinical data from the state spinal cord injury unit. Of a total of 324 adult patients treated at the SCIU, 255 could be identified as having been cared for by paramedics from the accident site to the SCIU. They were able to report similar figures to the national data for causes of SCI, with traffic accidents (31%), high falls (19%), surfing and diving (13%) and low falls (11%). Paramedics had a reported accuracy of diagnosing SCI of 88% during the study period, with reasons for non-recognition of SCI including; a highly variable presentation, multiple trauma, incomplete legions and normal vital signs. An example of where clinical signs provide little specificity for the paramedic and so add to the challenge of diagnosis at the scene of an accident is when a paramedic is called to an elderly patient after a fall. These patients are likely to be managed for episodes of dizziness or weakness and these distractions along with the unremarkable mechanism of injury renders the paramedic less suspicious of likelihood of a SCI.

Remoteness of the accident site was also found to significantly influence patient outcomes from spinal column injury. Middleton *et al.* (2012) found that patients who did not reach a specialised SCIU in less than 24 hours, tended to have a poorer outcome, with a 2.5 times greater chance of developing deep vein thrombosis, pulmonary embolism or pressure sores. These patients were from regional areas and had multiple transfers between hospitals or had multiple trauma (59% of patients) and required more intensive stabilisation prior to transfer. An acknowledged limitation of this study (Middleton *et al.* 2012) is the absence of detailed clinical data from intervening hospital prior to transfer to the SCIU. It may be argued that patients with multiple trauma were probably subject to extensive stabilisation prior to transfer to the SCIU and the nature of their injuries probably rendered them prone to adverse outcomes. Interestingly, no comment was made on the consequence of delayed transfer to SCIU and the incidence of secondary SCI.

An interesting contrast in epidemiology is provided by Kawu (2012) who presents the situation in Nigeria. This study drew data from a major regional hospital; The University of Abuja Teaching Hospital Gwagwalada Abuja, Nigeria, a regional centre which receives patients from outlying primary care facilities. Causes of SCI was predominantly caused by traffic accidents (79.7%) followed by falls (13.4%). This contrasts sharply with Australia, which has a significantly lower level of SCI from traffic accidents. The Nigerian study also highlights the 100% incidence of SCI following vertebral fracture, which is a dramatically higher level than the 14-38% reported in more developed countries (Kawu 2012). The author proposes the difference is probably due to a complete lack of prehospital care and limited primary health care prior to admission to a tertiary hospital, leading to secondary neurological damage through inappropriate handling. This observation adds weight to the argument that SCI may be exacerbated by secondary injury between the incident and arrival at definite care (Cloward 1980). In contrast, some studies suggest that secondary injury from manual manipulation will not happen due to the relatively low forces applied to the neck by manual manipulation in the prehospital setting (Hauswald 2013) providing a debate that needs resolution.

4.3.2 Incidence of neurological damage following cervical spinal column injury

4.3.2.1 Impact of manipulation

The incidence of secondary neurological injury after spinal column injury remains an enigma in the out-of-hospital setting with no clear data identifying any causes. However, it is intuitively clear that an unstable column injury could compromise the spinal canal if the head was moved carelessly. Cloward (1980) claimed that *"25% of fatal complication was related to the period between the accident and arrival of the victim in the emergency room"* but did not elaborate on the source of his evidence. This statement has been used by many to suggest that the care during the prehospital phase is critical to prevent secondary SCI.

Marshall *et al.* (1987a) attempted to clarify the amount of secondary SCI and the causes of these catastrophic events. In their prospective study of SCI patients admitted to five trauma centres in the United States of America, they were able to identify 283 SCI patients who underwent a range of interventions. Those interventions reported to have caused deterioration included surgery, halo vest application, Stryker frame rotation, skeletal traction application and 'Rotobed' rotation. Fourteen patients (4.95%) suffered clear decline in neurological function as a consequence of discrete events involving manipulation of the cervical spine during the routine interventions. Four of these events involved some form of manual manipulation of the cervical spine, indicating that it is possible to inflict secondary injury from manual manipulation, although the incidence is relatively low. The authors of this study also indicate that the secondary injuries were probably an inevitable consequence, given the instability of the individual's vertebral fracture. While their work was entirely based within the hospital setting, it shows that manipulation may contribute to secondary SCI, which has relevance for the out-of-hospital setting where some similar elements of manipulation may be used.

Harrop *et al.* (2001) reviewed patients who demonstrated secondary neurological deterioration after spinal column injury at the Delaware Valley Regional Spinal Cord

Injury Center at Thomas Jefferson University Hospital, during a 6.5 year period. They found that 12 patients with spinal cord injury (6.6%) demonstrated neurological deterioration during the acute phase of their treatment. Two patients, with ankylosing spondylitis, deteriorated during the application of a halo vest. A further two deteriorated due to inadequate immobilisation; one caused by a combative patient self-manipulating the neck and the other caused by obesity. While all these patients may be described as extraordinary with high risk of secondary injury, it does demonstrate the potential for mechanical causes of secondary neurological deterioration. This study enrolled a total of 1904 patients with spinal column injury, with only four patients showing secondary deterioration through manual manipulation, suggesting the incidence is a negligible 0.21%.

Farmer *et al.* (1998) attempted to identify specific events which lead to secondary spinal cord deterioration in a study of patients admitted to the Regional Spinal Cord Injury Centre of Delaware Valley, USA, from a period between 1978 and 1993. They identified 19 out of 1031 patients with cervical SCI suffering deterioration in neurological function (1.84%). Factors identified at the time of the deterioration were sepsis, intubation and vertebral artery injury. Ankylosing spondylitis was seen as a factor in 3 of 5 patients who died after neurological deterioration. Four patients developed sepsis, and four cases deteriorated near the time of intubation. One case of vertebral artery injury caused a rapid deterioration post-surgery where the patient had deteriorated from hemiplegia to quadriplegia. There appeared to be an increased morbidity related to early surgery (<5 days) with all patients within this group (5 patients from the 19 that deteriorated) deteriorating within one day of surgery. These findings are suggestive of risks of secondary SCI being related to surgery, sepsis, intubation and vertebral artery injury. No specific reference is made to manual manipulation as a causative factor for worsening SCI, but presumably the process of intubation would account for some manual manipulation. While this evidence suggests that the incidence of manual manipulation inducing deteriorating neurological function is low, it should be considered an avoidable complication which has a high potential for costly and catastrophic consequences.

4.3.2.2 Cellular mechanisms

Several reviews have examined the evidence of elaborate processes which lead to cellular damage secondary to SCI. In a detailed review, Anderson and Hall (1993) summarised the existing evidence for damage caused by hydrolysis and peroxidation of membrane lipids that occurs after mechanical trauma. They concluded that there is convincing evidence of eicosanoid production and oxygen reactive species-induced lipid peroxidation resulting in significant cellular damage, including cell membrane dysfunction. Calcium ions invade the cell and further disrupt cellular process and promote cell death. Sekhon (2001) detailed the primary-secondary nature of SCI, with a description of a complex cascade of biochemical and cellular processes that cause cellular dysfunction and death. Again oxygen reactive species, eicosanoids, inflammation and calcium ion influx were implicated in neuronal damage. Vascular insufficiency, with a variety of possible causes; such as oedema, vessel rupture, microvascular changes or vasospasm, are thought to contribute to the secondary damage through ischaemic damage and excitotoxicity. These studies suggest that neurological deterioration has much wider aetiology than manual manipulation.

4.3.2.3 Anatomical considerations

A study by Fujimura *et al.* (1995) examined the neurological prognosis of patients with upper cervical spine injuries at Keio University Hospital, Japan, and affiliated hospitals during a period from 1966 to 1992. In this retrospective study 275 patients were identified with 11 fatalities and 82 cases showing neurological deficit (33%). Of those who survived to hospital, 4 had very severe neurological deficit, resulting in death and 78 had relatively mild paresis with good recovery. The reason given for the relative infrequency of SCI in upper cervical spine injuries relates to the sagittal diameter of the spinal canal and the ability of this part of the spine to move longitudinally which allows the spinal cord room to expand or be slightly distracted. No cases were reported with secondary deterioration after admission. Even though the majority of patients had mild and transitory neurological deficits, the injuries to the vertebral structures were mostly regarded as unstable. The relevance of this finding for the out-of-hospital setting is the potential for very unstable fractures to present with only mild symptoms, thus reinforcing the need for stringent attention to spinal care by paramedics.

4.4 Methods of prehospital care used for suspected cervical spine column injuries

The management of SCI has provoked much debate, with opinions ranging from the absolute necessity of using spinal immobilisation, through to those opposed to its use. The fundamental tenet underpinning the debate is the concern that victims of spinal trauma are prone to incurring a secondary injury with inappropriate management. The evidence for this in the prehospital setting is almost non-existent. Even in the hospital setting there is only minimal evidence that shows a definitive secondary ascending neurological injury as discussed in section 4.3.1. However, the debate is also driven by the fear of damage and the severe consequence of doing that damage. Consequently, over the last 30 years, there have many studies which have aimed at illuminating the evidence supporting spinal immobilisation, with 27 studies that have attempted to measure the effects of the treatment and 14 studies which have reported adverse outcomes from the treatment.

De Lorenzo (1996) provided a comprehensive review of the state of spinal immobilisation in the prehospital setting. This study provided a synopsis of the accepted spinal care techniques used at the time within the United States of America. The recommended treatment for trauma cases was the use of a long spinal board, rigid cervical collar and firm strapping of the patient to the spinal board. Adjunct padding and foam backed tape were recommended to improve positioning, stability and patient comfort. Field clearance was not recommended with the statement; *"...if in doubt, immobilize"*. However, the author acknowledged a lack of evidence to answer two key questions; whether spinal field clearance of trauma victims could be safely performed and does spinal immobilisation improve patient outcomes.

Kwan Bunn, & Roberts (2001) undertook a Cochrane systematic review on behalf of the WHO Pre-Hospital Trauma Care Steering Committee. Unfortunately, but probably not surprisingly, they were unable to find any studies which met the inclusion criteria, due to an absence of randomised controlled trials. Most studies were experimental and used healthy volunteers or cadavers. The authors speculate about the historical and legal influences that limit the gathering of scientific evidence and express concern about the use of unnecessary spinal immobilisation. They point out that there is no evidence to suggest prehospital spinal immobilisation has improved patient outcomes and evidence suggesting adverse outcomes from inadequate spinal immobilisation is exaggerated. The authors conclude that the benefit of spinal immobilisation is uncertain and may increase mortality and morbidity.

In a comprehensive review of prehospital management of spinal cord injury, Bernhard, Gries, Kremer, & Böttiger, (2005) noted the lack of any clearly identified management factors that have improved patient outcomes. In a well-structured review the authors examine each aspect of prehospital care, from patient assessment, immobilisation, transport and pharmacological and fluid therapies. Vigilant assessment in the field was identified as a vital component of patient care, in order to identify the sometimes subtle signs of SCI. Immobilisation was recommended with a long spinal board, rigid cervical collar and sandbags on either side of the head.

However the use of cervical collars in conjunction with vacuum mattress was recognised as a suitable alternative.

Ahn et al (2011) systematically reviewed the literature on prehospital spinal care and used a panel of experts to make a set of recommendations. The questions asked were:

1. What is the optimal type and duration of spinal immobilization in patients with acute SCI?
2. During airway manipulation in the pre-hospital setting, what is the ideal method of spinal immobilization?
3. What is the impact of pre-hospital transport time to definitive care on the outcomes of patients with acute SCI?
4. What is the role of pre-hospital care providers in cervical spine clearance and immobilization?

The expert panel comprised a traumatoligist, triage trauma specialists, spine surgeons, a critical care intensivist and a scientist, but no paramedics. The authors recommended that spinal boards, cervical collars and head immobilisation should remain the principle method of spinal immobilisation, although the evidence supporting this recommendation was not made clear. They also recommended early removal from spine board to prevent pressure sores. Quite reasonably, the authors recommended that patients with SCI should be transported to a facility with the capacity to effectively manage the care, although they concede that there is little evidence to support improved outcomes. Finally they recommend that field clearance of trauma patients to reduce the number of patients who endure spinal immobilisation should be considered.

A substantial contribution to all aspects of spinal care was published in March 2013 by the "Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons"(Hadley & Walters 2013) . This group has provided a comprehensive systematic review of the evidence and developed a series of recommendations spanning prehospital care, resuscitation, clinical assessment, radiographic assessment, classification schemes and surgical management of SCI. In the prehospital setting, Theodore et al (2013b) made a number of relevant recommendations. These included the use of spinal immobilisation with a rigid cervical collar, supportive blocks and straps for extrication and transportation. Subsequent removal of these devices was recommended to reduce the chance of adverse effects from the spinal immobilisation. The authors conceded that the recommendation is based on level III evidence but conclude that it is a:

> *"... time tested practice is based on anatomic and mechanical considerations in an attempt to prevent spinal cord injury and is supported by years of cumulative trauma and triage clinical experience."*

They also claim that a dramatic improvement in neurological outcomes of patients arriving at trauma centres over the last 30 years may be attributed to the development of improved levels of care rendered by emergency medical services (EMS) personnel. This evident confidence in level III evidence and patient outcome data may be justified, but the weakness of the evidence demands further studies to provide greater validation.

More substantial evidence exists for the appropriate triage of patients by experienced EMS personnel to determine the need or otherwise of spinal immobilisation. If a patient is alert, not intoxicated, has no neck pain or abnormal motor or sensory responses and no other injuries which may distract, then spinal immobilisation is deemed unnecessary. Spinal immobilisation is also not recommended for any patient with penetrating trauma (Theodore et al. 2013b).

Theodore *et al.* (2013a) also examine the issue of transportation of SCI patients, concluding that expedient transfer to a specialty spinal care facility results in improved outcomes. However they concede that all the evidence is at level II and large prospective studies are needed.

In a "Rapid Response Report" published on-line by the Canadian Agency for Drugs and Technologies in Health (2013) the use of the spinal board was examined. This report noted that there was no evidence to support the use of the spinal board. The authors also expressed concerns about the adverse patient outcomes caused by spinal board use, but concluded that there was inadequate justification to change practice. Consequently, the use of spinal immobilisation with cervical collars, spinal boards and strapping remains the recommended management in North America.

4.4.1 Evaluation of cervical spine immobilisation

4.4.1.1 Cervical collars and orthoses

Evaluation of techniques of spinal immobilisation began more than 30 years ago with a study that used a goniometer to evaluate the capacity of cervical collars and sandbags to limit head movement (Podolsky *et al.* 1983). This study used 25 healthy volunteers who were asked to move their necks as far as possible while secured by a number of different methods, compared against unsecured as a control. The immobilising methods included four different types of cervical collar, sandbags and tape and a combination of sandbags, tape and one of the cervical collars. Soft collars provide very little restriction to head movement, while rigid collars did provide some limitation to head movement, but not adequate to prevent cervical misalignment. Sand bags and tape did effectively and dramatically limit movement, particularly in axial rotation, but the addition of a rigid collar to the sandbags and tape did not significantly alter neck movement. A key outcome of this work was the adoption of sand bags and tape into prehospital practice. However, the impact of inertia of the sand bags could not be determined, which in fact has ultimately lead to the practice being discontinued. Moreover, a significant limitation of this study was the use of healthy volunteers who were asked to actively move their head, which would not provide a realistic model of a trauma patient. The use of the goniometer was also a limiting factor as the device could only be applied on a supine patient and the accuracy of the measurements may be affected by the method of securing.

The effectiveness of cervical collars was investigated using fresh cadavers with surgically created C4/C5 instability by McGuire et al (1990). In this experiment, the investigators compared three brands of rigid collars and a Philadelphia Collar Halo Stabilizer, using radiological methods to measure the amount of movement. A weight was then applied to produce a fixed flexion force for each of the collars and cadavers. The study showed that the three rigid collars performed equally with a 13.4 to 15.4 degree mean flexion with the application of the flexion force, but the Philadelphia Collar Halo Stabilizer produced a much reduced mean flexion of 0.5 degrees. The Halo Stabilizer has additional splinting with rigid extensions to the chest and back, providing greater resistance to flexion and extension, resulting in this improved performance. The study, however, overlooked any affect in other planes as only lateral radiography was used, so the impact on axial rotation is unknown (McGuire *et al.* 1990).

Horodyski et al (2011b) used an electromagnetic tracking device to measure the amount of movement between C5 and C6 in cadavers to determine whether cervical collars provide effective spinal immobilisation. Tests were performed using force applied to the head through Garden-Wells tongs, on five cadavers wearing a two piece collar, a one piece collar and no collar. The results of this study suggested that there was no statistically significant difference between collars or no collar, although the authors claimed that the collar restricted motion better than no collar for five of the six tests. The application of forces externally to the cadaver, probably do not provide a reasonable replication of neck movement which would be expected in a live patient, but possibly could represent the worst-case scenario of rough handling of an unconscious patient. The authors concluded that cervical collars do reduce the range of motion during injury healing, but the effectiveness for spinal immobilisation requires further research (Horodyski *et al.* 2011b).

Prasarn *et al.* (2012a) also examined the cervical spine movement caused by the application and removal of a one piece and a two piece cervical collar. They found that application of the two-piece collar caused more angulation and translation in the sagittal plane than application of the one piece collar, but these differences were small; 1.2 degrees and 0.2 mm respectively. Removal of both collars did not produce any significant differences (Prasarn *et al.* 2012a).

Overall, studies aimed at evaluating the effectiveness of rigid cervical collars appear to indicate that cervical collars have little effect in limiting neck movement. The only collar which produced significant splinting was the Philadelphia Collar Halo Stabilizer, but this is not used in the out-of-hospital setting due to the technical complexity of application.

4.4.1.2 Patient movement

During the care of a trauma victim, it is necessary to perform a range of manoeuvres to extricate the patient from the scene, move them to an ambulance stretcher and transfer the patient to the hospital barouche. The role of the paramedic is to provide safe care whilst extricating the patient from the scene and transporting them to hospital. A variety of issues arise when the safety of spinal immobilisation practices is examined. Numerous researchers have reported issues related to; the log roll, the use of spinal boards, the effect of vehicle motion, the relative safety of vacuum mattresses compared to spinal boards and the misalignment that can be caused by spinal immobilisation. The follow section reviews the current literature regarding these issues.

(i) The log roll

The amount of neck movement created by the log roll technique has been the subject of numerous evaluations. McGuire et al (1987) used a comparison of radiological images of a healthy volunteer, a patient with a T12-L1 fracture-dislocation and a cadaver with a surgically disrupted T12-L1 joint. Their focus was to examine the effect of the log roll and compare this with the use of a scoop stretcher. The investigators showed that even in a healthy volunteer there was considerable scoliotic twisting of the spine when in the lateral position. The cadaver showed considerable displacement in the sagittal plane and the lateral plane while the patient was in the lateral position, which persisted once supine. The scoop stretcher also produced some sagittal and lateral displacement in the cadaver. The injured patient demonstrated moderate lateral displacement while in the lateral position. The authors concluded that the log roll technique produced an unacceptable amount of thoracolumbar movement, even with a healthy volunteer. While their study was limited by the lack of repetitions and an incomplete evaluation of the scoop stretcher, it did identify a concern about to the common place use of the log roll manoeuvre in prehospital practice (McGuire *et al.* 1987).

Del Rossi et al (2003) examined the amount of cervical spine movement caused by a log roll compared to a lift and slide technique. In this study, electromagnetic motion capture technology measured the amount of neck movement in a healthy volunteer. The outcome of this study showed less neck movement caused by the lift and slide technique when compared with the log roll technique. This study was followed by a series of investigations using the electromagnetic motion capture technology to examine the effects of log rolls in cadavers (Conrad *et al.* 2007, Conrad *et al.* 2012, Del Rossi *et al.* 2004a, Del Rossi *et al.* 2008a, Del Rossi *et al.* 2008b, Del Rossi *et* *al.* 2010, Horodyski *et al.* 2011a, Prasarn *et al.* 2012b, Rechtine *et al.* 2007). In all these studies the investigators concluded that log rolling patients causes greater neck movement than the lift and slide method and should not be relied upon to minimise neck movement while caring for a trauma victim.

The thoracic and lumber effects of log rolling were also investigated by Del Rossi *et al.* (2008a). In this study, fresh cadavers were used with electromagnetic tracking sensors attached to T12 and L2 vertebra. The log roll, lift and slide and the 6-Plus-Person Lift were compared. This study showed that lumbar movements in a destabilised lumbar spine were close to double in the log roll than obtained with either of the other procedures (Del Rossi *et al.* 2008a).

Boissy *et al.* (2011) compared a lift-and-slide technique with the log roll for placing a patient on a spinal board, and compared a "head squeeze" versus a "trap squeeze" method of controlling the head during the log roll. The lift-and-slide techniques required five lifters to lift the patient from the ground while a sixth person slid the spinal board into position under the patient. The head squeeze involved holding either side of the head, while the trap squeeze involved grasping the shoulders, whilst trapping the head between the forearms. This study utilised inertia tracking devices (MotionPod, Movea Inc) to measure head movement in relation to the thorax, in a healthy volunteer. These studies were conducted firstly with a cooperative patient and then with a 'confused' patient who actively tried to sit up or rotate his head to the side. The investigators found that the lift and slide technique was superior with less movement than the log roll for both the grip types. When conducting a log roll, the trap squeeze proved to be more reliable and effective at limiting motion. In an agitated patient scenario, the trap squeeze was evidently significantly superior to the head squeeze. Consistent with the other studies reported here, the authors recommended the use of the lift and slide technique over the log roll (Boissy *et al.* 2011).

(ii) Spinal board

The use of the spinal board has also received some attention by researchers. Mazolewski and Manix (1994) attempted to study the effectiveness of a variety of strapping techniques at controlling lateral movement of the body whilst strapped to a spinal board. Lateral movement of the participants was measured as the spinal board was rolled sideways from horizontal to vertical by means of a wooden dowel marker strapped to the volunteer's torso. The study found that lateral movements of the participants' torso from 2 to 10cm occurred, depending on the method of strapping used. While a simple study technique, it did highlight the extent of lateral movement that that may occur with any lateral force, even with thorough strapping on a spinal board (Mazolewski & Manix 1994).

Krell et al (2006) used electromagnetic tracking to compare neck movement of healthy volunteers being placed on either a spinal board or a scoop stretcher. During the placement on the spinal board there were two identified phases; the log roll to facilitate board placement behind the patient, followed by a "Z-manoeuvre" to centre the patient on the board. Using a scoop stretcher required much less patient movement to secure the patient effectively. The patients were then tilted to 90 degrees while secured to the device and then lifted to a height of one metre. Comfort was also compared for each device after being secured for a period of 20 minutes. The spine board proved to generate much greater cervical movement, caused primarily during the log roll and Z-manoeuvre. The 90 degree tilt resulted in no difference between devices, and the one metre lift showed slight superiority of the spinal board at preventing sagittal flexion. The scoop stretcher proved to be more comfortable to the majority of participants. The authors conclude that the scoop stretcher provides at least the same level of spinal immobilisation as the spine board and does not require the deleterious log roll manoeuvre for its application (Krell *et al.* 2006).

(iii) Vehicle motion

The impact of vehicle motion on effective spinal immobilisation was the theme of a study by Perry *et al.* (1999). This study used healthy volunteers secured to a board which was subjected to lateral motion using a computer controlled moving platform. Measurements were taken using an optical motion capturing system. The head was secured to the board using rolled towels and tape, a proprietary head bed and a new system of Styrofoam wedges. This was to replicate a commonly implemented immobilisation technique used in the prehospital setting. The authors reported disparity between head and body motion which they described as substantial, with 4 to 8 degree rotational motion and similar lateral bending. The different methods of securing the head had some effect, although only small differences in angles were noted. This benefit was outweighed by the much larger relative body to head movement ratio which effectively created a fulcrum at the level of the cervical spine. The study only examined lateral vehicle motions, and did not explore the effect of longitudinal or vertical accelerations. The final conclusion was that securing of the head to a spinal board does not improve the immobility of the spine if the body cannot be similarly secured (Perry *et al.* 1999).

(iv) Vacuum mattress

The vacuum mattress appeared in the late 1990's as an alternative method of securing patients with SCI. This device used polystyrene beads in a body length bed. Once the air is extracted, the beads form a rigid splint which conforms to the shape of the body. Luscombe and Williams (2003) investigated the relative body movement between the vacuum mattress and the spinal board immobilisation. Nine healthy volunteers were secured in each of the systems, which were then placed on an operating table. The table was fitted with wired markers that provided reference points that could be marked on the volunteers in the horizontal position. The table was then tilted to 45 degrees head down, 45 degree head up and laterally to an unspecified angle, with the movement of the body measured with respect to the reference markers. This rather simple process showed that there was significantly less movement of the patient’s body when secured in the vacuum mattress compared with the same patient secured to the spinal board. Comfort was also measured using a 1to10 scale, with the spinal board causing significantly greater levels of discomfort. The investigators questioned the validity of the spinal board as the preferred method for the management for spinal injuries (Luscombe & Williams 2003).

(v) Spinal alignment

Another aspect of spinal immobilisation which has received attention was the posture that the immobilisation imposes on the patient. The cervical spine alignment achieved during spinal immobilisation of adults was the subject of a unsophisticated study by Schriger *et al.* (1991). In the study, the investigators asked 100 healthy participants to stand with their back to a wall and gaze at a distant eye level point. Shims were used to measure the distance between the wall and the participants’ occiput. A median value of 1.5 inches and a range of values from 0 to 3.75 inches were found. This data was used to conclude that some occiput padding was required for spinal immobilisation to maintain a neutral cervical spine alignment.

Similarly, the consideration of spinal alignment during spinal immobilisation of paediatric patients was the subject of a study by Nypaver and Treloar (1994). The investigators recruited children of less than eight years who presented to a paediatric emergency department. The children were asked to lay supine on a backboard and shims of padded material of various thicknesses were placed beneath the child's shoulders to achieve a neutral spinal alignment. Neutral alignment was defined as a gaze directly forward as assessed by the two investigators. They found that children under four years old required 27 mm of padding, while those between four and seven required 22 mm of padding. The relative size of the child’s head in proportion to its body was identified as the reason for additional shoulder padding required to achieve a neutral cervical spine alignment. The findings from this study were adopted in clinical practice to prevent young children from being immobilised in a head flexed position (Nypaver & Treloar 1994).

De Lorenzo *et al.* (1996) explored the concept of optimum positioning for best cervical spinal alignment of a patient secured to a backboard, using magnetic resonance imaging. Nineteen volunteers were imaged on a table which allowed the head to be moved in 2 cm increments from -4cm to +4 cm. The investigators measured the spinal canal diameter at each level of occiput support to calculate the highest spinal canal/spinal cord ratios. They argued that the higher the ratio, the better the safety for the spinal cord as it has more space available. It was found that a slight flexion provided the best ratio and concluded that 2 cm of padding beneath the occiput may be beneficial. However, they concede that this study was performed with healthy volunteers and those with spinal injuries may have differing spinal canal aspects, depending on the type of injury. As injury types cannot be readily determined in the field, there may not be a beneficial outcome to the routine use occiput padding (De Lorenzo 1996).

4.4.2 Adverse outcomes from cervical spinal immobilisation

During the last 20 years, numerous studies have reported adverse outcomes from the use of spinal immobilisation. These findings range from relatively minor effects, such as discomfort and mild spinal misalignment, to serious effects, such as raised intracranial pressure, respiratory compromise and potential cervical spine extraction injury. Tissue interface pressure and discomfort has proved to be significant issues, particularly for the patient who spends prolonged periods secured unnecessarily to a spinal board (Chan *et al.* 1994, Chan *et al.* 1996, Cordell *et al.* 1995, Main & Lovell 1996).

Claims that spinal immobilisation was ineffective and could lead to adverse outcomes were first raised by Hauswald *et al.* (1998) in a comparison between Malaysia, where no spinal immobilisation was practiced and New Mexico which had a rigorous spinal immobilisation protocol. Surprisingly, the Malaysian patient outcomes were slightly better than the outcomes in New Mexico in terms of spinal cord injury. While this study has a number of confounders, such as completely differing societies and health systems, it did arouse debate about spinal immobilisation.

Hauswald (2013) continued to argue against the accepted use of spinal immobilisation by suggesting that the extreme force required to cause a spinal column injury is patently greater than the forces imposed during normal patient care. The author reasoned that spinal immobilisation would provide no difference when compared with no spinal immobilisation, as neither method would impose any significant force upon the neck. However, the article presented no experimental data to support the claims and was based on a theoretical analysis of the physics involved in an accident and subsequent care. An omission in the study is the consideration of vertebral instability, and how a highly unstable spinal column injury would respond if subjected to minimal forces (Hauswald *et al.* 1998).

(i) respiratory compromise

Respiratory compromise has been identified as a potential adverse effect of spinal immobilisation. Strapping applied around the chest to effectively limit body movement needs to be tightened to the point where it could limit chest expansion, thus limiting tidal volumes. Schafermeyer *et al.* (1991) examined the issue in children using forced vital capacity (FVC) measurements. In this study 51 healthy children between 6 and 15 years of age were strapped to spinal boards. There was a statistically significant 20% reduction in FVC with spinal immobilisation compared with no spinal immobilisation. The investigators identified this as a clinically significant outcome, particularly in the case of the child with significant chest injury or where reduced gas exchange could impact on the patient (Schafermeyer *et al.* 1991).

Totten and Sugarman (1999) extended the theme of respiratory compromise due to spinal immobilisation in children and adults. The study compared spirometer results of 39 participants secured to a vacuum mattress, a spinal board and an unrestrained participant, lying supine, as a control. The authors concluded that both spinal boards and vacuum mattresses cause a respiratory restriction of an average 17%, which they suggested was clinically significant in the compromised trauma victim.

(ii) Discomfort

Chan *et al.* (1994) examined the issue of discomfort caused by immobilisation on a spinal board. In their study 21 participants were immobilised with spinal board, cervical collar, sandbags and tape for a period of 30 minutes. The participants were asked to grade any pain experienced, identify the site of pain and repeat the grading again at 48 hours. Not surprisingly, the study found that occipital and sacral pain was experienced by most participants, with many reporting moderate to severe pain. Interestingly, 29% of participants reported persistent pain after 48 hours. The investigators recommended further study of padding to reduce symptoms and alteration of clinical practice to limit time spent secured to a spinal board (Chan *et al.* 1994).

In a subsequent study, Chan *et al.* (1996) compared the newly developed vacuum mattress device with the conventional spinal board immobilisation. The investigators asked the 37 participants to rate their pain on a 1-3 scale and indicate the location of pain after a period secured to either of the devices. A fortnight later the experiments were repeated with the other device. It was found that participants were 3.08 times more likely to complain of pain on the spinal board than the vacuum mattress, and the sites of pain were mostly the occiput and the sacrum. The severity of the pain was significantly higher on the spinal board (Chan *et al.* 1996).

(iii) Tissue interface pressure

In a study to provide more quantitative data about the adverse tissue interface pressure and the risk of developing pressure sores, caused by spinal immobilisation, Cordell *et al.* (1995) used a skin pressure evaluator to measure interface pressures at the occiput, sacrum and heels of the participants. The participants were secured to a spinal board for a period of 80 minutes, with and without an interposing air mattress. Levels of pain during the immobilisation period were also recorded. Both pain and tissue interface pressures were significantly less with the air mattress compared with the no-mattress tests. The investigators argued that tissue interface pressures exceed perfusion pressures by as much as five fold, exposing the patient to a high risk of developing pressure sores. They recommend the use of an air mattress between the spinal board and the patient (Cordell *et al.* 1995).

Main and Lovell (1996) extended the tissue interface pressure study in an evaluation of seven different surfaces, including spinal boards, vacuum mattresses, army styles stretchers and conventional stretchers. Four healthy participants were secured to the seven surfaces with pressure sensors strapped to the skin. Sacral and thoracic kyphosis readings were recorded during an unspecified period of time. The resulting pressures were identified as dangerously high on the spinal boards and likely to cause necrotic tissue damage, whereas the pressures caused by the vacuum mattress were at a safer level. The use of vacuum mattresses or a combination of vacuum mattress and spinal board was recommended (Main & Lovell 1996).

(iv) Neurological impact

Cervical collars have been implicated in causing adverse effects, including increasing intracranial pressure (ICP) and physically causing distraction injuries in highly unstable cervical vertebra injuries. Davies *et al.* (1996) recruited 19 trauma victims who required intracranial pressure monitoring following trauma. Their data showed a statistically significant rise in intracranial pressure, above the normal range of 7 -15

(Steiner. 2006), of 4.5 mmHg when cervical collars were used, compared with no collar, which was deemed to be hazardous. No significant change in arterial pressure was noted, which suggested that the raised ICP was due to impaired venous drainage through the jugular veins. The investigators expressed concern about the use of cervical collars in the patients at risk of raised ICP in both the prehospital and intensive care settings (Davies *et al.* 1996).

Ben-Galim *et al.* (2010) also examined the potential hazards of cervical collar use in a cadaver based study. Nine fresh cadavers with surgically created C1/C2 instability had radiological studies before and after application of a cervical collar. The cervical collar was showed to produce an abnormal separation of the vertebrae at the level of the injury. The authors concluded that the separation was likely to cause secondary neurological injury in the trauma victim, with the majority of similar injuries in the clinical setting found to be fatal (Ben-Galim *et al.* 2010).

(v) Summary

In a review of the evidence regarding the use of cervical collars Sundstrom *et al.* (2013) conclude that cervical collars are more harmful than beneficial and recommended that they should be abandoned in the prehospital setting.

Overall, studies into the adverse effects of spinal immobilisation have demonstrated that the methods are not without risk and should be more thoroughly evaluated. This is particularly so when spinal immobilisation is combined with common patient handling manoeuvres, such as the log roll. While there are a range of significant risks inherent with current practices, further evidence is required to validate best practices and provide viable alternatives suitable for the prehospital environment.

4.5 Biomechanical approaches to measuring joint movement

Motion capture technology has used a range of instruments in cervical range of motion studies. Electromagnetic tracking systems (EMT), such as the 'Flock of Birds' system by Ascension Technology Corporation have been used for motion tracking. This system required a transmitter source to emit an electromagnetic field as a reference, through which the movement of sensors could be tracked. Koerhuis *et al.* (2003) used the system to track neck movement on ten participants as a proof of concept study. They reported an accuracy of ± 2.5 degrees on a 'test dummy' and suggested that it could be used with human studies if properly calibrated. However, there are significant limitations to the system, including the cumbersome instrumentation, interference created by magnetic materials and lack of portability. Although accuracy of measurements on a human was reasonably accurate, the reproducibility between sessions was variable due to the complexity of calibration (Koerhuis *et al.* 2003).

Another method of motion capture is the inertia measurement unit (IMU) system. This system utilises three gyroscopes and three accelerometers positioned orthogonally to measure angular velocity and acceleration. Integration of angular velocity provides information about changes in sensor orientation, and when combined with acceleration data, a calculation of real orientation per a global coordinate system may be produced (Roetenberg et al 2013). However, the integration of gyroscope data will produce a drift over time affecting the sensor accuracy. This drift may be corrected with Kalman filter which fuses the data from gyroscopes and accelerometers to estimate a true heading. The addition of orthogonally positioned magnetometers enhances the IMU reporting by providing a global coordinate system aligned with the earth magnetic field (Brunetti *et al.* 2006). In an evaluation of IMU for ambulatory motion Luinge and Veltink (2005) were able to validate the system and the Kalman filter to an accuracy suitable for ambulatory motion recording. In an analysis of sensor error, orientation errors were found to result from the angular velocity which caused an increase in sensor noise (Pasciuto *et al.* 2015). The suitability of IMU systems should take into account the type of motion they are required to measure. In human movement studies, this issue probably is less important unless the movement is very rapid.

Jasiewicz *et al.* (2007) used a comparison between an IMU system and an EMTS to validate the accuracy of IMU's for the measurement of CROM. They were able to demonstrate a very high correlation between the systems with a root mean square error ranging from 0.7 to 2.5°. The lack of linear translation data was noted as a limitation, but concluded that the IMU system was sufficiently accurate and feasible for cervical motion studies. They note that the IMU system reports primarily Euler angles and acceleration, which provide good orientation accuracy, but linear translation must be estimated by double integration of the acceleration data. This data manipulation fails to provide the same level of accuracy in linear translation that may be achieved from an EMT system (Jasiewicz *et al.* 2007).

In a similar study Saber-Sheikh *et al.* (2010) compared an IMU system with an EMTS for the analysis of hip joint motion. A comparison of the two systems again showed a very high correlation with a mean difference of 0.05° (SD 0.77°) when measuring hip movement of approximately 45°.The relative low cost of the IMU system and it ease of use outside the traditional laboratory, was identified as a distinct advantage (Saber-Sheikh *et al.* 2010a).

Lee *et al.* (2003) investigated lumbar motion of healthy volunteers using IMU sensors placed over the sacrum and L1. The accuracy of the system was also tested on a joint simulator which could be moved to known angles. They were able to record movements of the lumbar spine consistent with a reported mean error of 0.81 ± 0.14°. The investigators noted the loss of accuracy when the sensor orientation approach gimbal lock, but concluded that this orientation may be avoided in most biomechanical application.

Theobald *et al.* (2012) attempted a validation of an IMU system for use in cervical movement study. Joint angle was defined by the relative in orientation of a head and torso mounted sensor. This study used a number of variations of sensor mounting locations to investigate reliability of respective positions. Reliability and accuracy were determined by the consistency of results from subsequent trials, but did not use other instruments to assist in validation of results. An area of identified error was the method of attachment of the devices to the subject’s skin. In particular, the sternal position for sensor mounting caused less reliable results, presumable due to the difficulty in attaching to a concave area.

Yoon *et al.* (2015) also used a simple relative orientation of IMU's to determine the joint angle of the lumbar spine. This this study the sensors were directly affixed to the subject's skin using adhesive gel pads. The investigators note the limitation of a lack of linear positional data, but suggest that the orientation data is sufficient for the determination of lumbar spine range of motion.

The accuracy of IMU systems when compared with optical motion capture technology has been the subject of some investigation. Goodvin et al. (2006) proposed a three sensor IMU system, mounted on the head, at the level of T1 and L4 to model the spine into three flexible segments, each with a designated local coordinate system. The accuracy of the sensor data was compared to an optoelectronic system. Once differences in global coordinate systems were controlled, the concordance between the systems was very high; with mean differences of 0.1°, 0.42° and 0.2° for roll, pitch and yaw respectively. The spine model, however, was relatively unsophisticated and probably not effective as a model of the complex movement of the spine.

In studies aimed at investigating whole of arm movements, multiple IMU sensors were used in combination with an optoelectronic system to detect movements of the arm, shoulders and head (Gil-Agudo et al. 2013, Perez et al. 2010). Both these studies analysed motion across multiple joints, so complex kinematic modelling was necessary. Good concordance of data was reported in both studies with correlation coefficients of 0.95 to 0.99. Greatest differences between systems in the study by Gil-Agudo et al. (2013) was found in head lateral bending; 8.24°, but all other measures were not statistically different. The errors were attributed to soft tissue artefact due to mounting of IMU sensors and differing placement of IMU sensors and the optical markers. In a rather different application of motion capture technology, Skogstad et al. (2011) compared the low-cost Optitrack optoelectronic system with the Xsens IMU system in an analysis of concordance during rapid body motions during dance. In a detailed analysis of sources of error for both systems, the investigators identified sensor drift in the IMU system and spatial resolution of markers by the optoelectronic system as significant. Poor attachment of the marker and sensors also cause “jittery” noise in the recorded data. The study concluded that the Optitrack system was superior for positional precisions, while the Xsens system provided less noise and did not suffer from marker occlusion.

Inertia measuring systems also produce high accuracy motion capture data, but only in three degrees of freedom (Goodvin et al. 2006). They report sensor orientation in yaw, pitch and roll relative to the gravitational and magnetic field of the Earth. They may be affected by close proximity to ferrous material, which distorts the Earth’s magnetic field, but this is not as critical as the electromagnetic tracking distortion. It is possible to compensate for field disturbances with the IMU system.

In the study of joint motion, the IMU system has been shown to have the capacity to provide the accuracy necessary for the joint angles to be determined in terms of Euler angles. While the cervical spine is capable of a significant and complex range of movements, which exceed the Euler angles reported by IMU's, the system does have the ability to report gross head angulations relative to the torso. It is these angular motions which are of interest to the present study. Limitations of skin shear movements and the influence of nearby ferrous material can be managed with careful attention to these issues. Consequently, the validation of an IMU system to study the comparative head versus torso movement is deemed to be justify.

4.6 Summary of the evidence

Key findings from studies and review papers over the last thirty years, suggest that spinal cord injury investigations in the prehospital setting have been difficult to achieve and have not produced high quality evidence. Evidence supporting current practice stems mostly from expert opinion and experiments conducted with healthy volunteers or cadavers. How these studies represent the range of neck movement or risk of secondary spinal cord injury in the real trauma victim in the prehospital setting remains speculative.

The incidence of spinal column injury in trauma victims is reasonably well established, but the cause of secondary spinal cord injury is much less well explained. While secondary neurological damage due to a range of inflammatory processes have been proposed, the incidence of secondary damage due to excessive neck movement is not well established. Some incidents of damage due to neck manipulation have been identified in the hospital setting, but not in the out-of-hospital setting. Early publications suggested an incidence of as much as 25%, but the real incidence probably is less than 6% (Farmer *et al.* 1998, Harrop *et al.* 2001, Marshall *et al.* 1987b, Oto *et al.* 2015) .

Neurological damage from spinal trauma may occur at any level, but is most common at the level of C5 to C7. Axial compression and flexion compression injuries may be extremely unstable, particularly in the case of ankylosing spondylitis, flexion tear drop fracture and facet dislocations. The extent of disruption to the disco-ligamentous complex and the direction and strength of the applied force appear to be the key factors in predicting neurological damage. The key issue for the paramedic is inability to determine the type of injury and its stability in the field (Domeier *et al.* 1997). Therefore the paramedic is obliged to treat all suspected spinal column injuries as unstable, with a potential for worsening neurological damage through secondary spinal cord damage. Unfortunately, the common spinal immobilisation techniques currently in practice are not well validated and there is also some clear indication that they may cause harm. Consequently, there is a strong case to examine current practices to determine if they are both effective and safe. One such practice is the log roll manoeuvre, which is frequently used to move a trauma patient from the accident scene to the hospital emergency department and beyond. Evidence from motion capture studies has shown this manoeuvre to cause significant misalignment to the cervical spine. Further research is needed, however, to clarify the effects and safety of the log roll and other commonly used spinal care procedures to provide much needed evidence regarding this important area of trauma care in the prehospital context.

4.7 Identified evidence gaps and the aims of this study

As reviewed here, spinal immobilisation is based on limited evidence and is overall poorly evaluated. It is practiced on the negative principle that a lack of spinal immobilisation may promote secondary neurological damage. However, there is no definitive evidence to either support or discourage the use of spinal immobilisation in the out-of-hospital setting. In part, this is due to significant limitations in the way acute spinal care can be studied in the clinical setting. As yet, randomised control trials appear to be beyond the scope of ethical research due to the apprehension of promoting harm by the research. Consequently, the problem has to be approached without involving trauma victims, which dictates the use of healthy volunteers or cadavers. These studies have generally lacked statistical power due to low participant numbers, or reported findings that could not easily be translated into the clinical setting. Moreover, the accurate measurement of neck movement has been limited until the recent development of motion capture technology. This technology has now opened the way for kinesiological studies of movement of the neck, and should allow more detailed evaluation of spinal immobilisation techniques. As motion capture technology has not previously been used in the evaluation of spinal care methods, this thesis will report the outcomes of a study designed to validate the system so that it may subsequently be used in larger scale studies.

This study used healthy volunteers as patients, and measured neck movement during a log roll manoeuvre. The study compared the range of cervical movement across three axes between two log roll techniques and across the experience of the operators. By validating a method to measure techniques that minimise adverse neck movements, this study aims to advance the key goal of prehospital spinal immobilisation, which is the maintenance of cervical alignment without aberrant neck movements whilst stabilising and transporting the injured patient to definitive care.

5 METHODOLOGY

5.1 Introduction

This research project utilised innovative motion tracking technology in a biomechanical study of the cervical spine. The purpose of the study was to validate a methodology of measuring cervical spine movement which could be applied further in the analysis of the effectiveness of spinal immobilisation techniques. Spinal care research in the prehospital setting has been criticised for not producing enough high quality randomised controlled trials (Kwan *et al.* 2001). In many situations, ethical issues would prevent performing a randomised controlled trial, where a group of patients did not receive spinal immobilisation. Consequently, it is necessary for the researcher to focus on biomechanical research within the laboratory with healthy volunteers, animal models or cadavers. This project used healthy volunteers as a first step in the generation of useful evidence.

The log roll was selected as a relevant test case for the study. The practice of log rolling is recommended for the movement of trauma patients (Spinal Cord Medicine 2008) and is in routine use throughout the prehospital and hospital setting for the management of patients with suspected SCI. However, the practice of log rolling has never been thoroughly tested and its acceptance is based on negligible evidence. The safety of the log roll has been challenged, using evidence from biomechanical studies on cadavers with unstable spines (Conrad *et al.* 2012, Del Rossi *et al.* 2004a, Prasarn *et al.* 2012b). Given the debate regarding the log roll, it is a useful procedure to form the basis of this study.

5.2 Study design

The study is a laboratory based, comparative motion tracking study, conducted solely within the campus of Flinders University. It was designed as a pilot study to investigate the feasibility of using an IMU system as means of comparing modes of spinal immobilisation. Comparisons are made between two techniques of performing the log roll; head hold and head-shoulder hold, and between experienced and novice participants.

All trials were performed during the first half of 2010, in laboratories based in the Bedford Park campus of Flinders University. Participant information statements were drafted and received ethics approval in 2007, but the research was delayed due to competing commitments for the researcher. Ethics applications were renewed and the research was recommenced in 2010.

5.3 Participants

A sample of thirty six volunteer participants was recruited from both undergraduate students within health disciplines at Flinders University and from practicing paramedics within SA Ambulance Service. These participants formed the groups who performed the log roll trials. A healthy volunteer was also recruited to act as the patient for all the trials. Initial planning specified two volunteer patients, but this was reduced to one patient to remove the ‘patient factor’ from the study, which was deemed to be beyond the scope of this initial study. Participants were recruited through advertisements targeted at paramedics and student paramedics, which were placed on the notice board of the office of the Paramedic Unit at Flinders University and the workplaces of the SA Ambulance Service. Advertisements were also posted electronically on web pages and by email to eligible students and paramedics. A copy of the advertisement can be found in appendix C.

5.3.1 Inclusion criteria

Paramedics or student paramedics who have previously been trained in safe and effective methods of log rolls.

5.3.2 Exclusion Criteria

Participants were excluded if they had:-

- known shoulder, neck or back injury or has reported back, neck, shoulder or arm pain during the preceding two weeks
- not received prior training in the log-roll spinal immobilisation technique.

The patient participant was required to have no recent musculoskeletal injuries or pain and no allergies to adhesive tape, due to the need for affixing sensors to the skin.

5.3.3 Withdrawal Criteria

All participants were free to withdraw from participation at any time, at their own discretion, without prejudice. In addition, any participant who demonstrated any adverse effects from the participation would have been requested to withdraw. As adverse effects such as neck, shoulder or back pain are exclusion criteria, participants who demonstrate these effects would have been excluded from re-entering the study. No participants elected to withdraw or were asked to withdraw.

5.4 Instruments

The inertial measuring unit (IMU) used was the Wireless InertiaCube3 produced by Intersense Inc. (Bedford, Massachusetts, USA). The IMU uses an integrated solid state arrangement of gyroscopes, accelerometers and magnetometers aligned in three perpendicular axes. This arrangement allows the sensor to report angular orientation, angular rate of rotation and linear acceleration in each axis (see figure 5-1).

Figure 5-1 Wireless Inertia Cube 3

The Inertia Cube 3 sensor is constructed with gyroscopes, accelerometers and magnetometers aligned in three perpendicular axes. It is a solid state device that is precision manufactured to ensure correct orientation of all elements. Gyroscopes use the principle of a coriolis force distorting the alignment of a vibrating part due to the angular rate in that axis. This distortion may be detected to report the angular rate. Accelerometers detect movement along a single axis. Magnetometers primarily use the magnetic field of the earth to provide an orientation which is used to correct drift in the gyroscopes output. A Kalman filter is employed to use the accelerometer and magnetometer data to correct for orientation error. Angular orientation is reported as degrees in Yaw (Z axis), Pitch (Y axis) and Roll

(X axis). Contextualised to head movement in this project, yaw represents lateral flexion, pitch represents flexion-extension and roll represents rotation. (InterSense 2012).

The IMU system used in this study consisted of two Inertia Cube 3 sensors and a wireless receiver for connection with a computer. The sensors were each powered by a 9 volt lithium ion battery. It was found that a lithium ion 9 VDC battery was necessary to provide adequate and sustained power for a single day of testing. Each sensor measured approximately 31 x 43 x 15 mm and weighed only 30 grams, or 70 grams with the battery. The size and weight ensured that they did not impede movement during a log roll procedure and could be secured relatively easily to ensure negligible artefact movement. The wireless assembly facilitated free movement of the subject without risk of dislodging leads and cables, provided that the battery was also firmly secured. A working range of 30 metres from the receiver was reported by the manufacturer. As the IMU contain magnetometers to detect heading reference it is recommended that they are not mounted close to large magnetic sources or ferrite materials such as steel. Such sources distort the natural magnetic field causing errors in data and can cause the system to fail completely (InterSense 2012). Early experimentation using simulation manikins was unsuccessful due to system failure caused by the manikin circuitry.

5.4.1 Software

The IMU system was supplied with a software package which included the applications; *Isdemo32.exe*, *IServer.exe*, *DeviceTool2.exe*, and USB Drivers. Other optional software that was not used for this research project included The Joystick Emulation drivers, JMouse and the Intersense SDK (software development kit). Software could be obtained from the Intersense website[1] where the most recent copy of the installation package (ProductCD InertiaCube 2010) was available. User manuals and associated documents were also included in the installation package (InterSense 2012).

The program supplied by Intersense to display the movement of the trackers is IsDemo. The most current version available and used for this study was version 4.1715. To see both trackers the IsDemo program needed to be opened twice so that each tracker had its own window. This was facilitated by opening the program and selecting the first sensor (serial number: 5212) from the list of the trackers. The program was again opened and the second sensor (serial number: 6586) selected. The window for each tracking device could be identified by moving each tracker independently and observing the matching movement on the screen. IsDemo displays a graphical representation of the three perpendicular axes; yaw, pitch and roll in degrees (figure 5-2).

[1] http://www.intersense.com/uploads/archive/InterSense_SDK_4.2110.zip

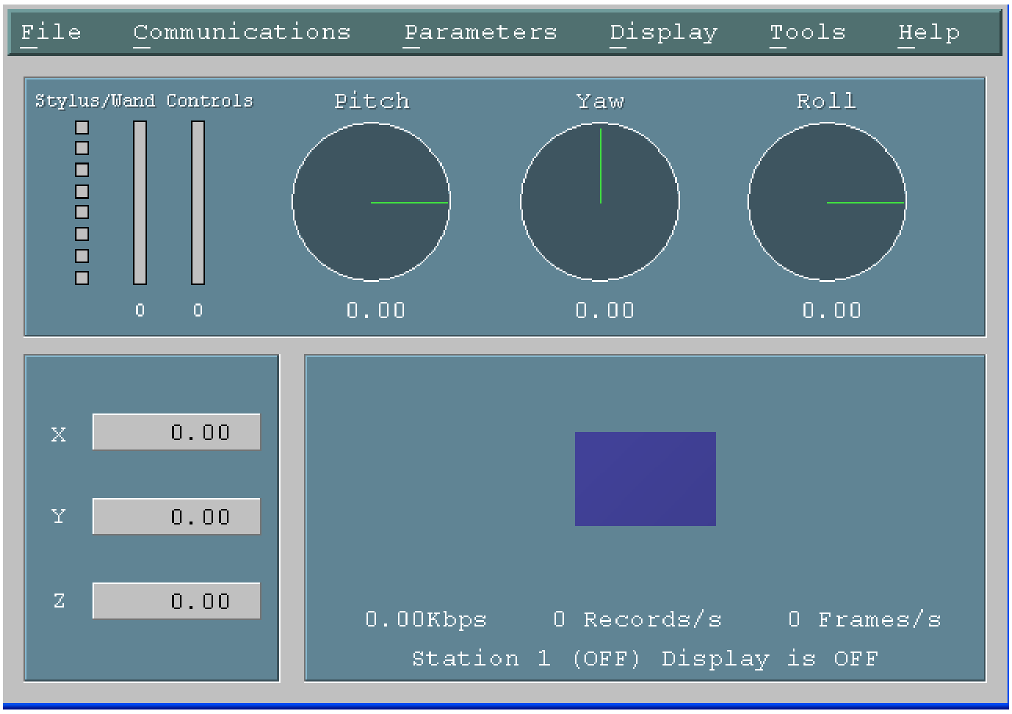

Figure 5-2 IsDemo Graphical interface

IsDemo software provided a functional capacity to connect and operate the sensors. Sensor orientation may be displayed in real time with a digital presentation in degree and a graphical representation of angles. The blue cube in the low centre of the scene depicts the actual orientation of the sensor. Sensor position could be zeroed in any position using the bore sight tool. IsDemo also had the capacity of recording data, but was limited by the inability to record data from multiple sensors simultaneously.

An additional application was obtained through personal communication with the technical support personnel of Intersense (D'Antuono M 2008). This program, IsPlot 1.004 allowed the graphical presentation and logging of the data (figure 5-3), but was limited to presenting data from only one sensor at a time and proved to be convoluted in operation. Due to this complexity of operation, some tests were lost due to failure to properly cleardata from the logs prior to the subsequent test. The data was recorded in ascii flat file format, which may be imported to applications such as Microsoft Excel (see figure 5-1).

Figure 5-3 IsPlot 1.004 graphical user interface

The IsPlot program used to log data directly from the IMU sensors using a shared isens.dll application extension in common with the Isdemo32.exe and Iserver.exe. This program simultaneously logged data from two sensors, but graphically presented from a single sensor. It was important to save individual logs from both sensors by selecting the log using the "select current" command, selecting the appropriate sensor and then "save current" command using an identifiable file name. It was also important to clear both logs prior to recording the next test to prevent the data adding to the previous test.

Linear movement			Orientation				Data Quality		Angular rate			Linear acceleration			
X	Y	Z	Yaw	Pitch	Roll	Timestamp	Tracking	Communication	Yaw	Pitch	Roll	X	Y	Z	Compass heading
cm	cm	cm	Degrees	Degrees	Degrees	Millisecond	quality (%)	Integrity (%)	Deg/sec	Deg/sec	Deg/sec	m/s/s	m/s/s	m/s/s	Degrees
0	0	0	76.029	13.758	2.137	3474851.074	100	100	1.47	-0.47	0.22	-2.65	0.506	-9.732	165.35
0	0	0	76.029	13.758	2.137	3474857.422	100	100	-0.34	-0.46	1.37	-2.63	0.563	-9.674	165.38
0	0	0	76.029	13.758	2.137	3474864.258	100	100	-0.34	-0.45	-0.38	-2.63	0.505	-9.694	165.61
0	0	0	76.029	13.758	2.137	3474876.465	100	100	-0.35	-1.07	-0.38	-2.61	0.562	-9.617	165.66
0	0	0	76.029	13.758	2.137	3474882.813	100	100	0.26	-0.46	1.37	-2.571	0.504	-9.617	165.64
0	0	0	76.029	13.758	2.137	3474889.648	100	100	0.86	-1.71	3.12	-2.63	0.466	-9.656	165.53
0	0	0	76.029	13.758	2.137	3474901.611	100	100	0.26	-0.46	3.71	-2.512	0.445	-9.599	165.51
0	0	0	76.029	13.758	2.137	3474907.959	100	100	1.47	0.77	4.31	-2.571	0.407	-9.599	165.54
0	0	0	76.029	13.758	2.137	3474914.795	100	100	0.26	0.78	2.55	-2.571	0.407	-9.599	165.54
0	0	0	76.029	13.758	2.137	3474926.758	100	100	3.27	-2.34	3.13	-2.571	0.292	-9.639	165.51
0	0	0	76.029	13.758	2.132	3474933.105	100	100	0.25	-1.7	1.95	-2.61	0.369	-9.619	165.42
0	0	0	76.029	13.758	2.123	3474939.941	100	100	-0.35	-2.31	0.77	-2.61	0.389	-9.676	165.51
0	0	0	76.029	13.758	2.106	3474951.904	100	100	-0.95	-1.07	-0.39	-2.63	0.331	-9.715	165.54
0	0	0	76.029	13.758	2.097	3474958.496	100	100	3.27	-1.72	3.14	-2.669	0.312	-9.696	165.72
0	0	0	76.03	13.758	2.086	3474965.088	100	100	0.87	0.78	1.39	-2.727	0.254	-9.583	165.73
0	0	0	76.03	13.758	2.066	3474977.295	100	100	0.86	-0.46	1.38	-2.649	0.293	-9.677	165.83
0	0	0	76.031	13.758	2.055	3474983.643	100	100	1.47	0.15	0.22	-2.591	0.331	-9.734	165.98
0	0	0	76.031	13.758	2.044	3474990.479	100	100	0.86	0.16	0.8	-2.63	0.177	-9.717	165.85
0	0	0	76.031	13.757	2.023	3475002.441	100	100	2.08	2.63	0.83	-2.571	0.273	-9.677	165.88
0	0	0	76.032	13.757	2.012	3475008.789	100	100	2.07	0.15	0.23	-2.532	0.292	-9.658	165.86
0	0	0	76.032	13.757	2	3475015.625	100	100	0.27	1.4	-0.94	-2.571	0.312	-9.734	165.72
0	0	0	76.032	13.757	1.982	3475027.588	100	100	1.47	-0.47	-0.95	-2.571	0.428	-9.733	165.74
0	0	0	76.032	13.757	1.978	3475033.936	100	100	-0.34	0.78	1.38	-2.552	0.369	-9.695	165.82
0	0	0	76.032	13.757	1.978	3475040.771	100	100	-0.35	-2.31	0.19	-2.532	0.369	-9.676	165.88
0	0	0	76.032	13.757	1.978	3475052.979	100	100	0.26	0.78	-0.36	-2.551	0.331	-9.677	165.9
0	0	0	76.032	13.757	1.978	3475059.326	100	100	0.26	0.16	-0.37	-2.473	0.426	-9.599	165.88
0	0	0	76.032	13.757	1.978	3475066.162	100	100	2.08	1.39	0.24	-2.512	0.291	-9.601	165.95
0	0	0	76.032	13.757	1.978	3475078.125	100	100	0.86	-1.08	-1.54	-2.59	0.311	-9.601	165.93
0	0	0	76.032	13.757	1.978	3475084.473	100	100	3.89	2.62	0.84	-2.649	0.33	-9.6	165.84
0	0	0	76.032	13.757	1.978	3475091.309	100	100	2.07	-1.09	-0.36	-2.61	0.33	-9.6	165.74
0	0	0	76.032	13.757	1.978	3475103.271	100	100	2.07	-0.47	-1.53	-2.493	0.388	-9.657	165.8
0	0	0	76.032	13.757	1.978	3475109.863	100	100	1.46	-1.08	-0.95	-2.591	0.37	-9.734	165.77
0	0	0	76.032	13.757	1.978	3475116.455	100	100	0.87	0.16	-1.53	-2.708	0.448	-9.676	165.83
0	0	0	76.041	13.757	1.98	3475128.662	100	100	3.28	-0.48	-1.52	-2.786	0.525	-9.656	165.9
0	0	0	76.05	13.757	1.982	3475135.01	100	100	2.67	-1.09	0.22	-2.806	0.506	-9.675	165.95
0	0	0	76.055	13.756	1.984	3475141.846	100	100	-0.94	2.03	-1.53	-2.669	0.563	-9.636	166.11

Figure 5-4 Data output file from IsPlot

IsPlot exports data in an ascii flat file format which may be viewed as a basic text file. There are 16 columns of data reporting linear displacement (3 axes), angular orientation (3 axes), data quality, *angular rate (3 axes), linear acceleration (3 axes) and compass heading. For the purpose of this study, only the angular orientation data (highlighted) was utilised. Yaw represents lateral head flexion, pitch represents flexion-extension and roll represents head rotation. Each sensor generated a single text file for each test.*

5.4.2 Operation of the IMU system

5.4.2.1 Software issues

It was found necessary to ensure that the latest drivers were installed and any old drivers were removed from the system. Drivers were installed from the installation package, by searching for the receiver through the device manager in the control panel of Windows. The USB controlled receiver, in particular, needed careful attention to its drivers. The process to operate the trackers involves starting IServer and IsDemo programs. However, an error message of "failed to load isense.dll" would appear on opening IsDemo. The technical support did offer a recently released dynamic link library (isense.dll), to try to correct the problem but this did not seem to address the problem. The isense.dll file needed to be shared by both the Iserver program and ISDemo program but the computer would only allow one program to access the file at a time. It was found that it was necessary to exit both programs and open each one as an administrator for both programs to work. The research computer was running on Microsoft Windows Vista as an operating system, and different outcomes could be expected with different version of Windows or different operating systems.

5.4.2.2 Interference

The Intersense *'IntersiaCube3'* system utilises a wireless communication technology in the 2.4GHz spectrum, with 16 available channels (InterSense 2012). Higher levels of background emissions, from devices such as Bluetooth transmitters, microwave ovens, cordless phones, mobile phones and wireless routers can impede the wireless connection between the sensors and the receiver (InterSense 2012). An environment which has minimal interference was most suitable for the testing, but such an environment may be difficult to find in a modern building. These difficulties were overcome by conducting the tests in a large shed which was slightly remote from the campus buildings. Participants were asked to turn off mobile devices. The background levels of wireless interference could be assessed using the RF Scope facility in the IsDemo program (figure 5-5). This application detects the level of interference across the 16 channels utilised by the system. The channel displaying the least inferences may be selected using the “wireless configuration” menu within the program.

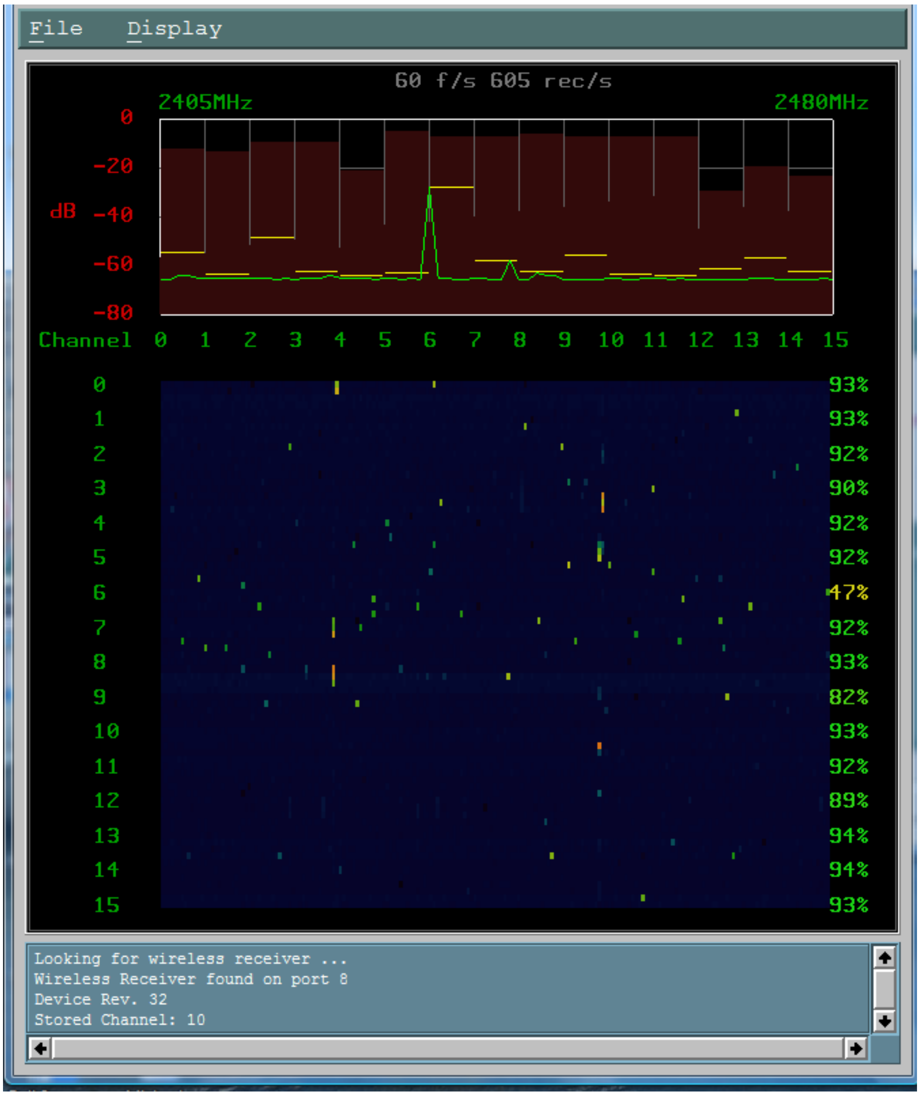

Figure 5-5 RF scope graphical presentation

The RF scope can detect interference that can prevent receivers from connecting with the trackers. This image is a screen shot of the RF Scope results obtained after running for approximately three minutes. The top graph displays the maximum levels recorded. As a peak is reached the yellow line marks the peak and then returns to the baseline depicted by the green line. The Blue panel again show the continuous background levels and which channels are clearer of interference. The test environment showed little continuous interference but did indicate that some channels were best avoided (for example channel six). When attempting to run this feature it is necessary to shutdown IServer as it interferes with this feature.

5.4.2.3 *Connection to sensors*

Initialising a wireless link to the sensors proved to be problematic, necessitating frequent communications with technical support officers. While the exact nature of the problems was never completely resolved, it was suggested that the main issues related to versions of device drivers and the dynamic link library (isense.dll), operation of the software as administrator and signal interference. The latter problem proved to be the most troublesome, but was eventually resolved by shielding the sensors and receiver during the start-up procedure. The advice from Intersense technical support suggested using either a Mylar bag or a “mostly enclosed metal box”. The metal box option was used, and this did achieve successful connection. Once connected, the sensors and receiver were removed from the metal box and could be operated normally. It is important to then remove the metal from the sensors by at least one metre to prevent magnetic field distortion.

Once the above issues were addressed, the system could be successfully operated and data recorded. Due to the moderately complex process needed to operate the system, a start-up and operating procedure was developed (appendix F).

5.4.3 Testing for accuracy

Prior to testing for accuracy it was necessary to consider the filtering algorithms used to manage the data. The IMU system incorporated filtering algorithms to compensate for drift and ‘jittering’ and there was a capacity to manipulate the level of filtering for differing purposes. Mode 0 is the default setting which provides the greatest accuracy, but allows greater noise (or jittering). Mode 1 applies a filtering algorithm to eliminate excessive noise, but may reduce accuracy slightly (InterSense 2012). Mode 0 was used throughout the current study as noise did not prove to be problematic.

The reported accuracy of the IMU is 1.0 degree in yaw, 0.25 in both pitch and roll at 25 degrees centigrade (InterSense 2012). This accuracy was tested in the laboratory by moving the sensor to an accurately measured angle 45° in each axis. Nine trials were performed for each axis, moving the sensor from horizontal to 45°.

In order to test precision, a simple board with both sensors affixed was used to track correlation between sensors in the rotation axis as the board was slowly moved from a horizontal to vertical plane. Two sensors were placed on a flat board to track movement simultaneously, to compare the precision of angles reported by the devices. The sensors and batteries were attached to the board using tape. Results from this testing are presented in 6.1 below.

5.5 Log Roll Procedure

The study utilised teams of participants to perform a log roll on a healthy volunteer 'patient'. The same patient was used for all log roll trials. Clinician participants were either novices, recruited from undergraduate paramedic students, or experienced, recruited from qualified paramedics. Participants were arranged into teams of three, with each member of the team rotating through the role of lead clinician. Teams were randomly formed, with no specific groupings of novice and experienced participants. While the log rolls were performed in teams, the performance for each log roll was attributed to the individual at the head of the patient who directed the log rolls; the lead clinician. The lead clinicaian performed six log rolls, three with the head hold technique and three with the shoulder hold technique (figure 5-6). The order in which the two techniques were performed was randomly selected to prevent any chance of fatigue or lapses of concentration being more prominent in either technique. Each log roll was recorded using the IMU under the direction of the technician operating the instruments. A brief rest period was permitted while the technician saved the data and the instruments were reset. After the six log rolls were performed, the role of lead clinician was swapped and the process repeated. Twenty minutes was generally sufficient to record the eighteen log rolls for one team.

As timing is considered vital in the execution of the log roll to ensure that the team works in unison, participants were asked to count to three with the roll commencing on the count of three. The patient was rolled from the supine position to the lateral position, held for one or two seconds and after another count of three, returned to the supine position.

a) Head hold   b) Shoulder hold

Figure 5-6: Log roll techniques

a) Head hold – supporting the head with hands grasping the patient's head gently on either side, third and fourth fingers providing support below the lateral aspects of the occipital area and thumbs supporting the temporal area. During the log roll the lead clinician guides and supports the head to maintain close to neutral alignment, with minimal flexion, lateral extension or rotation.

b) Shoulder hold – in this technique the shoulders were grasped with a supinated grip, with the operator's thumbs on the anterior shoulder and the fingers posterior adjacent the scapula. The head was effectively grasped between the operator's forearms during the entire log roll.

Note the harnesses used to secure the IMU sensors and battery for the head and thorax. The neoprene harnesses were secured with velcro strapping , which was,from visual inspection, effectivepreventing movement of the sensor in relation to the the anatomy of the patient.

It is acknowledged that a potential for artefact may be produced by slippage of the IMU sensors in relationship to the anatomical position on the body. This artefact would result in inaccurate reporting of skeletal position and joint movements. While it is difficult to eliminate this artefact, this study utilised a purpose built harness system manufactured from neoprene, fabric strapping and velcro. Pouches were sewn into the neoprene to accommodate both the IMU sensor and its accompanying battery. This system ensured that the components were securely located and could not move independently of the body. The head harness was located with the inferior edge aligned with the supraorbital process. The superior edge of the thorax harness was located at approximately the level of the fifth rib. Both harnesses were firmly, but comfortably fastened.

5.6 Data Management

Data was captured using the "ISplot" software, which simultaneously records log files for both sensors. Each log file was recorded separately, and saved carefully at the completion of each log roll. Recording, saving and clearing the data was a complex sequence and close attention to detail is necessary to ensure that log files were correctly saved, and data was cleared before the next log roll. In this project, separate folders were used for each participant and these were further subdivided into two folders for each technique. The log files were recorded as H1, H2 and H3 for the head sensor and T1, T2 and T3 for the thorax sensor. This careful attention minimised errors in the recording of the data.

Errors in data recording did occur in two identifiable ways; recording the data in the wrong sensor file, so that both files for the log roll were identical, and failure to properly clear the data from the previous log roll. Unfortunately these errors were not apparent until the data was later analysed so there was no way to retrieve the logs. Fortunately, careful attention to detail ensured that this occurred in only seven log rolls, from the total sample of 216 log rolls (just over 3%).

Log files from each log roll were recorded in a pair of text files. Microsoft excel was used to extract the data from the text files. Each text file was converted separately into column formatted excel worksheets using the text file import function with a space delimiter. Only columns E, F and G contain the angular data necessary for the analysis. Column H contains a time stamp. All other columns present data related to acceleration and angular acceleration. which was not use in this study. Positional data reported by the system output was derived by double integration of acceleration data, which lacked accuracy, as note above in 4.5.

To obtain the Euler angles between the head and thorax sensor, the data was simply subtracted for each axis; lateral, flexion and rotation. For convenience, the initial difference of the first data point was subtracted to give a starting value of zero using the formula:

$$\measuredangle_{diff} = \measuredangle_{head_n} \quad - \measuredangle_{thorax} - \left(\measuredangle_{head} - \measuredangle_{thorax}\right)$$

This provides a plot of the relative positions of each axis at any point during the log roll.

Maximum and minimum functions of excel were used to find the largest differential values between the sensors, either positive or negative. The absolute highest value in each axis was presented as the *peak angle* for the log roll.

Peak angles provided an instantaneous measure of largest joint angles achieved, but provide no information about the general trend of joint angles. A second measure; the area under the curve (AUC) was calculated using the trapezoidal rule, to provide more information about the joint angles over time. In biological systems an established method of measuring response over time is the use of non-compartment analysis (Bourne 2017, Gabrielsson, 2012). These measures provide a function of variation over time, allowing a means of comparing responses between trials. The first deflection and the final return to the baseline were identified to limit the calculation of the area under the curve to the actual log roll and eliminate most of the wobble, or noise that tends to occur at the completion of the log roll.

As each log roll was of a differing duration the area under the curve (AUC) data was then divided by the time, using a calculation of 118 frames per second, to produce area under curve per second according to the formula: (trapezoid method)

$$\int_{t_a}^{t_b} f(t)dt \sim \sum_{i=1}^{n} (t_{i+1} - t_i) \frac{f(t_{i+1}) + f(t_i)}{2}$$

Where t_a is the point of the log roll commencement,
t_b is the point of the log roll completion
and $f(t)$ is the data value at a t

. Both the peak angle values and the area under curve values were analysed using the same statistical methods.

5.7 Statistical analysis

All data was analysed using IBM SPSS version 19 software. All data was entered and classified in SPSS according to the lead clinician, technique used, axis and experience of the participant. Data was tested to determine if it satisfied the criteria for a Gaussian distribution, by using the Levene's Test of homogeneity of variances. Where the data satisfied the requirements of normality, it was deemed to meet the assumptions for parametric ANOVA. Where the data did not have a normal distribution, it was transformed using four forms of transformations; the Lognormal transformation, the square root transformation, cube root transformation and the Box-Cox transformation, allowing for parametric testing. The Box-Cox transformation, used the formula:

$$y_i^{(\lambda)} = \begin{cases} \dfrac{y_i^{\lambda} - 1}{\lambda}, & \text{if } \lambda \neq 0, \\ \ln(y_i), & \text{if } \lambda = 0. \end{cases}$$

where λ = .33 (Box & Cox 1964).

In order to analyse the effects of the individual, the axis, the techniques and the experience of the participant, it was necessary to use a multiple comparison of means for subcategories. A one way analysis of variance (ANOVA) was performed on all subcategories of both peak angle data and area under curve data. Post hoc tests were performed to analyse for statistical differences between categories. These post hoc tests were either a Bonferroni test where the data satisfied the homogeneity of variances (Levene's Test) or a Games-Howell test for data that violated the homogeneity of variances (Motulsky, 2010).. Further details of the statistical analysis of the data is presented in appendix 9.7.

As there appeared to be a trend seen in individual participants with high mean peak angle values to also have highly inconsistent results, an analysis of the individual means and variances was used to determine if there was an identifiable relationship between the high mean values and inconsistent results.

Inconsistency in peak angle and area under curve in the rotation axis prompted a linear regression analysis of the data. This analysis was done with all the axes combined and then with the rotation axis separately from the lateral and flexion axes.

5.8 Ethical considerations

5.8.1 Benefits anticipated from study.

This study will begin to provide a means of evaluating the management of SCI. The experiences derived from this study will be applicable to further studies which will aim to evaluate existing spinal care techniques, improve student training and examine the potential of patient simulators in training. Ultimately, this study and future studies will provide a rich source of data which will be clinically valuable for any health care organisation which manages SCI.

The economic impact of SCI has been estimated at $500 million annually (Walsh J *et al.* 2005) with little evidence to prove that current procedures are effective in managing victims in the prehospital setting. Those who would most benefit from the study would be trauma victims with unstable vertebral fractures, who have not yet incurred a secondary SCI. Improved spinal immobilisation techniques would lead to a reduction of these secondary injuries with an improvement in trauma outcomes. The paramedic profession and emergency health service providers would also benefit by obtaining clear evidence which would aid the purchase of equipment and the provision of training.

5.8.2 Risks of any harm

The log roll technique is a frequently practiced skill, which has been developed with the aim of ensuring safe management of a trauma patient with minimal risk of injury to the providers. It was performed in a safe environment with participants who had adequate training. It is extremely unlikely that the patient volunteer would be injured from the log rolls. Both patient and provider participants were closely monitored during the data collection and would have been withdrawn from the study if significant pain or discomfort occurred. This proved to be unnecessary. It is acknowledged that manual handling procedures were utilised, but all participants had previous manual handling training and annual updates. Intensive care paramedics were present during all trials in case of injury.

5.8.3 Dependent relationships

Some participants (Bachelor of Health Sciences – Paramedic students) were in a dependent relationship of the principle investigator. However the researcher did not participate in any practical or theoretical assessment of these students in areas related to spinal care. The student participation was entirely voluntarily.

5.8.4 Separation of research and clinical responsibilities

The only identified area of conflict between research and clinical responsibilities would arise from the identification of learning deficits in the participants. As a clinician and an educator, the principle investigator had the ethical responsibility to correct any erroneous performance of skills. However, remediation could only be achieved in such a way as to prevent a breach in confidentiality. One to one communication with the participants with the goal of explaining the learning points would have been the first step. This would be followed, if necessary, by an offer to arrange further tuition with skilled educators within the participant's organisation. Again, this strategy did not need to be implemented as no competence deficiencies were identified.

5.8.5 Source of payment for normal participants

There was no payment to participants.

5.8.6 Protection of privacy and preservation of confidentiality

All data collected was identified only by record numbers. A register of the team members was kept only to ensure that each team remains consistent. This register and the names of participants are not identifiable in the final analysis of the data or subsequent reports.

5.8.7 Restriction of use of data

Data will be restricted for use by the principle investigator, the research assistant, and the supervisor for the purpose of the completion of a higher degree research project.

Findings of the study will be published in an appropriate scientific journal. All records will be kept in accordance with the Flinders University Policy on Research Practice.

6 RESULTS

The underpinning aim of this project was the validation of the IMU system for use on the measurement of cervical spine motion. This validation was performed in the first phase by measuring the reported Euler angles of the sensors during controlled movements in each plane. The second phase of this project reported Euler angles in the three axes representing lateral bending, flexion-extension and rotation, during the log roll procedure. The findings are presented in terms of system accuracy, differences of movement between axes, individual performance and the differing dynamics of the axes. The impact of the type of hold used and the experience of the participant were also reported. Results have been presented for peak angles and area under curve measures.

An examination of alignment seen in each axis revealed the range of movement seen in each axis and where this movement is most pronounced. Relatively large misalignments were consistently produced in all axes.

Variations between individual performances was then examined in an attempt to see if there was a consistent trend in misalignment and in what axis was this most pronounced. The highly variable performance of individuals was explored with a comparison between individual means and individual variance. Results could be reasonably stratified into those who were consistent and had low mean misalignment, and those who were erratic and had high mean values.

The relationship between peak angle and area under curve measures was analysed using a linear regression. This showed some inconsistency within the rotation axis. Visual inspection of the log roll plots showed the trend to produce sharp spikes in rotation but broad deflections in both lateral and flexion axes, thus accounting for the difference seen in the rotation axis. Asynchrony between the team members appears to be the main cause of the rotational inconsistency.

A comparison of the head hold and shoulder hold techniques, to determine the superiority of either technique, showed some improvements achieved in the rotation axis for the shoulder hold. However, the improvement possibly comes at the expense of alignment in the flexion axis. In a similar comparison, the experience of the participant directing the log roll was used to detect if length of time in the roll impacted on the ability to maintain alignment. This analysis of novice versus experienced participant suggests that the novices tend to slightly outperform the more experienced participants.

6.1 System accuracy

Testing the angle accuracy using a simple board, raised from horizontal to angles of 15, 30 and 45 degrees, indicated the instruments were capable of reporting yaw within an accuracy reported in the manufacturers' specifications, but slightly less accuracy than the specifications in pitch and roll (table 6-1). These tests were able to produce results which were accurate to at least one degree.

Table 6-1 Accuracy testing of the IMU system

Mean angle errors reported from a single IMU sensor that has been moved to known angles of 15°, 30° and 45°, measured using a protractor, in nine trials for each axis. The sensor was reorientated after each series of nine trials to test the three axes with nine further repetitions.

Axis	Manufacturers reported accuracy	Results reported from this study	
		Mean angle error	95 % Confidence Interval
Lateral bending (yaw)	1°	0.273°	-0.020° to 0.565°
Flexion - extension (pitch)	0.25°	-0.673°	-0.990° to -0.355°
Rotation (roll)	0.25°	0.289°	-0.098° to 0.686°

Measuring the agreement of the two sensors was done by fixing both to a board, and measuring the closeness ofconcordance of results as the board was tilted from horizontal to vertical. In eleven tests, the difference in reported angle produced a mean difference between sensors in the Y axis (pitch) of -0.478 degrees with a 95% confidence interval of -0.861 to -0.094 degrees. This indicates that precision of one degree or better between sensors could be expected.

In the log roll trials, experimental error was evident in 4.6% of the trials, which were identified by either excessively high peak angles, beyond the range of motion of the human neck, or by total concordance between the sensors. The first error probably resulted from slippage of the sensors within their harnesses during the procedure. The latter error clearly resulted in the saving process which recorded only values for a single sensors in both files, rather that the two sensors. These errors were easily detected and these results were removed from the data.

6.2 Log roll testing

Log roll trials may be presented graphically as the Euler angle between the head and thorax for the duration of the trial. Examples of these plots are presented in figure 6-1 below.

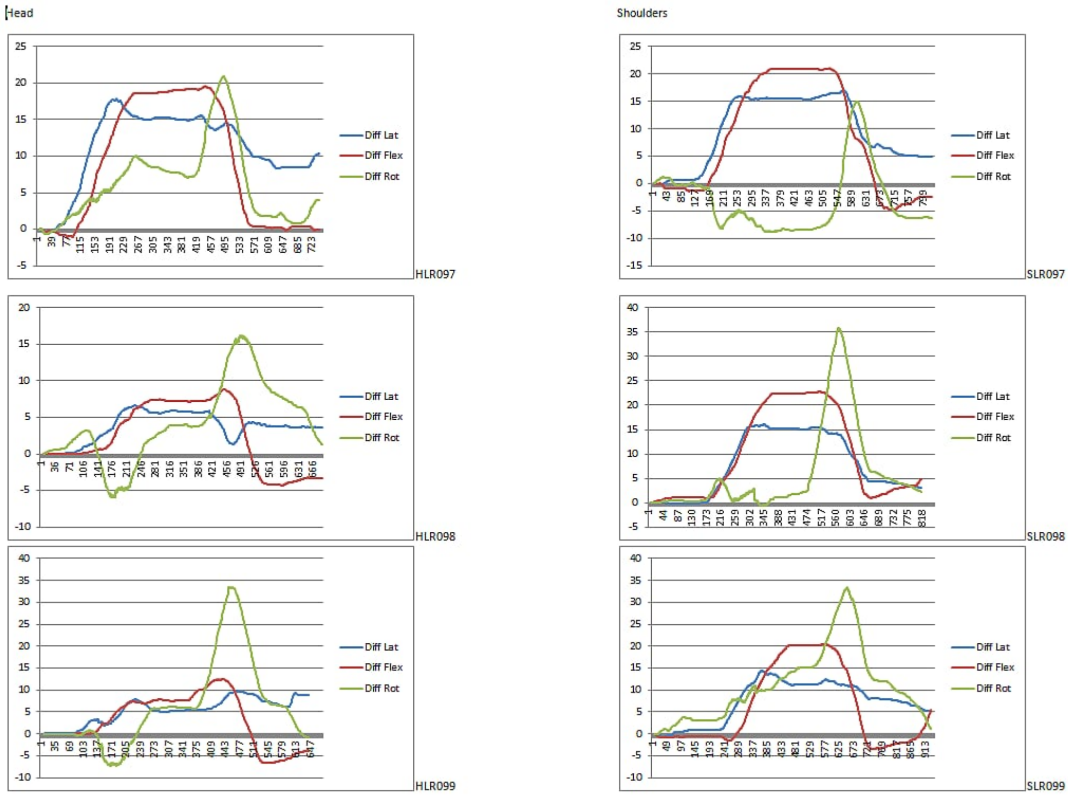

Figure 6-1 Examples of log roll Euler angle plots.

Each plot represents a single log roll trial, with plots on the left hand side of the page representing log rolls using the head hold, while plots on the right hand side of the page representing log roll using the shoulder hold. The horizontal scale is time (milliseconds) while the vertical scale represents Euler angles between the head and torso for each axis; blue for lateral flex, red for flexion-extension and green for axial rotation

6.2.1 Movement within axes across all tests

Head movement relative to the thorax movement showed a significant degree of relative rotation in all axes. Peak Angle (PA) measurements in each axis returned the following mean and 95% confidence interval values:

- Lateral: M=17.40˚, 95% CI [16.21˚, 18.54˚]
- Flexion: M=16.79˚, 95% CI [15.88˚, 17.73˚]

- Rotation: M=17.99˚, 95% CI [16.81˚, 19.26˚]

Full descriptive statistics are presented in Appendix G: table 9-1. A one way analysis of variance (ANOVA) with a Bonferroni post-hoc test showed no statistically significance difference between axes (figure 6-1 and Appendix G: table 9-2). This suggests an equal degree of cervical misalignment occurs in each axis.

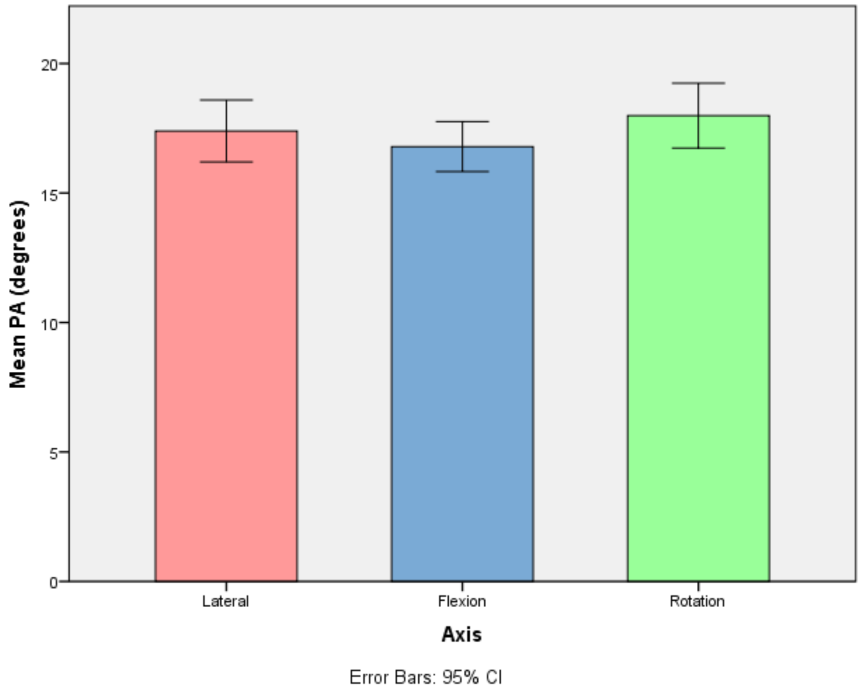

Figure 6-2: Mean peak angle values for all axes

The peak angle shows the maximum difference between the head and thorax sensors. The bar graph represents the mean values for each axis; lateral, flexion and rotation, with a greater value representing a greater misalignment of the cervical spine. Error bars represent the 95% confidence interval.

The median value for all logs roll in all axes was used to calculate a median peak angle value. Individual peak angle means, in all axes, were used to stratify individuals into a high (above median) group and a low (below median) group, with the aim of identifying an association between high mean values and a tendency to produce these high values in any particular axis. It was found that there was no significant difference between axes in the low (below median) group, and between axes in the high (above median) group. This result indicates that there was the same level of fluctuation in all axes in both groups (figure 6-2 and Appendix G: table 9-3). Rotation axis in the low group did have a slightly higher mean, but this was not statistically significant.

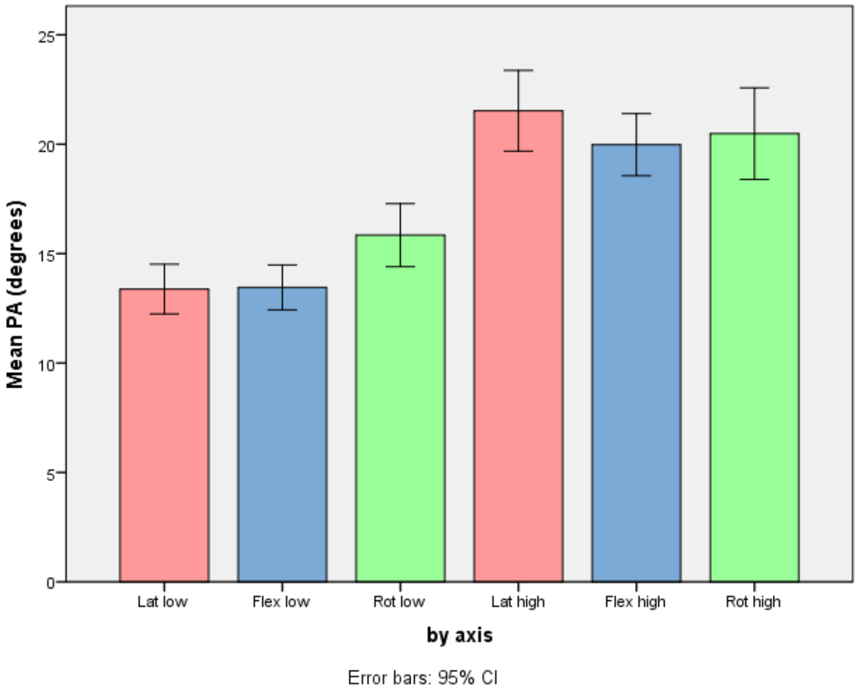

Figure 6-3 Mean peak angle values for all axes

The peak angle is shown for median split groups, the low group representing all the data for individuals with a median score below the overall median, and the high group representing all the data for individuals with a median score above the overall median. The bar graph presents mean values and standard errors for each axis in each group.

The area under the curve per second measure (AUC) was used to analyse the extent of the misalignment over time. In this analysis it can be seen that the mean values showed significantly more misalignment in the lateral and flexion axes than in the rotation axis (figure 6-3 & Appendix G; Table 9.4). This inconsistency between peak angle and AUC values in the rotation axis will be analysed in further depth below.

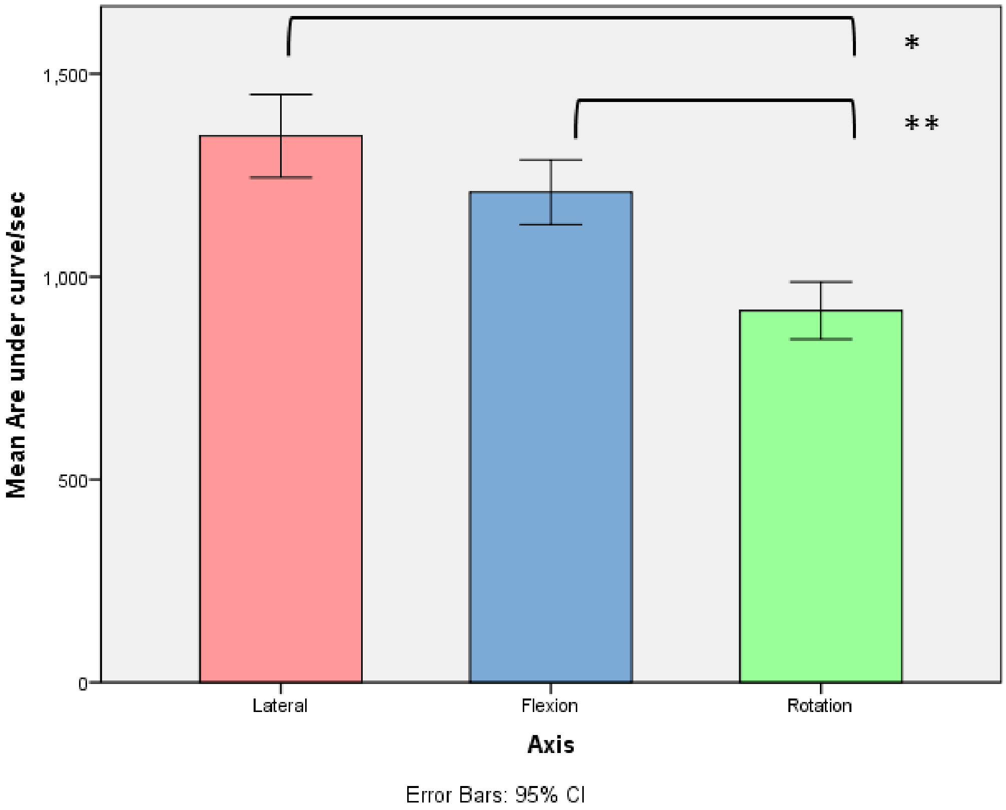

Figure 6-4: Mean AUC values for all axes

*The area under the curve per second shows the integrated data of the difference between the head and thorax sensors. The bar graph represents the mean values for each axis; lateral, flexion and rotation, with a greater value representing a greater difference between sensors. Significant differences in AUC values may be seen between the lateral and rotation axis; $p<0.005$ (marked by *) and the flexion and rotation axis; $p<0.005$ (marked by **).*

An analysis of the AUC in median split groups showed that the statistically significant difference between the rotation axis and other axes lies mainly with the high group (figure 6-4 & Appendix G; Table 9-5). This is suggestive of a tendency for the individuals in the high group to demonstrate the high AUC values as prolonged misalignment in the lateral and flexion axes, but only short duration misalignments within rotation. The lateral and flexion misalignments were consistently caused by a forward flexion of the head and a downwards lateral bend of the head as the patient rotated to the lateral position. As rotation between the high and low groups was not different, there is an indication that high group individuals were prone to more prolonged lateral and flexion misalignments.

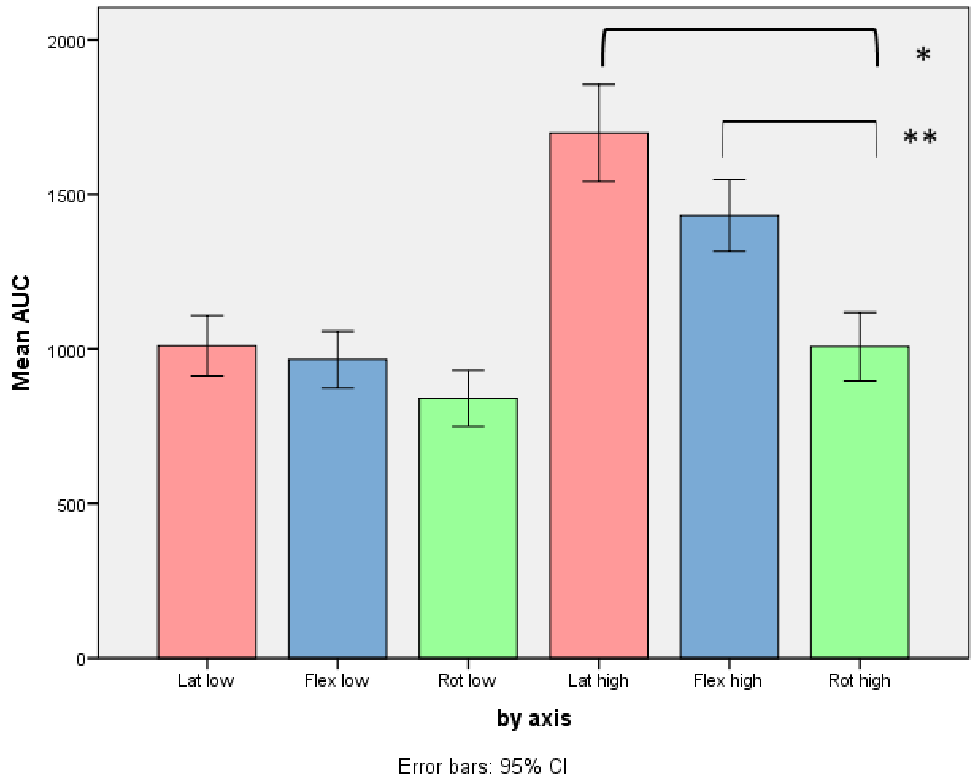

Figure 6-5: Mean axis AUC split by median values for each axis

The area under the curve per second is shown for median split groups, the low group representing all the data for individuals with a median score below the overall median, and the high group representing all the data for individuals with a median score above the overall median. The bar graph presents mean values and standard errors for each axis in each group. Significant differences are seen between rotation and lateral axes; p<0.005 (*), and rotation and flexion axes; p<0.005 (**) in the high group.

6.2.2 Variability of the individual lead clinician

The performance of the lead clinician (i.e. the participant at the head of the patient who controls the log roll) tended to produce a widely variable range of results. A boxplot of peak angles from all lead clinicians (figure 6-5) shows a marked variability of performance between individuals. Additionally, there was considerable variability between lead clinicians in the axis which demonstrated greatest variance.

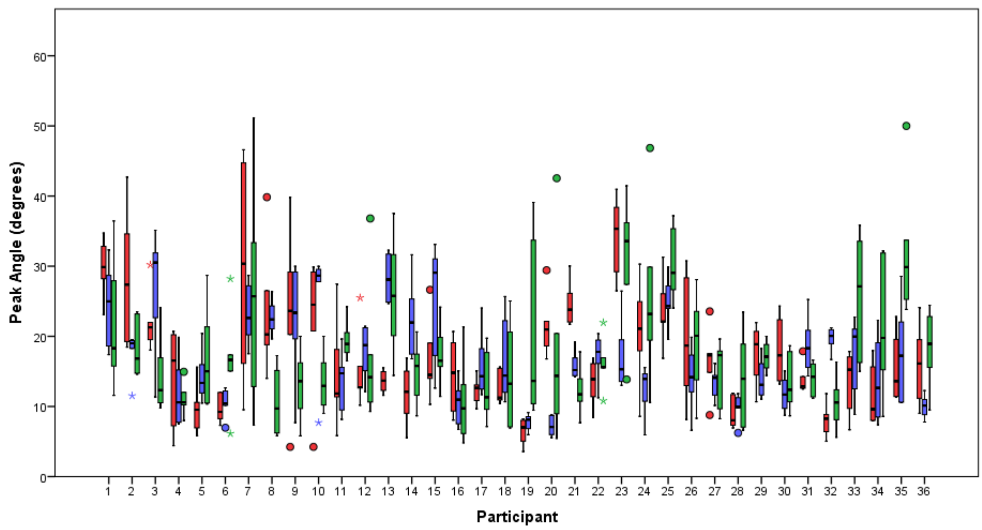

Figure 6-6 Box and whisker plot of participant peak angles in all axes

Each participant performed six log rolls which were recorded in three axes: Lateral (red), Flexion (blue) and Rotation (green). The box represents peak angle values between the 25th and 75th quartiles, while the horizontal line represents the median value. Whiskers represent the range of values, excepting the outliers (identified as circles for outliers and asterisk for extreme outliers). Participant identify is protected by random assignment of participant numbers.

The trends in variance of the lead clinicians was analysed by examining the overall mean and variance in peak angle across all axes for all trials by the lead clinician. This analysis allowed categorisation of the individual performance into those who fall above and below the median values for both the means and variances. A plot of mean and variance for each individual (figure 6-6) demonstrated that most participants fell into one of two groups; low means and low variance or high means and high variance. A smaller number of lead clinicians demonstrated mean and variance values which were opposed.

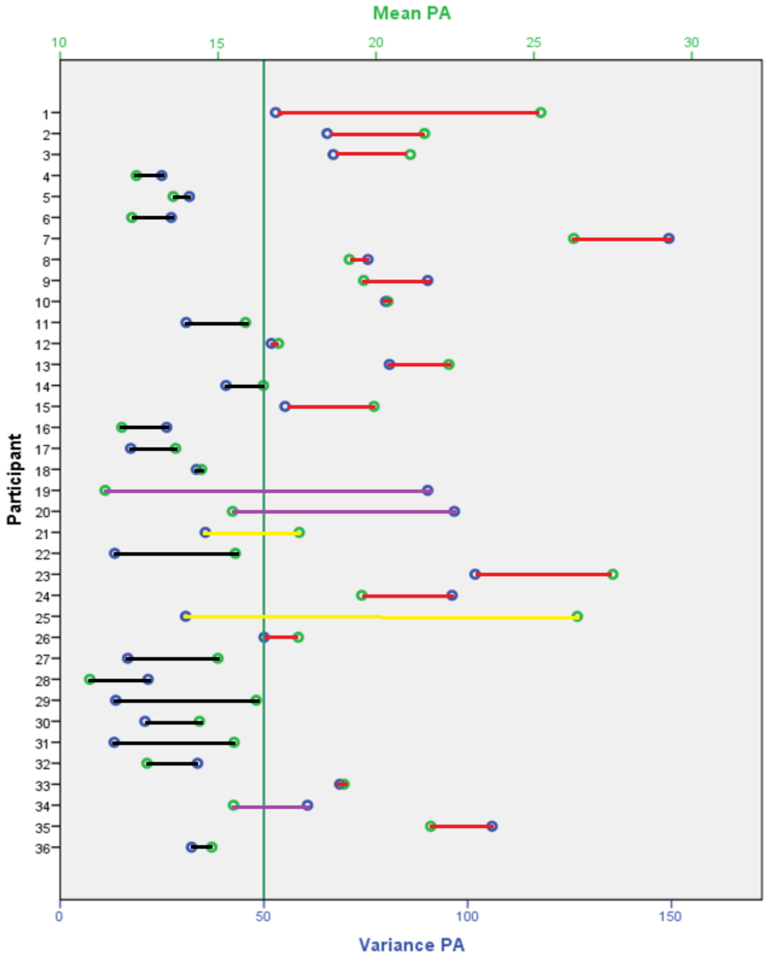

Figure 6-7 Caparison of individual lead clinician mean and variance values

Mean peak angle values for each individual are plotted on a dual axis plot with peak angle variance values for the same individual. The plot is divided on the horizontal axis by the median value for both the mean and variance values. Lines link the mean (green circles) and variance (blue circles) for each participant; black indicating a low mean and low variance, red indicating a high mean and high variance, yellow indicating a high mean but low variance while purple indicates a low mean but high variance. Both the mean and variance values were calculated from all log rolls performed and all axes combined.

The resulting four groups give an indication of participant performance in terms of ability to maintain cervical alignment and the consistency of performance. Table 6-2 demonstrates that 44% are consistently able to keep good spinal alignment, whilst 42% are both inconsistent and tended toward high spinal misalignment. Smaller numbers were able to achieve good spinal alignment even with inconsistent performances (2%), or were consistently causing poor spinal alignment (3%). This data indicates that nearly half the participants were highly inconsistent with maintaining cervical spine alignment during the log roll, and demonstrated greater mean values of cervical spine alignment. This suggests the capacity to perform log rolls without causing misalignment is a significant and problematic issue.

Table 6-2 Comparison of overall participant mean and variance values for all axes

Mean peak angles for all axes combined are compared with variance for all axes combined for each participant to measure analyse the individual performances of each participant. Median values for both the individual mean and individual variance were used to distribute participants' performances into above and below median groups. Below median for both mean and variance suggests the participant is able to maintain good spinal alignment (low peak angles) consistently. Below median for the mean and above median for the variance suggests an overall good performance, but with some inconsistency. The above median for the mean values suggest poorer spinal alignment, with most of these participants also presenting high variance values, indicating an inconsistent performances.

Participant frequency		Variance (Indication of Consistency)	
		Below median	Above median
Mean peak angles (Indication of good alignment)	Below median	16 (44%)	3 (8%)
	Above median	2 (6%)	15 (42%)

To determine if there was a trend that demonstrated worse or more erratic performance in any axis, the lead clinician's axis of worst peak angle mean and variance values was plotted (figure 6-7). This indicated that mean peak angles were consistent across axes, suggesting that there is no particular trend towards a dominant axis related error in performance. However, when examining the variance, as an indication of participant consistency, there is a clear trend showing less variation (and greater consistency) in the flexion axis and more variation (and so more inconsistency) in the rotation axis.

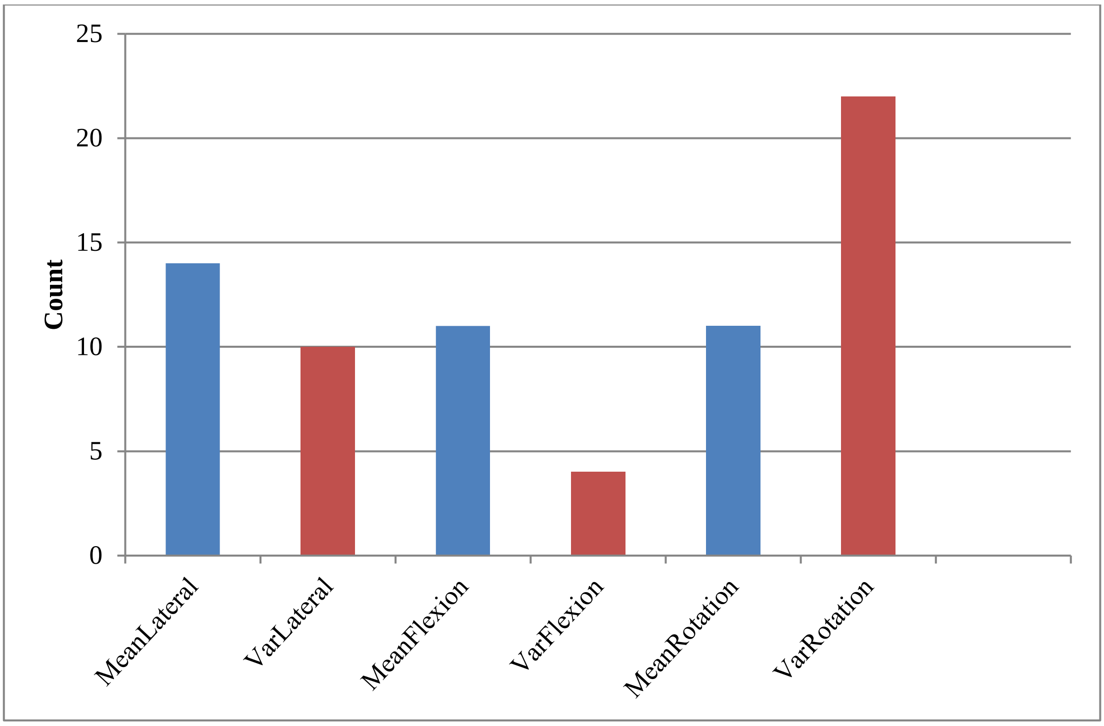

Figure 6-8 Frequency of worst (greatest) peak angle means and variances

The worst performing axis for each participant in terms of mean value and variance value was counted; mean frequency shown in blue and variance frequency shown in red. It may be seen that across the 36 participants the axis of worst performance distributed relatively evenly in terms of mean values.

A chi-square test for association was conducted between lead clinician peak angles mean and variance values for each axis. Cell frequencies were less than 5 in 66.7% of the cells, so the Fisher's Exact Test has been reported. There was a statistically significant association between mean and variance for PA; $\chi^2(1) = 9.118$, $p = 0.046$. There was a moderate association between mean and variance in peak angle, Cramer's V = 0.374, $p = .039$. This association was strongest in the lateral bending, moderate in flexion-extension and only weak in rotation, suggesting that more clinicians performed more erratically in the rotation axis than the other axes. (Appendix G; Table 9-6).

6.2.3 Log roll dynamics

The relationship between PA and AUC was further examined to identify the association of the measure in each axis. Figure 6-8 shows a close association between PA and AUC in the lateral and flexion axes, but a marked difference in the rotation axis. The mean AUC for rotation is statistically significantly lower than the mean AUC values for the lateral and flexion axes, but this trend is not replicated in the mean PA values.

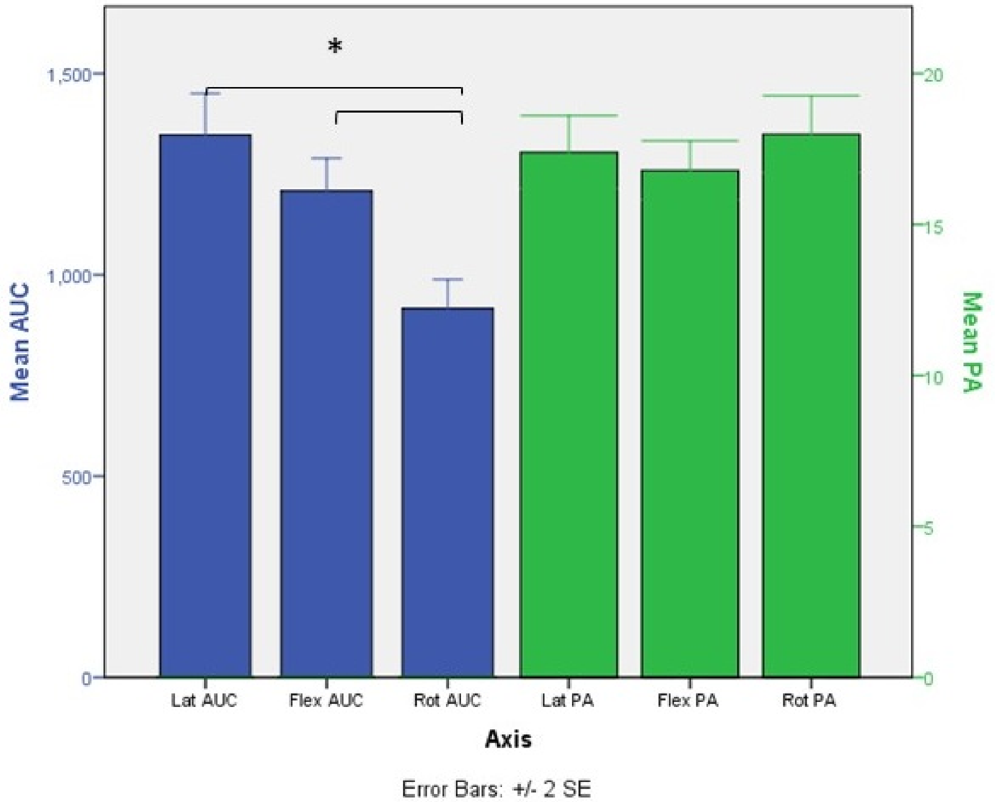

Figure 6-9 Dual axis graph of AUC & PA for each axis

A dual axis graph is used to plot AUC means (in green) against the left axis and PA means (in red) against the right axis. This graph shows that AUC and PA values are proportionally similar in the lateral and flexion axes. However, the rotation in AUC is significantly lower than the lateral and flexion axis in AUC..

When the relationship between AUC and PA was calculated using the Pearson Correlation, there was a strong positive correlation between AUC and PA (figure 6-9, Appendix G; Table 9-7), but a large number of values fall outside the 95% confidence interval of the linear regression.

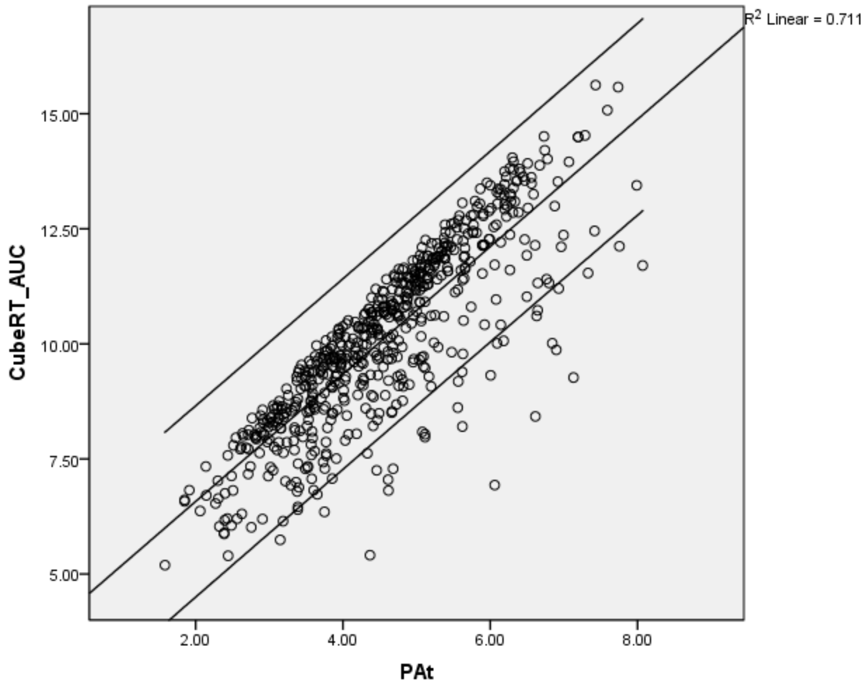

Figure 6-10 Scatter plot of AUC against PA

Cube root transformed AUC data is plotted against cube root transformed PA data. There is a clear linearity and s strong positive correlation between the variables; $r(618) = .832$, $p < 0.005$ (2-tailed). A linear regression established that PA could statistically significantly predict AUC, $F(1, 613) = 1500$, $p < 0.005$ and accounted for 71.1% of the explained variability in AUC.

To further examine these relationships, the data was subdivided into two groups; group one representing the rotation axis while group two represented a combination of both lateral and flexion axes.

The scatter plot (figure 6-10) from this subdivided data set shows that the data points falling outside the confidence interval are almost entirely from the rotation axis(Appendix G; Table 9-8 and 9-9). This is consistent with the higher rotation PA values identified in the AUC-PA comparison (figure 6-8)

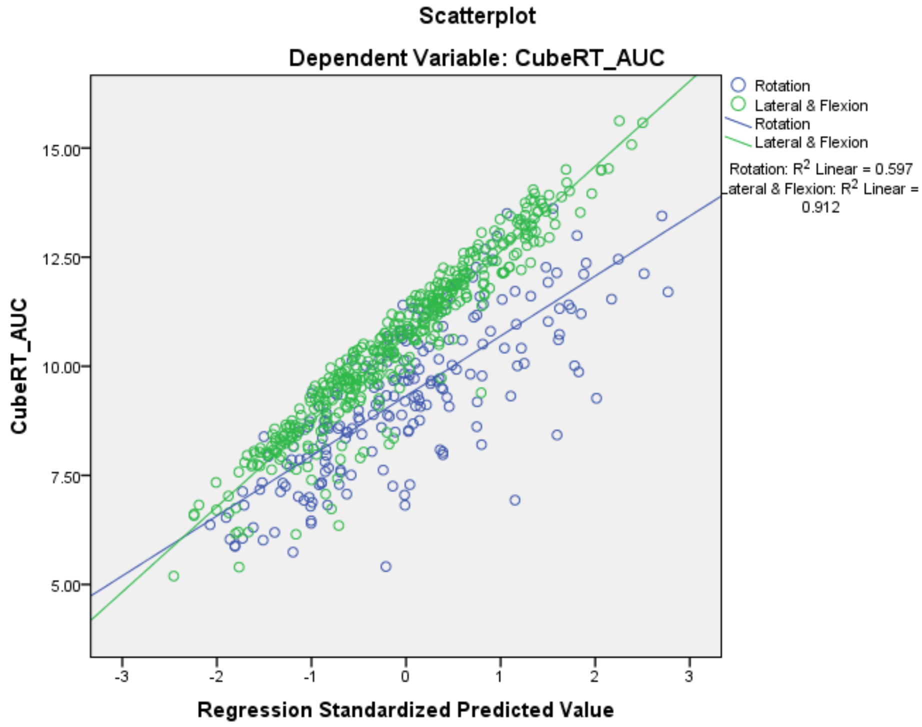

Figure 6-11 Scatter plot of AUC against PA with data subdivided into a Rotation group and a Lateral/Flexion group

A separate linear regression calculations for rotation (shown in blue) showed that PA could statistically significantly predict AUC in rotation, **F***(1, 201) = 298,* **p** *<0 .005 and accounted for 59.7% of the explained variability in AUC in rotation. The remaining axes (shown in green) showed stronger linearity with PA statistically significantly predicting AUC in lateral and flexion,* **F***(1, 410) = 4251,* **p** *< 0.005 and accounted for 91.2% of the explained variability.*

This linear modelling clearly shows that expected PA values in rotation are higher than the other axes and are not as strong predictor of AUC values. To explain this apparently anomalous result, the individual log roll plots were examined (figure 6-11). It can be seen that these plots show a greater tendency to show narrow spikes in PA in the rotation axis than seen in the other axes. These spikes produce high PA values, but do not necessarily produce higher AUC data. These plots showed two characteristic features; a broad positive deflection in lateral and flexion axes, and sharper spikes in the rotation axis at the commencement and completion of the log roll. The lateral deflection shows a sustained lowering of the head laterally while the patient is rolled and held on their side. Similarly, the flexion shows a sustained tendency to flex the head during the log roll. The spikes in rotation indicate that there is an asynchrony between the actions of the lead clinician and the other team members. In this case, the early negative deflection shows that there is a lag between the commencement of head movement and the commencement of body movement. Similarly, the positive deflection towards the end of the log rolls shows a lag between the commencement of head return movement and the body return movement.

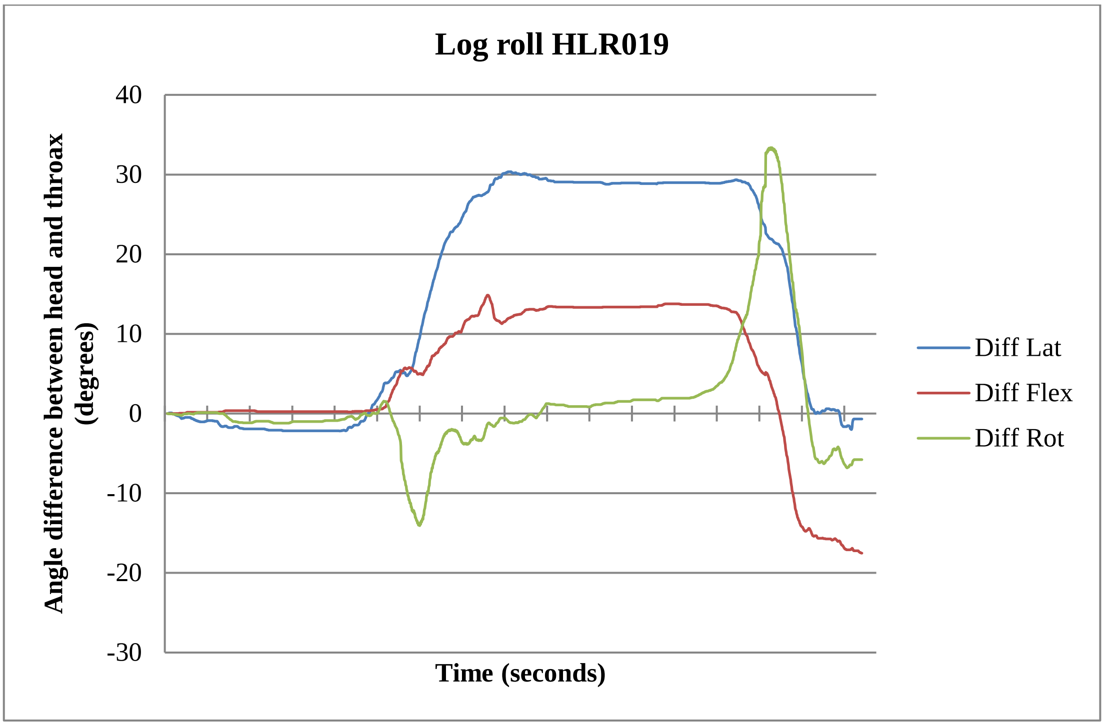

Figure 6-12 Typical log roll plot

Each log roll may be graphically represented by the differential angles between head and thorax in each axis; Diff Lat represents the difference in the lateral axis, Diff Flex represents the difference in the flexion axis and Diff Rot represents the difference in the rotation axis. The positive deflection in lateral and flexion indicate a lateral droop and forward flexion during the course of the log roll. The sharp spikes in rotation indicate asynchronous movement, usually associated with the commencement of a movement.

6.2.4 Impact of the techniques used

6.2.4.1 Impact of techniques on movement between axes

To examine the influence of the techniques used to support the head during the log roll, the impact of the head hold and the shoulder hold on PA and AUC were analysed using a one way analysis of variance. Differences in the magnitude of PA and AUC between the techniques, provided information about the quality of the log roll. Statistically significant differences were detected in the rotation axis where the shoulder hold produced less movement than the head hold. In the lateral and flexion axis, the head hold tended to have lower values in PA, but these results were not statistically significant (figure 6-12 and Appendix G; table 9-10). This indicates that the shoulder hold appeared to provide less head rotation during the log roll than the head hold.

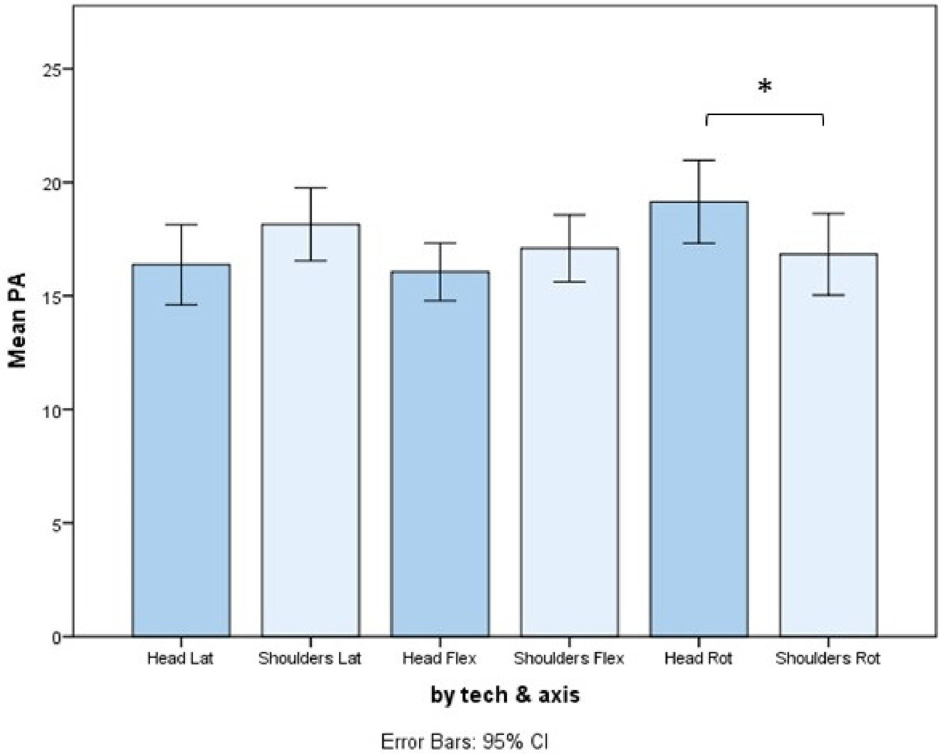

Figure 6-13 Mean PA defined by Axis and Technique: highlighting differences in technique

Mean PA data is used to present a graphical view of differences between the variable; axis, and technique. When technique is considered, it may be seen that statistically significant difference lies between the head hold and shoulder hold in the rotation axis (p=0.007). No statistically significant differences were seen between the head and shoulder holds in lateral and flexion axes.

A similar one way analysis of variance of the AUC variable to examine differences between techniques, supported the findings from the PA analysis. The key finding was a poorer performance in rotation using the head hold compared with the shoulder hold (figure 6-13). No statistically significant differences were found in the lateral and flexion axes, although the head hold AUC did appear lower than the shoulder hold in the lateral axis. Figure 6-13 (and Appendix 9-11) reports the comparison of axes, experience and technique, where significant differences between techniques was in the rotation axis.

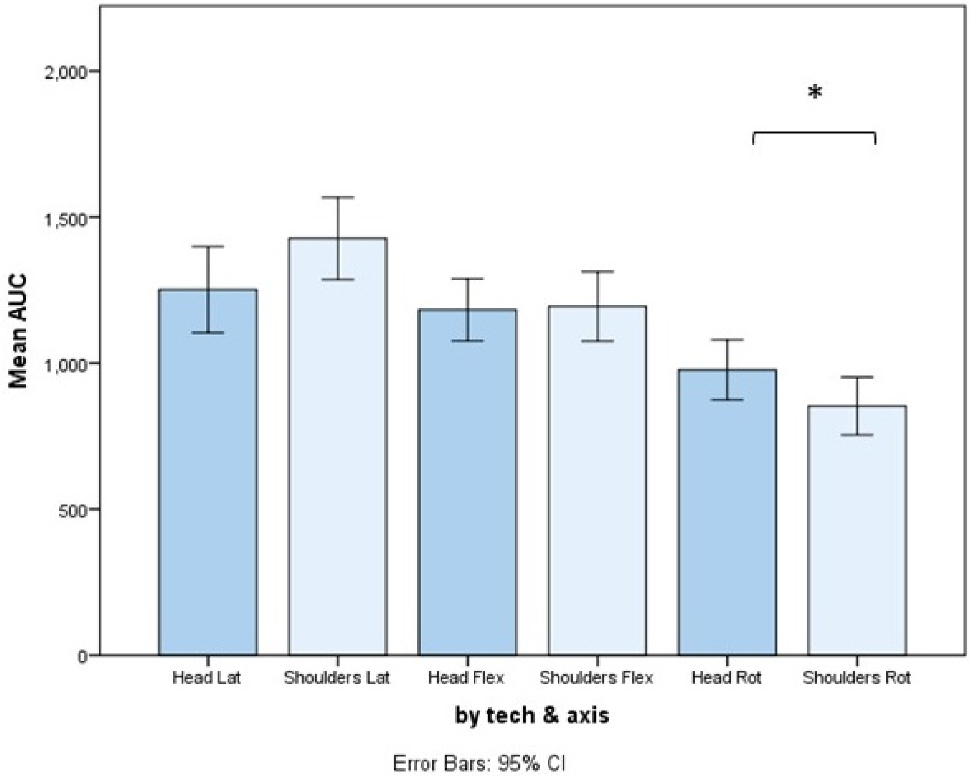

Figure 6-14 Mean AUC defined by Axis and Technique: highlighting differences in technique

Mean AUC data is used to present a graphical view of differences between the variable; axis, and technique. When technique is considered, it may be seen that statistically significant difference lies between the head hold and shoulder hold in the rotation axis (p=0.029). No statistically significant differences were seen between the head and shoulder holds in lateral and flexion axes.

A boxplot comparison of median, interquartile and outlier values for each technique in each axis showed very similar outcomes for the techniques (figure 6-14). A visual inspection of outliers showed greater number in the rotation axis and occurred almost entirely in the head hold. The lateral axis also produced numerous outliers, but these were evenly distributed between techniques. The flexion axis did not produce any outliers for either technique.

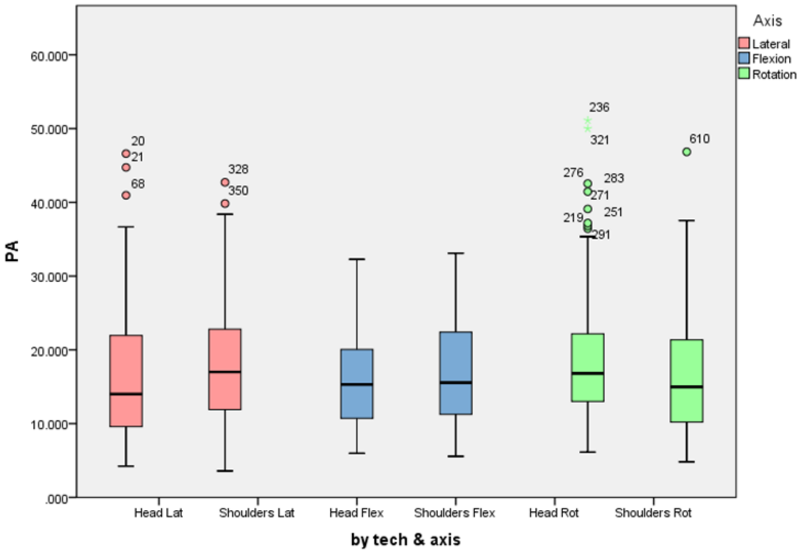

Figure 6-15 Boxplot of PA for the head hold and shoulder hold in each axis

PA median, interquartile, range and outliers for the head hold and shoulder hold are shown for all log rolls by all participants. This boxplot shows a relatively consistent outcome of PA values, but greater numbers of outliers in the lateral axis (both techniques) and the head hold of the rotation axis.

6.2.4.2 Variability of Individual Performance between Techniques

The individual lead clinician performance variability between techniques was examined by an evaluation of median and interquartile ranges of each participant across the two techniques (figure 6-15). This analysis showed a relatively even distribution of best performance for either technique, but tended to favour the head hold. When the best median and lowest interquartile range was used as a measure of best performance, the head hold tended to have slightly better outcomes (table 6-3). However, these performances suggest a highly individual dominance of one technique over the other technique and the sample size is probably too small to allow a definitive conclusion.

Table 6-3 Frequency of best individual techniques

The distribution of best performance of the lead clinician for the head hold and the shoulder hold for all log rolls. The measure of best performance was the lowest median value, indicating low angles of misalignment, and the lowest interquartile range, indicating a more consistent performance. Best performances were found to be relatively evenly spread across the two techniques.

Measure	Frequency of best performance	
	Head hold	Shoulder hold
Best Median	23	13
Lowest Interquartile Range	16	20
Best median and interquartile range	14	11

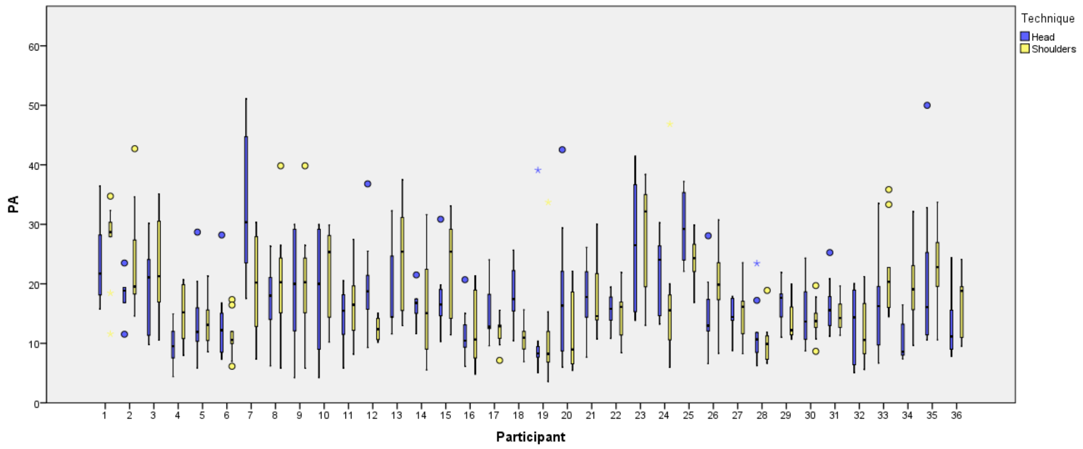

Figure 6-16 Boxplot of PA for the head hold and shoulder hold for each individual participant

This boxplot presents the lead clinician median, interquartile range and outliers for all log rolls for each participant. The head hold is represented by the blue boxes and the shoulder hold by the yellow boxes. While considerable variability was seen in the individual plots, there was not a clear dominant techniques which produced best practice.

6.2.4.3 Differences in log roll dynamics due to techniques

The log roll dynamics for the techniques of head hold and shoulder hold show a trend for close correlation of lateral and flexion PA with AUC(figure 6-16a&b), but a weaker correlation of the same variables in the rotation axis (figure 6-16c and Appendix G, Table 9-12). As previously defined in 6.2.3 above, the lack of correlation suggests spikes of rotation misalignment related to asynchronous movement of the log roll team. In this analysis it is apparent that the shoulder hold is slightly better than the head hold in preventing these sharp misalignments. Misalignments in the lateral and flexion axes are more sustained for the duration of the log roll, but do not seem to be affected by the technique used. These findings suggest that the shoulder hold has an improved capacity to control asynchronous movements of the head in relation to the thorax.

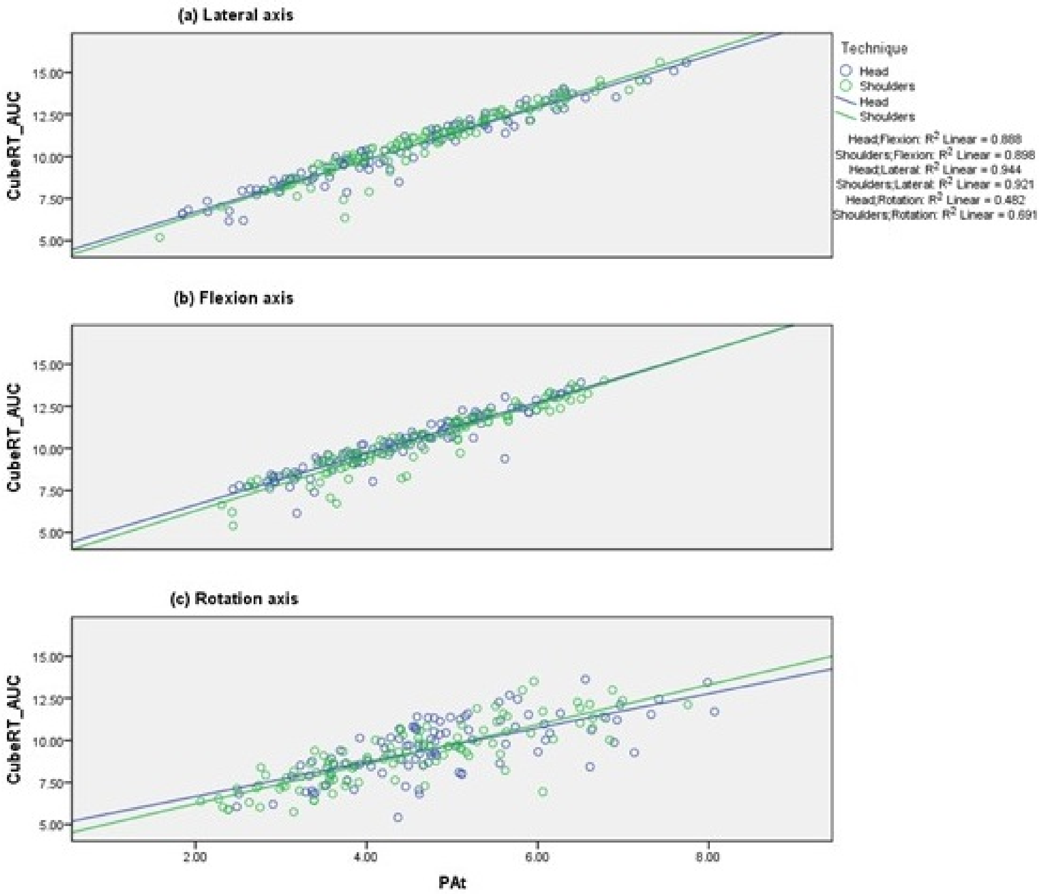

Figure 6-17 Scatter plot of AUC against PA with data subdivided into the head hold and shoulder hold for each axis

A separate linear regression calculations for the head hold (shown in blue) and the shoulder hold (shown in green) in (a) the lateral axis, (b) the flexion axis and (c) the rotation axis. These plots showed that PA could statistically significantly predict AUC in the lateral and flexion axis for both the head hold and the shoulder hold with R^2 values of 0.888 or higher. PA could statistically significantly predict AUC in the rotation axis, but with weaker correlation; R^2(Rotation head) =0.482 and R^2(Rotation shoulders)=0.691. Notably the rotation head category was less likely to produce a close correlation of PA with AUC than the rotation shoulders category, indicating a greater tendency to produce sharp spikes in rotation.

6.2.5 Impact of the experience of the lead clinician

6.2.5.1 Impact of experience on movement between axes

The results within the grouping of lead clinicians by experience are influenced by an uneven sample size in each group. The novice group comprised 26 members, while the experienced group comprised 10 members. Consequently, the statistical power of the following analyses must be considered in relation to the sample sizes of each group. It should be noted that while the trials attributed to the lead clinician record the performance of that participant as either a novice or an experienced clinician, it has no bearing on the experience of the other two members of that teams. It is possible that an experienced clinician was acting in the lead role with one or more novice clinicians, who may have influenced the results. Consequently, the team make-up is a factor which should be considered when interpreting the results of this experienced versus novice comparison. However, the role of lead clinician is seen as crucial to the performance of the procedure, and this study asserts the appropriateness of analysing the individual lead clinicians' performance.

A one way analysis of variance (ANOVA) was used to examine the influence of the lead clinician's experience on performance in PA and AUC. Differences in the magnitude of PA and AUC between the experienced and novice lead clinician provided information about the quality of the log roll. Statistically significant differences were detected in the PA means for the flexion axis, where the novice produces less movement than the experienced lead clinician (figure 6-17). In the lateral and rotation axes, the novice tended to have lower values for PA, but these results were not statistically significant (figure 6-17 and Appendix G; table 9-13). This indicates that the novice was superior in providing less cervical misalignment during the log roll than the experienced lead clinician.

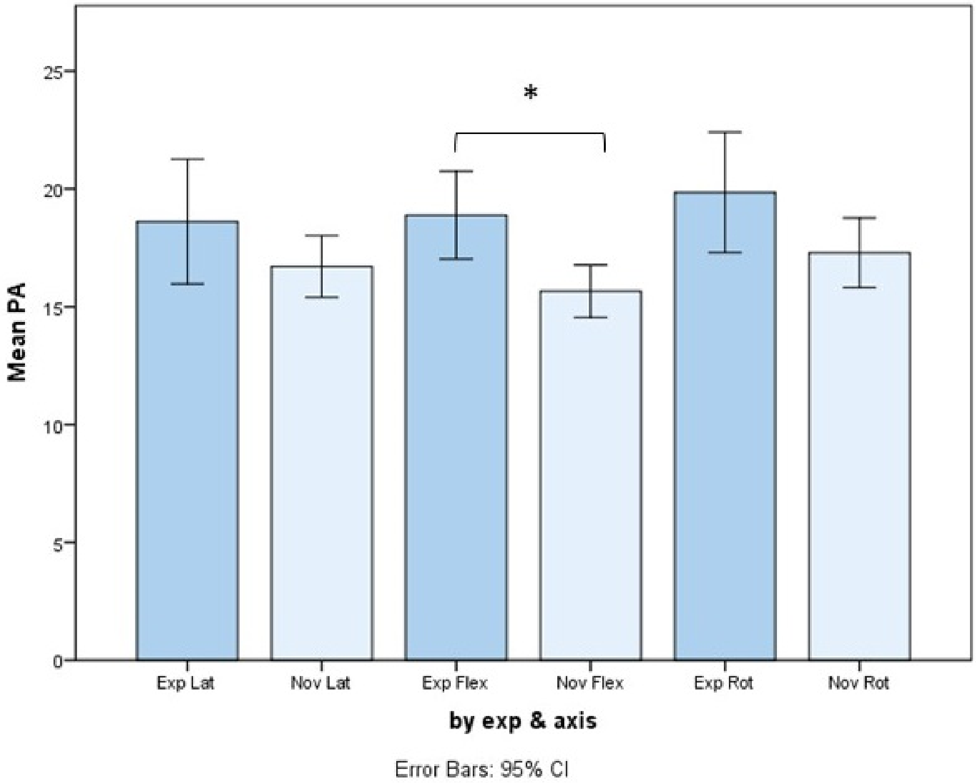

Figure 6-18 Mean PA defined by Axis and Experience: highlighting differences in experience

Mean PA data is used to present a graphical view of differences between the variable; axis, and experience. When experience is considered, it may be seen that statistically significant difference lie between the experienced lead clinician and novice lead clinician in the flexion axis (p=0.011). No statistically significant differences were seen between the lateral and rotation axes.

Similar findings were reported from the one way analysis of variance (ANOVA) of AUC. A statistically significant difference between the experienced and novice lead clinicians was found in the flexion axis, with this not replicated in the lateral and rotation axes (figure 6-18 and Appendix G; table 9-14). This finding further supports a superior performance at limiting cervical misalignment by the novice lead clinician.

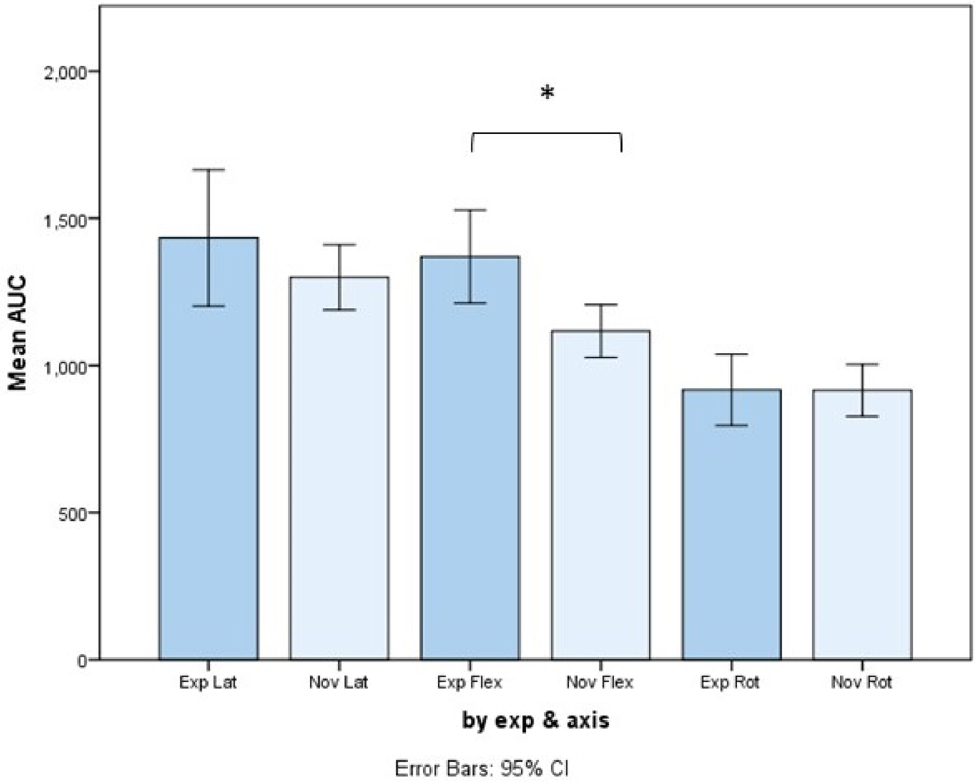

Figure 6-19 Mean AUC defined by Axis and Experience: highlighting differences in Experience

Mean AUC data is used to present a graphical view of differences between the variable; axis, and Experience. When Experience is considered, it may be seen that statistically significant difference lie between the experienced and novice lead clinician in the flexion axis (p=0.029). No statistically significant differences were seen between the head and should holds in lateral and flexion axes.

A boxplot comparison of median, interquartile and outlier values for each technique in each axis showed very similar outcomes for the two experience groups (figure 6-19). Outliers were more frequent in the rotation axis and more commonly seen in the novice group. However, this distribution is affected by uneven sample size of the two groups and probably should not be used to determine differences between the groups.

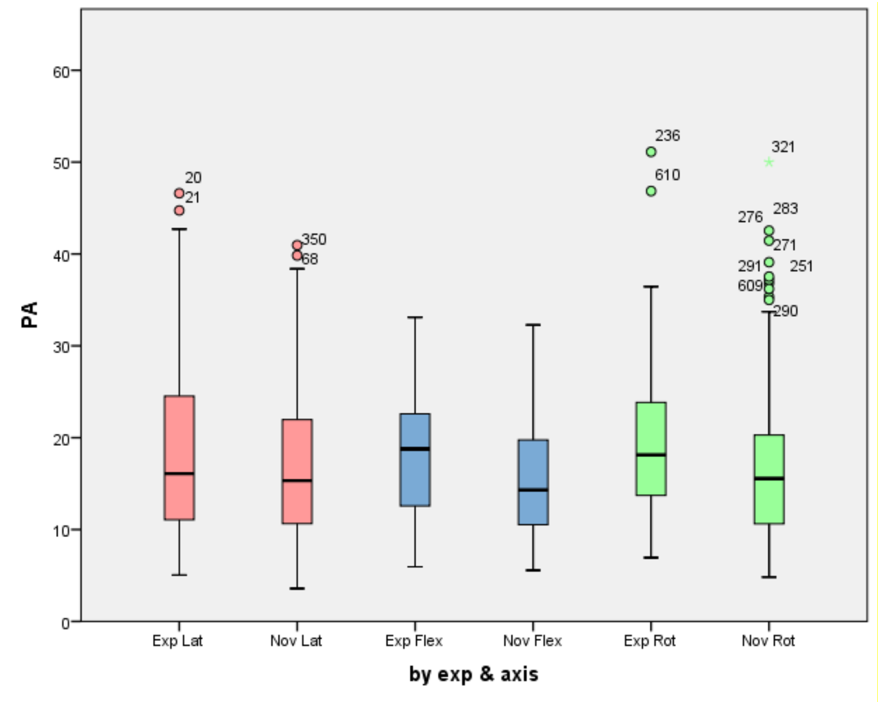

Figure 6-20 Boxplot of PA for the experienced and novice participants in each axis

PA median, interquartile, range and outliers for the experienced and novice participants are shown for all log rolls by all participants. This boxplot shows a relatively consistent outcome of PA values, but greater numbers of outliers in the rotation axis (both experience groups .

6.2.5.2 Variability of Individual Performance between experienced and novice lead clinicians

The individual lead clinician performance variability between the experienced and novice lead clinician was examined by a visual inspection of the individual boxplots for PA across all axes (figure 6-20). This analysis failed to show any specific trends between the two groups, with a wide range of performances apparent in both groups. Again, however, the sample size is probably too small to allow a definitive conclusion.

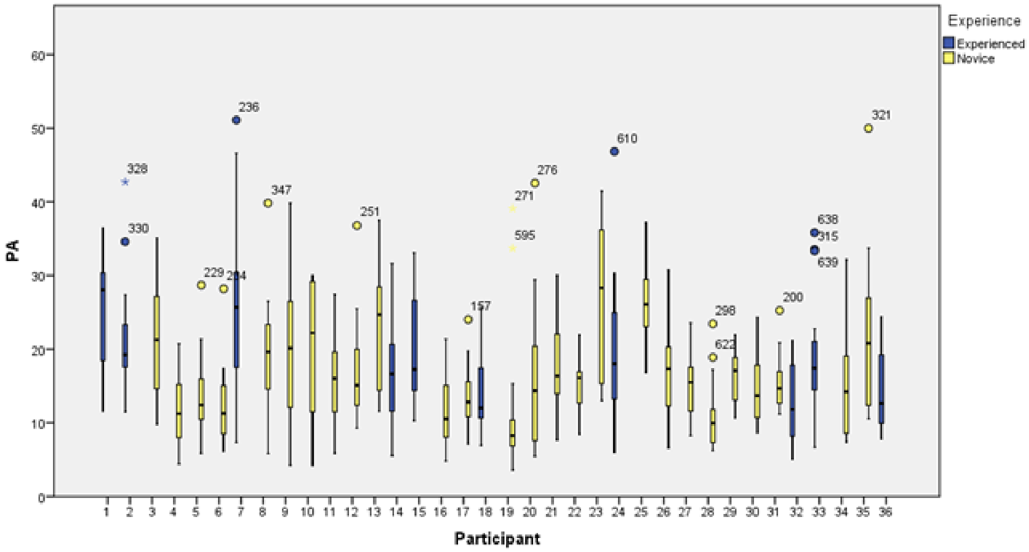

Figure 6-21 Boxplot of PA for each participant, highlighting exper4einced and novice participants

This boxplot presents the lead clinician median, interquartile range and outliers for all log rolls performed by the participants. The experienced participants are shown in blue, while the novice participants are shown in yellow. Considerable variability was demonstrated in both group, but is should be noted that the sample size was low and unevenly distributed between groups.

6.2.5.3 Differences in log roll dynamics between experienced and novice participants

The log roll dynamics for the two levels of experience show a trend for close correlation of lateral and flexion PA with AUC(figure 6-21a&b), but a slightly weaker correlation of the same variables in the rotation axis (figure 6-21c and Appendix G, Table 9-15). As previously defined in 6.2.3 above, the lack of correlation suggests spikes of rotation misalignment related to asynchronous movement of the log roll team. In this analysis it is apparent that the novice participants are slightly better than the experienced participants in preventing these sharp misalignments. Misalignments in the lateral and flexion axes are more sustained for the duration of the log roll, but do not seem to be affected by the experience of the participant. These findings suggest that those who have more recently learnt the techniques have a better capacity to control asynchronous movements of the head in relation to the thorax. However, this result must be regarded with some caution due to the small sample size of this study.

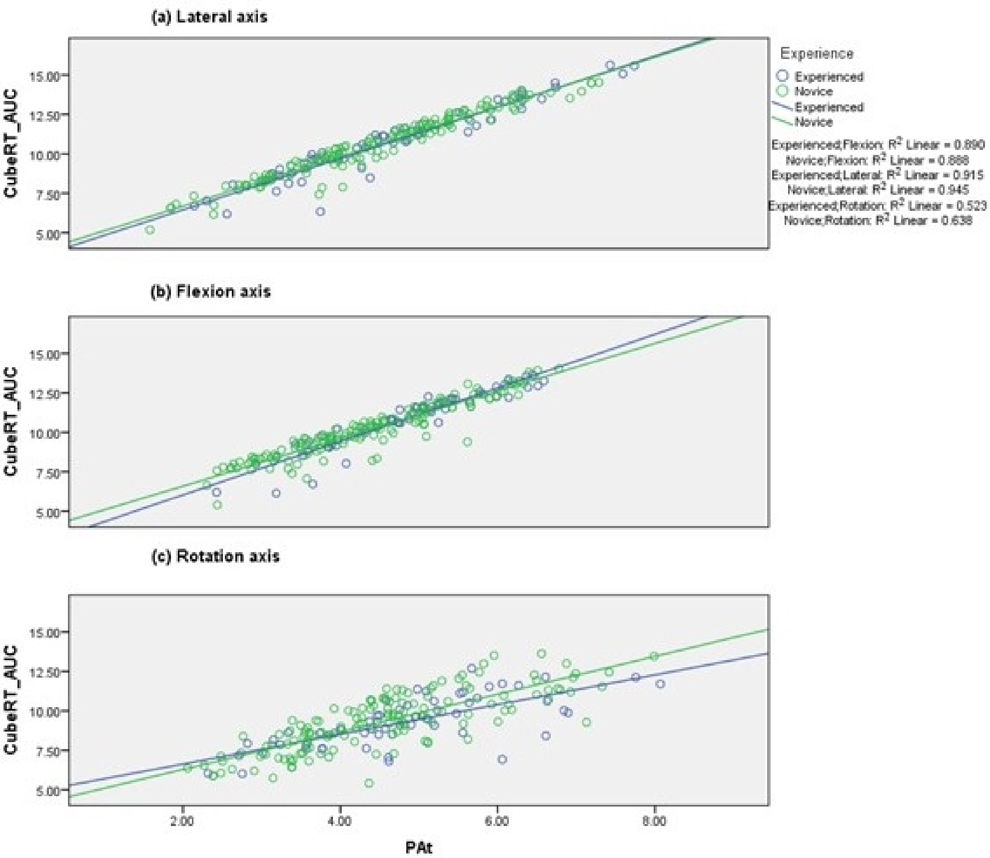

Figure 6-22Scatter plot of AUC against PA with data subdivided into experienced and novice participants.

A separate linear regression calculations for the experienced (shown in blue) and the novice group (shown in green) in (a) the lateral axis, (b) the flexion axis and (c) the rotation axis. These plots showed that PA could statistically significantly predict AUC in the lateral and flexion axis for both the experienced and novice groups with R^2 values of 0.888 or higher. PA could statistically significantly predict AUC in the rotation axis, but with weaker correlation; R^2(Rotation experienced) =0.523 and R^2(Rotation novice)=0.638. Notably the rotation experience category was less likely to produce a close correlation of PA with AUC than the rotation novice category, indicating a greater tendency to produce sharp spikes in rotation by the experienced participants.

6.3 Key findings

The log roll study has been able to support the following outcomes:

1. The IMU system is feasible to use in the simulated setting and reports cervical range of movement with sufficient accuracy to make it a feasible system for further biomechanical studies
2. Log rolls produce 16-18 degrees of misalignment in all axes, with all axes showing similar results.
3. There is a wide individual variability, and the individual generally has one single axis which produces the high misalignment. There is no discernible trend in the axis which has the highest misalignment.
4. Individuals who have low misalignment means tend to be consistent, while individuals with high misalignment means tend to be erratic. Team make-up may have influenced this result.
5. Lateral and flexion axes tend to produce broad lateral head drop and a forward flexion that last for the duration of the log roll. The rotation axis tends to produce sharp spikes of misalignment at the start of the initial movement and the start of the return movement.
6. The holding technique produces a small improvement in the rotation axis with the shoulder hold, showing less rotational misalignment than the head hold.
7. Novice participants tend to produce less misalignments than experienced participants, suggesting that skills maintenance is an issue. Again, team make-up may have influenced this result.

7 DISCUSSION

This study has been able to present a model of biomechanical analysis that allows the evaluation of the effectiveness of commonly employed spinal care techniques used in the prehospital setting. The system has proved to be accurate and capable of being utilised in a simulated setting relevant to paramedic practice. This study used the log roll manoeuvre, as a pilot study, to test the system's suitability for a wider application. Not only did the system provide an effective model for further studies, it also produced some clinically relevant outcomes. Most importantly, there appears to be an excessive amount of cervical misalignment produced during the log roll. This has important implications for the clinical setting which relies heavily on the log roll for the care of spinally injured patients. The misalignment does not demonstrate any axes dominance, but has differing characteristics in the rotation axis than the lateral bending and flexion-extension axes. Asynchronous patient handling movements between members of the clinician teams contributes to the misalignment seen in the rotation axis. Techniques to limit this rotational misalignment show some promise, but further refinement of the techniques is needed to optimise alignment. Skills performance may decay over time, with implications for the individual and organisations to ensure maintenance of skills.

7.1 Validation of the motion tracking system

Accuracy

Analysis of the data shows that the IMU system produced results 95% of the time. Missed data was experienced in 4.6% of the trials from such issues as overwriting files, failure to clear previous trial data, and possibly physical slippage of IMU within their harnesses. These errors do not represent a measure of accuracy or precision of the IMU devices; rather they indicate a procedural error with the operation. The convoluted process that must be followed to log data has proved to be problematic, but may be managed with close attention.

The capacity of the devices to report accurately to an error of approximately ±1 degree was validated using a simple board test. While this was a greater error than the manufacturer's reported accuracy, it probably represents a reasonable functional accuracy in the application of biomechanical motion capture. Skin artefact, which is the shearing of skin over the underlying bone, is likely to be one source of error in calculating joint movements (Theobald 2012, Gil-Agudo et al 2013),   Further refinement of the accuracy would be unlikely with the devices used for this experiment.

The reliability of the experimental design and the IMU accuracy, supports the suitability of the use of the IMU system for the measurement of cervical range of motion, but the limitation of accuracy and precision should be taken into account when reporting the study outcomes. In terms of clinical significance, an error of less than two degrees probably could be regarded as insignificant, although the motion required to cause neurological damage has never been reported (Conrad *et al.* 2012).

The measurement of head movement by motion tracking systems is a relatively new form of study.

Consistent with this literature (Jasiewicz et al 2007Saber-Sheikh et al. (2010) Bakhshi, Mahoor, et al. (2011), the outcomes of this study support the use of the

IMU system as a reliable motion tracking device that is capable of producing valid data in cervical spine kinematic research. Further studies using the system should achieve reliable data acquisition in relation to cervical spine movement from a variety of procedures. Problems identified in the current study, related to slippage of sensors or incorrect data management, are rectifiable with close attention to procedure, allowing potentially greater reliability and accuracy.

7.2 Variability in head control during the log roll

7.2.1 Variability between individuals

A high level of variability between participants was seen, both in terms of peak angles and between the axes of worst performance. Those with high variance tended to also have high median values, with a strong correlation between median values and variance values for the individual. This is suggestive that there is a tendency for some individuals to not only produce misalignment, but to also be erratic in performance. Additionally, there was no identifiable axis in which the poor alignment was worse. In contrast, approximately half the individuals were able to produce minimal misalignment and do so consistently.

As the skill is so frequently employed in the care of a trauma patient, and poor spinal alignment may cause secondary spinal cord injury, it is imperative that clinicians maintain a consistently high standard of skill. It may be concluded from the findings of this study that this level of consistency does not exist and there is a plausible possibility that clinicians in the field may cause spinal misalignment which may be dangerous for the trauma victim. This has been highlighted by Conrad et. al. (2012) who question the safety of the log roll in the setting of unstable spinal column injury.

Training may provide an answer to the skill level of the participant, but possibly the procedure is the fundamental issue. The log roll manoeuvre may be too difficult to consistently perform without causing an alarming degree of cervical misalignment. As a trauma patient would routinely be log rolled numerous time from the scene of the accident to the spinal injury unit, with many different individuals involved in the log rolls, it is almost certain that some log roll events will be poorly performed. Given the likelihood of misalignment, it may be appropriate to question the safety of the procedure and think about how patient movements may be engineered to eliminate the individual variation. Investigations should take place that seek a safe alternative method of patient movement that would eliminate the log roll from the normal practices in the prehospital and hospital setting for trauma patients.

7.2.2 Variability between axes

The analysis of the 216 trials of the log roll procedure showed that there was an average peak angle, or misalignment, of 17.4˚, 16.8˚ and 18.0˚ in the lateral, flexion and rotation axes respectively. It is apparent that no axis is worse than another. It is also evident that there is high variability in performance, shown by high variance values for each axis. Even within performances of individual participants, there is evidence of relative high variance. This reinforces the major finding; the procedure may be unreliable at maintaining a safe cervical spine alignment and it is highly dependent on individual performance.

If the log roll is considered in terms of a complex three dimensional set of movements, with the head moving through an arc in three dimensions, it may be seen that there are considerable challenges in ensuring spinal alignment. The leader of the team must not only judge the head position in relation to the body, but must also continually track the body motion and adjust the head position in the three dimensions to ensure alignment. Added to the difficulty of this procedure is the accurate synchronisation of the team to ensure the whole body and head moves in unison. Slight asynchronous movements tend to cause significant misalignment in the rotation axis. Conrad et al (2012) report similar results in a study of neck movement in cadavers with surgically produced neck fractures, tracked by an electromagnetic tracking system. In this study the investigators highlighted the adverse cervical misalignments that result from the log roll procedure and questioned the safety of the continued use of the log roll in clinical practice. They speculate that the resistance to change may be based on a lack of clinical evidence of injury resulting from the log roll. In the trauma setting where the victim suffers an initial injury, followed by numerous essential movements to extricate, examine and transport to an emergency department. It would be difficult to determine whether the initial insult or one of the many subsequent movements was the cause of the spinal cord injury.

Conrad et al (2012) also conclude that they have *"...been unable to determine how much motion of the unstable spine is required to cause secondary neurological injury"*. It is this paucity of evidence which poses the key question of 'how much is too much' in terms of neck motion. White et al (1975) described cervical instability as any horizontal displacement of adjacent vertebrae of more than 3.5mm or any angular rotation of adjacent vertebrae of more than 11 degrees. However, these measured were derived from radiological evaluation of individual vertebrae and do not provide meaningful criteria for gross neck movement. It is possible that this question will remain unanswerable, due to the highly individual nature of vertebral injuries, and the low incidence of manipulation induced secondary spinal cord injury. It remains reasonable to conclude that minimising neck movement to ensure minimal misalignment would be an appropriate clinical approach.

7.2.3 The effect of techniques on performance

This study sought to identify if the technique used to support the head influenced the peak angles recorded. The two techniques of head hold and shoulder hold proved to have only have little statistically significant differences, although axial rotation was slightly better controlled with the shoulder hold with a 1.6º mean difference While statistically significant, the clinical significance is difficult to define. There were slightly worse results seen in the lateral and flexion axes, although not consistently across all sub-groups. These differences were not statistically significant and certainly not clinically significant. The improvement in rotational control using the shoulder hold could be explained by examining the hold in detail. The hands of the participant grasp both shoulders which provides a cradle between the participant's forearms to receive the head. This tends to naturally align the head and shoulders well in terms of rotation. These results were consistent with the work by (Boissy *et al.* 2011), who found that the *"trap squeeze"*, which is the same as the shoulder hold, was more effective at limiting axial rotation, particularly with agitated patients. However, as the participant rolls the patient the alignment in the flexion axis tends to be disturbed due to a misalignment between the participant's forearms and the patient. This tends to flex the head of the patient. Similarly, the benefit of cradling the head of the patient is lost when both the participants' arms reach the apex of the log roll and are aligned vertically. In this situation the head tends to drop laterally compared with the head hold. The head hold, in contrast, tends to ensure slightly better control in flexion and rotation but allows greater freedom of movement in the rotation axis. Again, the clinical significance of these results remains unclear.

The issue of rotation spikes was evident from an examination of the graphical presentation of each trial. Commonly, these spikes relate to the commencement of a movement, whether that be the initial start of the log roll, or the commencement of return movement from the lateral posture toward the supine posture. It is at these moments where it is surmised that asynchrony between team members is at its greatest. These asynchronous movements, depicted as spikes in the relative angles, only occur in the rotation axis. The worst moment for asynchronous movement is the second phase of the log roll where the return movement commences, occurring 47% of the time compared with 19% of the time in the initial movement.

Spikes in rotation were noted in the head hold with greater frequency (38% of trials) than the shoulder hold (28% of trials), suggesting that it is more difficult to accurately synchronise movement within the team using the head hold. This provides some evidence to recommend the shoulder hold in preference to the head hold. However, it does not eliminate the overall evidence of excessive neck motion during the log roll.

Further studies are needed to investigate ways in which the excessive neck movement during patient handling may be reduced. The key focus of these studies should be the reduction of neck movement during the log roll, or the development of an alternative procedure that achieved the same outcomes as the log roll, but minimised the chance of neck movement. Once such alternative could be the use of a scoop stretcher device which does not require a log roll for placement under the patient. Comparing the range of neck movement between techniques and devices will provide strong evidence to validate clinical practice in this area.

7.2.4 The effect of experience on performance

Experience of the participant who takes command of the log roll was analysed. Each log roll was performed by a team of three, with the actual trials for a participant recorded when they were in command at the head of the patient. The performance of the trials was used to measure if experience of the lead participant had any impact on the performance of the team. It did not compare experienced teams with novice teams, as the teams were mixed. It only compared the experience of the lead participant. As previously stated, in 6.2.5.1, the lead clinician is crucial in directing the performance of the log roll, with other team members taking direction from the lead. Consequently, the performance attributed to the lead clinician is considered as the principal influence in the performance of the log roll. However, the performance of the other team members cannot be wholly disregarded as it could influence the outcomes.

The results showed that there was significant difference between experienced and novice leaders with experienced leaders producing slightly greater misalignment in all axes, but most pronounced in the flexion axis. Experience of the lead participant seemed to influence the peak angles, although the magnitude of this influence was negligible. The effects, while statistically significant, were small, with a mean difference, in the transformed data, of 0.466, which equates to approximately 1.5° in real terms.

The reason for slightly poorer performance of the experienced participants probably relates to retention of skills. It is suggestive that some individuals acquired the skills and were able to maintain those skills consistently, while others perhaps never acquired the skills adequately or the skill level has declined over time. Time since training may have had a role to play, with those who have not retrained recently having less success at the skill. This suggests a degradation in skills over time, although it should be placed in context of high individual variability of both the experienced and novice groups. Skills maintenance is a considerable issue in any clinical practice with decay of skills over time being a problem seen in the prehospital setting (De Lorenzo & Abbott 2007) .

7.3 Study limitations

The study of cervical spine movement with the IMU system has four limitations.

i. This study used the principle that any misalignment of the neck could cause neurological damage in the presence of an unstable spinal column injury. However the amount of movement required to cause spinal cord injury has not been established by any published research. Cadaver studies with surgically fractured necks, such as Del Rossi *et al.* (2004b) have been used to track movement during log roll execution, but these studies have not been directly linked to a prediction of neurological damage. Detailed biomechanical studies, such as Saari *et al.* (2011), have provide much information regarding the mechanisms of spinal cord injury, but have not shown how the unstable spine responds to minor neck movements after the initial damage. Nor does the literature report the effects of muscle and ligament tone of a live person on vertebral instability. It may be impossible to elucidate the degree if movement required to exacerbate an existing primary injury and cause a secondary spinal cord injury. However, biomechanical studies do provide a comparative measure of how much neck motion may be caused by a variety of procedures. This data may be used to identify procedures which minimise the risk of further spinal cord injury should there be instability in the cervical spine.

ii. The second limitation relates to the use of healthy volunteers as the patient. Lacking neck injuries, these volunteers had normal range of neck movement and could not replicate a person with a neck injury. How well supported a neck may be after an unstable cervical fracture is largely unknown, and could be quite dependent on the type of injury and the degree of muscle tone in the neck. In reality, the patient participant probably have some influence on the neck motion during the log roll.

iii. The final limitation of the study was the composition of the clinician teams. Each team comprised a leader, who controlled the patient's head, and two other members who rolled the body. Performance of the leader was recorded, but this performance was influenced by the skills of the other two members. In particular, the proficiency of the helpers in executing a smooth and well synchronised roll could have played a significant role in the leader's performance. The team performance was effectively measured, but attributed to the leader for sake of recording convenience.

iv. The IMU system was capable of reporting angular rotation, but its accuracy at reporting linear translation was poor. This means that this type neck movement could not be measured.

8 CONCLUSION

This study proposed the hypotheses that the log roll procedure did not produce any head movement in relation to the body. The results show, however, that this hypothesis was not supported, with a significant amount of head movement produced in all axes. Participants tended to allow the head to drop laterally and flex forward during the procedure. Asynchrony between the leader of the team and those rolling the body allowed sharp spikes of misalignment in the rotation axis. Although it cannot yet be determined how much misalignment is too great, it is likely that the amount of movement measured, ranging from 16 to 18 degrees in all axes, would be regarded as excessive. This brings into question the safety of the practice and prompts further study to seek safer alternatives.

An important outcome of the study was the identification of a widely varying performance between individuals in all axes. The study has not been able to identify why individuals varied, but did show that those with low misalignment were able to consistently maintain low values, while those with higher misalignment tended to be considerably more erratic in their performance. Further study is needed to ascertain the reasons for variations between individuals.

The study proposed that there would be no difference in performance using a technique of holding the patient's shoulders and head whilst performing a log roll compared with holding only the head. This hypothesis was not supported as there was a statistically significant improvement detected in the rotation axis using the shoulder hold, but this improvement was 1.6 degrees, the clinical significance of which still needs to be determined. This study cannot draw a conclusion that one technique is superior to the other, but a statistically insignificant worsening in the lateral and flexion axes using the shoulder hold, suggest that further study is required to fully evaluation the impact of the type of hold.

This study proposed that the experience of the participant plays no role in performance of the participant. This hypothesis was not supported with poorer performance by experienced participants than by novices. This is suggestive of a skills decline over time, and the currency of training may play a part in maintaining skills. The implication of this may be the need for a greater focus on training and retraining. However, these outcomes must be interpreted on the basis of a statistically significant difference of 1.5 degrees. The small size of the sample also makes it difficult to make any definitive conclusions with any degree of confidence. As discussed in 7.2.4 above, the trials were attributed to the lead clinicians' performance, but the influence of the other team members cannot be fully discounted, and the differences between experienced and novice lead clinicians may have been influenced by the random make-up of the teams.

Finally, this study proposed that the IMU system would be an effective motion tracking system that could be used in the biomechanical studies of neck motion. This hypothesis was supported with the IMU system found to reliably report angles of movement."

The results of this study have led to the following recommendations for future studies:

1. The IMU system is a valid and reliable system for further biomechanical research into joint motion in the prehospital setting. There are many

procedures frequently used in patient handling that have never been fully evaluated for their safety or efficiency. In the area of spinal immobilisation, there is a paucity of evidence that shows that any of the procedures are safe, effective or efficacious. The system can be used to examine cervical spine rotational movement in the areas of patient lifting, vehicle extrication and during ambulance transport. Comparative studies of the variety of spinal splinting devices are also recommended, such as the investigation the effect of a cervical collar, or any other spinal splint, on neck motion, using the un-splinted spine as a control.

2. The use of a healthy volunteer is problematic for the study as it does not replicate a trauma victim with an unstable cervical vertebral fracture. Further study into the design and manufacture of a manikin which could realistically represent both a stable range of movement and an inherent instability is recommended. This manikin, although it possibly would never truly represent the real spinal injured patient, could provide a reasonable standard that would produce consistent results for further studies.
3. Alternative patient movement procedures, in the setting of suspected neck trauma, should be developed, with the aim of replacing the log roll manoeuvre. The data from this study, and other studies, suggest that it is an unsafe procedure which cannot adequately control the amount of cervical spinal movement. Alternate procedures which are effective and practical in the prehospital setting should be explored, such as the use of alternative lifting techniques, the use of the scoop stretcher device and the evaluation of the cervical collar. It is recommended that a range of alternatives be evaluated by measuring neck movement with the IMU system.. All new systems of

patient handling should be simple and independent of fine motor skills of the participants to ensure consistent outcomes.

9 APPENDICES

9.1 Appendix A – Participation information sheet

FLINDERS UNIVERSITY
ADELAIDE • AUSTRALIA

GPO Box 2100

Adelaide 5001 Australia

Telephone: (+61 8) 8201 5512

Fax: (+61 8) 8357 6803

Email timothy.pointon@flinders.edu.au

SPINAL IMMOBILSATION RESEARCH

STUDY

PARTICIPANT INFORMATION SHEET

An investigation of the range of cervical spine movements incurred during spinal immobilisation procedures

This is a research project, and you do not have to be involved.

You are invited to participate in this study as an experienced emergency care provider or a student. Participants will be required to:-

- work in a team of three, taking turns at being the leader
- log roll a patient simulator and a human patient
- perform the log-roll a total of 18 times
- give up approximately 30 minutes of your time

Additionally the research will require two further volunteers to act as patients who will be fitted with small electromagnetic or accelerometer sensors to measure head movement during multiple log rolls. Over the period of the study, you will be log-rolled up to 90 times.

This study will measure how effective the log-roll technique is at maintaining a straight spine in a volunteer. It will also compare a human volunteer with a simulation manikin to determine how well the simulator replicates real human movements. Both experienced emergency care provides and students will be performing the log-rolls. The neck movement of the volunteer patient and the simulator will be recorded using an electromagnetic system and a purpose built accelerometer system. The researcher is looking for methods that may improve students learning and evaluating existing spinal care methods. In the future this information will allow the development of a learning package to train new student paramedics and possible improve clinical management of trauma patients.

While you are log-rolling the patients, the procedure will be recorded using both the electromagnetic and the accelerometer systems. Both systems are safe for use with humans with no harmful radiation emitted. You will not be asked to lift the patient, but correct manual handling techniques would be required to comfortably perform the log roll. To ensure your safety and success of the project, you will be expected to already have training in manual handling and log-roll techniques.

If you suffer injury as a result of participation in this research or study, compensation might be paid without litigation. However, such compensation is not automatic and you may have to take legal action to determine whether you should be paid.

Your participation in this study is entirely voluntary and you would be free to withdraw from study at any time without prejudice. All records containing personal information will remain confidential and no information that could lead to your identification will be released. According to usual practice, it is possible that the results of this study may be published in a scientific journal at a later date. It is possible that the results may not be published for commercial, scientific or other reasons.

The research team will not receive any financial benefit from enrolling you in this study, but the study will form the research project for the chief researcher's Masters of Health Science. Additionally, the technical support for the project will be provided by students in engineering and their work will form their Honour projects.

Should you require further details about the project, either before, during or after the study, you may contact Tim Pointon on 8201 5510, email to timothy.pointon@flinders.edu.au or by mail to the following address:-

Department of Paramedic and Social Health Sciences

Flinders University

GPO Box 2100

Adelaide SA 5001.

This study has been reviewed by the Flinders Clinical Research Ethics Committee. Should you wish to discuss the project with someone not directly involved, in particular in relation to matters concerning policies, your rights as a participant, or should you wish to make a confidential complaint, you may contact the Executive Officer, Research Ethics Committees, Ms. Carol Hakof, on 8204 4507.

9.2 Appendix B: Consent Form

CONSENT TO PARTICIPATION IN RESEARCH

I, ... request and give consent to my

first or given names surname

involvement in the research project:

An investigation of the range of cervical spine movements incurred during spinal immobilisation procedures.

I acknowledge that the nature, purpose and contemplated effects of the research project, especially as far as they affect me and have been fully explained to my satisfaction by:

Timothy Pointon

and my consent is given voluntarily

I acknowledge that detail(s) of the following procedure(s) has/have been explained to me, including indications of risks; any discomfort involved; anticipation of length of time and the frequency with which the procedure(s) will be performed:

EITHER: 1. Log-rolling of a patient and a simulated patient. This is a once only procedure which is anticipated to take 30 minutes of your time

OR: 2. Acting as a patient, which will require you to be fitted with sensors and log rolled 90 times. As a patient the procedure is expected to take 6 hours spread over 3 days

Strike out 1 or 2 above as appropriate

I have understood and am satisfied with the explanations that I have been given.

I have been provided with a written information sheet.

I understand that my involvement in this research project and/or the procedure(s) may not be of any direct benefit to me and that I may withdraw my consent at any stage without affecting my rights or the responsibilities of the researchers in any respect.

I acknowledge that I have been informed that should I receive an injury as a result of taking part in this study, I may need to start legal action to determine whether I should be paid.

I declare that I am over the age of 18 years.

Signature of research participant: .... Date: ....

Signature of Witness: ....

Printed Name of Witness:

I, Timothy Pointon have described to

the research project and the nature and effects of the procedure(s) involved. In my opinion he/she understands the explanation and has freely given his/her consent.

Signature: Date:

Status in project: Chief Researcher

9.3 Appendix C: Advertising for participants

Dept Paramedic & Social Health Sciences
Dept Anesthesia & Pain Medicine
School of Informatics & Engineering

EMERGENCY SPINAL IMMOBILISATION RESEARCH

Researcher: Tim Pointon

INVITATION TO PARTICIPATE

This study is the first phase of the evaluation of spinal immobilisation techniques used in the emergency setting. The aim of this research is to establish best practice in care of spinal injured trauma victims. This is a poorly studied area, with many of the procedures commonly used today having little evidence to prove their value. My goal is to produce some reliable evidence to fill this void.

The first part of this research is a pilot study, which will establish the best methods of measuring cervical spinal movements during care procedures. In conjunction with Honours students from the School of Informatics and Engineering, at Flinders University, we will be designing systems to measure actual head movement as patients are immobilised. Initially, we will start with a simple log-roll procedure as a test case.

The outcomes I wish to achieve are:-

- Development of a reliable, portable motion tracking system for future spinal research
- Analyse the safety of spinal care procedures we currently use
- Develop a superior training package for paramedic students and other in the health care industry

This study will measure how effective the log-roll technique is at maintaining a straight spine in a volunteer. It will also compare a human volunteer with a simulation manikin to determine how well the simulator replicates real human movements. The neck movement of the volunteer patient and the simulator will be recorded using an electromagnetic motion tracking system and a purpose built accelerometer system.

I would like to invited you to participate in this study either as emergency care provider or a patient. The data collection is expected to be conducted over several sessions in July and November 2007. As a participant, you will be asked to:-

- Work in a team with two other team members, taking turns at being the leader
- Log roll a simulated patient and a human patient
- perform the log-roll a total of 18 times
- Give up approximately 30 minutes of your time

If a patient, your commitment would include:-

- being fitted with small sensors which detect head movement
- being log-rolled 90 times over a period of 3 days

Note that the sensor system has been declared safe for use with humans.

As a participant in research you cannot be offered any financial incentive to encourage your participation. However, the reward for your effort will be the knowledge that you are helping to improve a vital part of trauma management and aiding professionalization of your industry.

Results from the study will be analysed and presented as a thesis for my Masters in Prehospital and Emergency Care. I expect to also publish my finding in a scientific journal. No participants will be identified within any of the reports or publications.

Please contact Tim Pointon on the numbers shown if you would like more details.

Tim Pointon
Chief Researcher

Co-researchers
Prof Harry Owen
A/Prof Karen Reynolds
Dr John Plummer

Phone: 8201 5510
Mob: 0400 513 651
E-mail: timothy.pointon@flinders.edu.au

FLINDERS UNIVERSITY
ADELAIDE • AUSTRALIA

9.4 Appendix D: Insurance approval

Date: Fri, 13 Apr 2007 11:24:35 +0930

From: Mike Stevens <mike.stevens@flinders.edu.au>

To: Tim Pointon <timothy.pointon@flinders.edu.au>

Subject: Project Title: An investigation of the range of cervical spine movements incurred during spinal immobilisation procedures.

Hello Tim

The above project will be indemnified under the University's liability protection program for the duration of the study.

You may attach a copy of this email to your ethics application as confirmation of the above.

Regards

Mike

Tim Pointon wrote:

> Dear Mike

>

> Could you please examine my ethics application (attached) for

> insurance implication? I was advised to send it to you for your

> appraisal. If this is not the correct process, could you let me know

> how it should be done?

>

> Thanks

> --

>

> Tim Pointon

>> Course Coordinator – BHS Paramedic

>> Flinders University

>> Ph 8201 5510

>> Fax 8357 6803

>> Mob 0400 513 651

>

/Mike Stevens/

/Flinders University Adelaide Australia

Insurance Officer

Financial Administration

Ph (08) 8201 2618

Fax (08) 8201 3066

mike.stevens@flinders.edu.au <mailto:mike.stevens@flinders.edu.au>*

*/ http://www.flinders.edu.au/finance/html/insurance/index.h

<http://www.flinders.edu.au/finance/html/insurance/index.html>

9.5 Appendix E: Letter of ethics approval

FLINDERS MEDICAL CENTRE
Flinders Clinical Research Ethics Committee
FWA00001785
IRB00001792

Government of South Australia
Southern Adelaide Health Service

22 May 2007

Bedford Park 5042
South Australia

Level 2
Room 2A221
Telephone
08 8204 6453
Facsimile
08 8204 4586

MEMORANDUM

TO: Mr. T. Pointon, Department of Paramedic & Social Health Science

FROM: Ms. C. Hakof, Executive Officer, Flinders Clinical Research Ethics Committee

TOPIC: **Review of Research Application**

The Flinders Clinical Research Ethics Committee (FCREC) considered your application at the meeting held on 14 May 2007, with the following result:

Approval Status: CONDITIONAL

Period of Approval: 14 May 2007 to 14 May 2010

067/154.9 L1

Research Application 198/067 – Mr. T. Pointon
An investigation of the range of cervical spine movements incurred during spinal immobilization procedures.
Reviewer: Mr. A. Govier

This application was approved subject to the following:

1. Clarify withdrawal criteria.
2. A separate information sheet and consent form are required for volunteers and patients.
3. Provide reimbursement of parking expenses for any extra visits to the campus.
4. Clarify if patients will require any extra padding of pressure points due to extra rolling time.
5. Clarify how the investigator will ensure that OHS requirements are met.
6. Changes to the advertisement which have been forwarded to the investigator.

As there was no quorum, this approval will be ratified at the next meeting. The investigator will only be notified if there are any further queries.

Please note the terms under which ethical approval is granted

1. **If conditional** *('subject to' or 'in principle')* approval is granted, research involving human subjects **may proceed only after written acceptance of the conditions of approval** (including a copy of the modifications) has been received by the Committee.
2. Researchers are required to immediately report to the FCREC anything which might warrant review of ethical approval of the project, including:
   a. Adverse effects of the project on participants, including the total number of participants recruited, and of steps taken to deal with these adverse effects.
   b. Proposed changes in the project.
   c. A change in the base for a decision made by the Committee, e.g. new scientific information that may invalidate the ethical integrity of the project.
   d. Other unforeseen events which might affect continued ethical acceptability of the project.
3. Projects are approved for up to 3 years only and a progress report must be provided annually. Extensions after 3 years will not be granted without a report to the Committee and the provision of an updated submission.
4. Confidentiality of the research participants shall be maintained at all times as required by law.

The Flinders Clinical Research Ethics Committee is constituted and operates in accordance with the National Health and Medical Research Council's National Statement on Ethical Conduct in Human Research (March 2007).

Addendum to Pointon20070430

1. The Participant information sheet - Introduction

For many years ambulance and other emergency care providers have been managing victims of spinal cord injury with little or no evidence to support their practices. My goal is to begin to fill this void in our knowledge of spinal care so that we may practice with confidence in our training and our procedures. This study is designed to examine the effectiveness of commonly practiced spinal care and immobilisation procedures. It will be achieved by accurate measurements of head movement in relation to the body in the performance of a simple procedure; the log-roll. Included in the scope of the study will be the development and fine tuning of an effective measuring system which is sensitive enough to detect fine head movements. Another aim of the study is the comparison of the head movement of a human compared to that of a manikin. In future research experience gained from this study will be applied to more complex procedures and more realistic environments. It is expected that the research will provide valuable evidence to guide future emergency care of spinal injured patients. In addition, lessons learnt will help to steer directions in the development of training packages for students.

2. The withdrawal criteria

All participants will be free to withdraw from participation at any time, at there own discretion, without prejudice. In addition, any participant who demonstrates any adverse effects from the participation will be requested to withdraw. As adverse effects such as neck, shoulder or back pain are exclusion criteria, participants who demonstrate these effects will be excluded from re-entering the study.

9.6 Appendix F: Instrument start-up procedure

Start-up procedure for Inertia Cube 3

Step 1: Sensor capture

1. Plug in receiver to USB port and batteries to sensors.
2. Run IServer as administrator.
3. Watch start up screen it should say trackers detected (screen disappears quickly). If successful there will be two lights on both the sensors and the receiver (may take up to two minutes).
    a. If only one tracker detected place both sensors and the reciever into metal container to force detection. Right click iserver icon in tray>select detect trackers. Once detected all items can be removed. Note that low battery levels may cause connection problems; lithium ion batteries are recommended.
4. Open IsDemo as administrator.
5. Select DLL component>Accept.
6. A screen with two sensors should appear. Chose one.
7. Open IsDemo again as administrator; DLL>accept.
8. When two sensors list appears choose the other sensor.
9. Both sensors should be working and displayed on IsDemo.

Step 2: Data recording setup

1. Run IsPlot(as administrator).
2. TRACKER>CONNECT. (Alert screen appears "Failed to set up ring buffers. Retry with ring buffers disabled?" >YES)
3. Should find 2 stations; 5212 and 6586
4. Select first station; 5212; Isplot screen appears.
5. To add the second sensors select TRACKER>SET STATION, choose the second station 6585.
6. Clear recording by PLOT>CLEAR. This will clear both station recordings.
7. Data from each sensor can be viewed by switching the view between each sensor. The program put sensor number 5212 on the top line and sensor number 6586 on the bottom line.

Step 3: Attach sensors to patient

1. Ensure same orientation; battery cord inferior.
2. Using the fabricated neoprene straps, place sensors and batteries in the pouches provided
3. Ensure correct anatomical alignment; sensor 5212, midline forehead 1 cm superior to eyebrows and sensor 6586, midline sternum at level of 4th rib.
4. Ensure participants moves carefully to prevent mal-positioning of sensors

Step 4: Record data

1. Ensure both screens are clear. Start with station 5212 on view.
2. Press RECORD.
    a. Note: when recording only one plot will be displayed at a time but both will be captured.
3. Perform single log roll.
4. Press STOP.
    a. Check data capture by rewinding to beginning and replay.
5. SAVE 5212 data by LOG>SAVE CURRENT.
    a. Popup screen requests file name (e.g. LOG ROLL 1 HEAD).
6. Load other sensor data by TRACKER>SET STATION, select bottom station (i.e. 6586)>OK. This new data will be displayed and needs to be saved.
7. Save 6586 data by LOG>SAVE CURRENT.
    a. Pop up screen , type in name> SAVE.
8. **Don’t use the auto prompt message as it will overwrite the previous log roll.**
9. Once saved, clear data by PLOT>CLEAR- CLEAR ALL>OK.
10. Change view to top tracker station (5211) via TRACKER>SET STATION>select top station.
11. Ensure screen clear before recording again.

9.7 Appendix G: Statistical analysis tables

Table 9-1 Descriptive statistics for Peak Angle (PA) for each axis

Peak angle statistics are presented for each axis; lateral, flexion and rotation. The peak angle data did not fulfil assumptions of normality so a bootstrap method was used to determine confidence intervals using 1000 bootstrap samples.

Descriptives
PA

				Bootstrap[a]			
						95% Confidence Interval	
			Statistic	Bias	Std. Error	Lower	Upper
Lateral	N		206	0	12	183	230
	Mean		17.39547	-.03463	.57312	16.20764	18.50435
	Std. Deviation		8.696902	-.030329	.476947	7.752610	9.616213
	Std. Error		.605942				
	95% Confidence Interval for Mean	Lower Bound	16.20079				
		Upper Bound	18.59015				
	Minimum		3.574				
	Maximum		46.606				
Flexion	N		206	0	12	183	230
	Mean		16.79044	-.01510	.48438	15.88029	17.72909
	Std. Deviation		7.028746	-.027487	.289836	6.444533	7.577774
	Std. Error		.489716				
	95% Confidence Interval for Mean	Lower Bound	15.82492				
		Upper Bound	17.75597				
	Minimum		5.559				
	Maximum		35.131				
Rotation	N		203	0	12	179	225
	Mean		17.98858	.00576	.63406	16.80462	19.26274
	Std. Deviation		9.061093	-.047350	.565768	7.932433	10.136374
	Std. Error		.635964				
	95% Confidence Interval for Mean	Lower Bound	16.73460				
		Upper Bound	19.24256				
	Minimum		4.816				
	Maximum		51.118				
Total	N		615	0	0	615	615
	Mean		17.38858	-.01670	.33435	16.75362	18.03614
	Std. Deviation		8.306501	-.015637	.288086	7.734926	8.837844
	Std. Error		.334950				
	95% Confidence Interval for Mean	Lower Bound	16.73080				
		Upper Bound	18.04637				
	Minimum		3.574				
	Maximum		51.118				

a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

Table 9-2: Multiple comparison of peak angle in axes

Differences between axes were analysed by using one-way analysis of variance (ANOVA). The data was transformed to the logarithm (base 10) of the variable to satisfy the assumptions of the tests. As the assumption of homogeneity of variances was not violated, as assessed by Levene's Test of Homogeneity of Variance (p = .112) a post-hoc Bonferroni test was performed. There was no statistically difference between any axes.

Multiple Comparisons: Axis PA						
Bonferroni post-hoc test Dependent variable: Log(PA)						
(I) Axis	(J) Axis	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Lateral	Flexion	.00001	.02093	1.000	-.0502	.0503
	Rotation	-.02636	.02093	.625	-.0766	.0239
Flexion	Rotation	-.02638	.02093	.624	-.0766	.0239

Table 9-3 Multiple comparison of peak angles in axes

Differences between axes were analysed by using one-way analysis of variance (ANOVA). The data was transformed to the logarithm (base 10) of the variable to satisfy the assumptions of the tests. As the assumption of homogeneity of variances was violated, as assessed by Levene's Test of Homogeneity of Variance (p = .005) a post-hoc Games-Howell test was performed. Significant differences were not found between axes in either the low or high groups.

Multiple Comparisons: Axis PA (high & low groups)						
Games-Howell post-hoc test Dependent variable: Log(PA)						
(I) by axis	(J) by axis	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Lat low	Flex low	-0.00446	0.02469	1.000	-0.0755	0.0666
	Rot low	-0.06483	0.02748	0.176	-0.1439	0.0142
Flex low	Rot low	-0.06038	0.02565	0.178	-0.1342	0.0135
Lat high	Flex high	0.00436	0.02612	1.000	-0.0708	0.0795
	Rot high	0.00993	0.02991	.999	-0.0761	0.0960
Flex high	Rot high	0.00557	0.02712	1.000	-0.0725	0.0836

Table 9-4: Multiple comparison of AUC in axes

*Differences between axes were analysed by using one-way analysis of variance (ANOVA). The data was transformed to the square root of the variable to satisfy the assumptions of the tests. As the assumption of homogeneity of variances was violated, as assessed by Levene's Test of Homogeneity of Variance (p =0 .005) a post-hoc Games-Howell test was performed. The lateral and flexion axes were not statistically difference from one another. However, the lateral axis was statistically significantly greater than the rotation axis (indicated by *) and the flexion axis was statistically significantly greater than the rotation axis (indicated by **). This indicates that lateral and flexion movements are more likely to be misaligned for a more prolonged period than rotation.*

Multiple Comparisons: Axis AUC						
Games-Howell post-hoc test Dependent Variable: SQRT(nAUC)						
(I) Axis	(J) Axis	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Lat	Flex	1.5511165	0.9180185	0.210	-0.608560	3.710793
	Rot	6.1840291*	0.9160908	**0.000**	4.028873	8.339185
Flex	Rot	4.6329126**	0.8279322	**0.000**	2.685404	6.580421

Table 9-5: Multiple comparison of AUC split by median values for each axis

Differences between axes were analysed by using one-way analysis of variance (ANOVA). The data was transformed to the square root of the variable to satisfy the assumptions of the tests. As the assumption of homogeneity of variances was violated, as assessed by Levene's Test of Homogeneity of Variance (p < .005) a post-hoc Games-Howell test was performed. Significant differences were found between the rotation axis and the lateral and flexion axes in the high group. No differences between axes were noted within the low group. This indicates that the high group differed from the low group in the lateral and flexion axes, but not the rotation axis.

Multiple Comparisons: Axis AUC (low & high groups)						
Games-Howell post-hoc test Dependent variable: SQRT_AUC						
(I) by axis	(J) by axis	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Lat low	Flex low	.55814	1.07195	0.995	-2.5255	3.6418
	Rot low	2.83432	1.09731	0.106	-0.3220	5.9906
Flex low	Rot low	2.27619	1.05159	0.259	-0.7486	5.3010
Lat high	Flex high	3.03252	1.27732	0.171	-0.6471	6.7121
	Rot high	9.51191*	1.32784	**0.000**	5.6881	13.3357
Flex high	Rot high	6.47940*	1.19467	**0.000**	3.0391	9.9197
*. The mean difference is significant at the 0.05 level.						

Table 9-6 Cross tabulation of lead clinician mean and variance

Association between lead clinician mean and variance values for were conducted with a Fisher' Exact Test use due to the small counts (less than 5) in 66.7% of cells. Chi-Squared Tests (Fisher's Exact) showed an association between means and variance: ; $\chi^2(1) = 9.118$, $p = .046$. This association was moderate; Cramer's $V = 0.374$, $p = .039$. The association was strongest in the lateral bending, moderate in flexion-extension and only weak in rotation as shown in red outlined cells.

Axis_worst_mean * Axis_worst_var Crosstabulation

			Axis_worst_var			
			lat	flex	rot	Total
Axis_worst_mean	lat	Count	**9**	1	3	13
		Expected Count	**5.4**	3.3	4.3	13.0
		% within Axis_worst_mean	69.2%	7.7%	23.1%	100.0%
		% within Axis_worst_var	60.0%	11.1%	25.0%	36.1%
		% of Total	25.0%	2.8%	8.3%	36.1%
	flex	Count	3	**7**	5	15
		Expected Count	6.3	**3.8**	5.0	15.0
		% within Axis_worst_mean	20.0%	46.7%	33.3%	100.0%
		% within Axis_worst_var	20.0%	77.8%	41.7%	41.7%
		% of Total	8.3%	19.4%	13.9%	41.7%
	rot	Count	3	1	**4**	8
		Expected Count	3.3	2.0	**2.7**	8.0
		% within Axis_worst_mean	37.5%	12.5%	50.0%	100.0%
		% within Axis_worst_var	20.0%	11.1%	33.3%	22.2%
		% of Total	8.3%	2.8%	11.1%	22.2%
Total		Count	15	9	12	36
		Expected Count	15.0	9.0	12.0	36.0
		% within Axis_worst_mean	41.7%	25.0%	33.3%	100.0%
		% within Axis_worst_var	100.0%	100.0%	100.0%	100.0%
		% of Total	41.7%	25.0%	33.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probability
Pearson Chi-Square	10.045[a]	4	.040	.039		
Likelihood Ratio	10.135	4	.038	.063		
Fisher's Exact Test	**9.118**			**.046**		
Linear-by-Linear Association	2.793[b]	1	.095	.100	.062	.026
N of Valid Cases	36					

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is 2.00.
b. The standardized statistic is 1.671.

Symmetric Measures

		Value	Approx. Sig.	Exact Sig.
Nominal by Nominal	Phi	.528	.040	.039
	Cramer's V	**.374**	**.040**	**.039**
N of Valid Cases		36		

Table 9-7 Linear Modelling; PA and AUC

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	PAt[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: CubeRT_AUC

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.843[a]	.711	.711	1.05332	.951

a. Predictors: (Constant), PAt

b. Dependent Variable: CubeRT_AUC

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1676.727	1	1676.727	1511.272	.000[a]
	Residual	680.111	613	1.109		
	Total	2356.838	614			

a. Predictors: (Constant), PAt

b. Dependent Variable: CubeRT_AUC

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	3.810	.168		22.719	.000	3.481	4.140
	PAt	1.384	.036	.843	38.875	.000	1.314	1.454

a. Dependent Variable: CubeRT_AUC

The regression equation is:

$$\sqrt[3]{AUC} = 3.81 + (1.38 * \sqrt[3]{PA})$$

Table 9-8 Linear Modelling; PA and AUC - Rotation axis only

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	PAt[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: CubeRT_AUC

c. Models are based only on cases for which Axis = Rotation

Model Summary[b,c]

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson Statistic	
	Axis = Rotation (Selected)	Axis ~= Rotation (Unselected)				Axis = Rotation (Selected)	Axis ~= Rotation (Unselected)
1	.773[a]	.955	.597	.595	1.13125	1.595	.306

a. Predictors: (Constant), PAt

b. Unless noted otherwise, statistics are based only on cases for which Axis = Rotation.

c. Dependent Variable: CubeRT_AUC

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	381.527	1	381.527	298.130	.000[a]
	Residual	257.227	201	1.280		
	Total	638.753	202			

a. Predictors: (Constant), PAt

b. Dependent Variable: CubeRT_AUC

c. Selecting only cases for which Axis = Rotation

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	4.191	.307		13.631	.000	3.585	4.798
	PAt	1.107	.064	.773	17.266	.000	.981	1.234

a. Dependent Variable: CubeRT_AUC

b. Selecting only cases for which Axis = Rotation

The regression equation is:

$$\sqrt[3]{AUC} = 4.191 + (1.107 * \sqrt[3]{PA})$$

Table 9-9 Linear Modelling PA & AUC - Rotation axis excluded

Variables Entered/Removed[b,c]

Model	Variables Entered	Variables Removed	Method
1	PAt[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: CubeRT_AUC

c. Models are based only on cases for which Axis ~= Rotation

Model Summary[b,c]

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson Statistic	
	Axis ~= Rotation (Selected)	Axis = Rotation (Unselected)				Axis ~= Rotation (Selected)	Axis = Rotation (Unselected)
1	.955[a]	.773	.912	.912	.57209	1.334	.738

a. Predictors: (Constant), PAt

b. Unless noted otherwise, statistics are based only on cases for which Axis ~= Rotation.

c. Dependent Variable: CubeRT_AUC

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1391.291	1	1391.291	4251.050	.000[a]
	Residual	134.186	410	.327		
	Total	1525.477	411			

a. Predictors: (Constant), PAt

b. Dependent Variable: CubeRT_AUC

c. Selecting only cases for which Axis ~= Rotation

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	3.401	.113		30.204	.000	3.180	3.623
	PAt	1.572	.024	.955	65.200	.000	1.525	1.620

a. Dependent Variable: CubeRT_AUC

b. Selecting only cases for which Axis ~= Rotation

The regression equation is:

$$\sqrt[3]{AUC} = 3.401 + (1.572 * \sqrt[3]{PA})$$

Table 9-10 Peak angle: one way analysis of variance in technique

Differences between axes were analysed by using one-way analysis of variance (ANOVA). The data was transformed using the Box-Cox formula to satisfy the assumptions of the tests. As the assumption of homogeneity of variances was not violated, as assessed by Levene's Test of Homogeneity of Variance (p =0.07) a post-hoc Bonferroni test was performed. Statically significant differences were found in the rotation axis with head > shoulders; p=0.007, but not for the lateral axis; p=0.161 or flexion axis; p=0.169.

Pairwise Comparisons

Dependent Variable:PAt

Axis	(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
Lateral	Head	Shoulders	-.256	.183	.161	-.615	.102
Flexion	Head	Shoulders	-.251	.183	.169	-.610	.107
Rotation	**Head**	**Shoulders**	**.498***	**.184**	**.007**	**.136**	**.859**

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Univariate Tests

Dependent Variable:PAt

Axis		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Lateral	Contrast	2.729	1	2.729	1.967	.161	.003
	Error	836.504	603	1.387			
Flexion	Contrast	2.630	1	2.630	1.896	.169	.003
	Error	836.504	603	1.387			
Rotation	Contrast	10.154	1	10.154	7.320	.007	.012
	Error	836.504	603	1.387			

Each F tests the simple effects of Technique within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Table 9-11 AUC: one way analysis of variance in technique

Differences between techniques were analysed by using one-way analysis of variance (ANOVA). The data was transformed to the cube root AUC to satisfy the assumptions of the tests. As the assumption of homogeneity of variances was not violated, as assessed by Levene's Test of Homogeneity of Variance (p =0.07) a post-hoc Bonferroni test was performed. Statically significant differences were found in the rotation axis with head > shoulders (p=0.39).

Pairwise Comparisons

Dependent Variable:CubeRT_AUC

Axis	(I) Technique	(J) Technique	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
Lateral	Head	Shoulders	-.440	.291	.131	-1.010	.131
Flexion	Head	Shoulders	-.197	.291	.497	-.768	.373
Rotation	Head	Shoulders	.600*	.291	.039	.029	1.170

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Univariate Tests

Dependent Variable:CubeRT_AUC

Axis		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Lateral	Contrast	8.056	1	8.056	2.292	.131	.004
	Error	2129.943	606	3.515			
Flexion	Contrast	1.622	1	1.622	.461	.497	.001
	Error	2129.943	606	3.515			
Rotation	Contrast	14.982	1	14.982	4.263	.039	.007
	Error	2129.943	606	3.515			

Each F tests the simple effects of Technique within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Table 9-12 Linear Regression: PA as a predictor of AUC by technique and axis

Analysis of the predictive value of PA (transform to PAt) of AUC (transformed CubeRT AUC). Each technique in each axis was calculated separately to produce an independent R Squared value for that technique. Assumption linearity, no significant outliers or influential points, independence of errors (residuals), homoscedasticity of residuals and normal distribution of errors were met.

Model Summary

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson Statistic	
	by tech & axis = Head Lat (Selected)	by tech & axis ~= Head Lat (Unselected)				by tech & axis = Head Lat (Selected)	by tech & axis ~= Head Lat (Unselected)
1	.972[a]	.821	.944	.944	.50698	1.173	.755
	by tech & axis = Shoulders Lat (Selected)	by tech & axis ~= Shoulders Lat (Unselected)				by tech & axis = Shoulders Lat (Selected)	by tech & axis ~= Shoulders Lat (Unselected)
2	.961[a]	.830	.924	.924	.53565	1.465	.735
	by tech & axis = Head Flex (Selected)	by tech & axis ~= Head Flex (Unselected)				by tech & axis = Head Flex (Selected)	by tech & axis ~= Head Flex (Unselected)
3	.942[a]	.836	.888	.887	.55363	1.470	.804
	by tech & axis = Shoulders Flex (Selected)	by tech & axis ~= Shoulders Flex (Unselected)				by tech & axis = Shoulders Flex (Selected)	by tech & axis ~= Shoulders Flex (Unselected)
4	.945[a]	.828	.893	.892	.60458	1.341	.925
	by tech & axis = Head Rot (Selected)	by tech & axis ~= Head Rot (Unselected)				by tech & axis = Head Rot (Selected)	by tech & axis ~= Head Rot (Unselected)
5	.694[a]	.897	.482	.476	1.23972	1.367	.501
	by tech & axis = Shoulders Rot (Selected)	by tech & axis ~= Shoulders Rot (Unselected)				by tech & axis = Shoulders Rot (Selected)	by tech & axis ~= Shoulders Rot (Unselected)
6	.839[a]	.862	.705	.701	.97414	1.826	.457

a. Predictors: (Constant), PAt
c. Dependent Variable: CubeRT_AUC

Table 9-13 Peak angle: one way analysis of variance in experience

Differences between experience groups were analysed by using one-way analysis of variance (ANOVA). The data was transformed using the Box-Cox formula to satisfy the assumptions of the tests. As the assumption of homogeneity of variances was not violated, as assessed by Levene's Test of Homogeneity of Variance (p =0.07) a post-hoc Bonferroni test was performed. The experienced participants performed worse than novice participants in the flexion axis, producing statically significant larger peak angle results. This trend was seen in the lateral an rotation axes, but did not produce a statistically significant result.

Pairwise Comparisons

Dependent Variable:PAt

Axis	(I) Experience	(J) Experience	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
Lateral	Experienced	Novice	.228	.183	.211	-.130	.587
	Novice	Experienced	-.228	.183	.211	-.587	.130
Flexion	Experienced	Novice	.466*	.183	.011	.108	.825
	Novice	Experienced	-.466*	.183	.011	-.825	-.108
Rotation	Experienced	Novice	.312	.184	.091	-.050	.673
	Novice	Experienced	-.312	.184	.091	-.673	.050

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Table 9-14 AUC: one way analysis of variance in experience

Differences between experience groups were analysed by using one way analysis of variance (ANOVA). The data was transformed using the cubed root to satisfy the assumptions of the tests. As the assumption of homogeneity of variances was not violated, as assessed by Levene's Test of Homogeneity of Variance (p =0.07) a post-hoc Bonferroni test was performed. The experienced participants demonstrated worst misalignment in AUC only in the flexion axis.

Pairwise Comparisons

Dependent Variable:CubeRT_AUC

Axis	(I) Experience	(J) Experience	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
Lateral	Experienced	Novice	.262	.291	.368	-.309	.832
	Novice	Experienced	-.262	.291	.368	-.832	.309
Flexion	Experienced	Novice	.682*	.291	.019	.112	1.253
	Novice	Experienced	-.682*	.291	.019	-1.253	-.112
Rotation	Experienced	Novice	.004	.291	.988	-.566	.575
	Novice	Experienced	-.004	.291	.988	-.575	.566

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

*. The mean difference is significant at the .05 level.

Table 9-15 Linear Regression PA as a predictor of AUC by experience and axis

Analysis of the predictive value of PA (transform to PAt) of AUC (transformed CubeRT AUC). Each experience group in each axis was calculated separately to produce an independent R Squared value for experienced and novice participants. Assumption linearity, no significant outliers or influential points, independence of errors (residuals), homoscedasticity of residuals and normal distribution of errors were met.

Model Summary[b,c]

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson Statistic	
	by exp & axis = Exp Lat (Selected)	by exp & axis ~= Exp Lat (Unselected)				by exp & axis = Exp Lat (Selected)	by exp & axis ~= Exp Lat (Unselected)
1	.954[a]	.831	.910	.908	.68836	1.689	.801
Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson Statistic	
	by exp & axis = Nov Lat (Selected)	by exp & axis ~= Nov Lat (Unselected)				by exp & axis = Nov Lat (Selected)	by exp & axis ~= Nov Lat (Unselected)
1	.975[a]	.820	.951	.950	.43961	1.295	.729
Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson Statistic	
	by exp & axis = Exp Flex (Selected)	by exp & axis ~= Exp Flex (Unselected)				by exp & axis = Exp Flex (Selected)	by exp & axis ~= Exp Flex (Unselected)
1	.944[a]	.836	.891	.888	.60298	2.020	.930
Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson Statistic	
	by exp & axis = Nov Flex (Selected)	by exp & axis ~= Nov Flex (Unselected)				by exp & axis = Nov Flex (Selected)	by exp & axis ~= Nov Flex (Unselected)
1	.939[a]	.828	.882	.881	.57676	1.375	.862
Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson Statistic	
	by exp & axis = Exp Rot (Selected)	by exp & axis ~= Exp Rot (Unselected)				by exp & axis = Exp Rot (Selected)	by exp & axis ~= Exp Rot (Unselected)
1	.701[a]	.878	.492	.482	1.13377	1.689	.474
Model	R		R Square			Durbin-Watson Statistic	

	by exp & axis = Nov Rot (Selected)	by exp & axis ~= Nov Rot (Unselected)		Adjusted R Square	Std. Error of the Estimate	by exp & axis = Nov Rot (Selected)	by exp & axis ~= Nov Rot (Unselected)
1	.805[a]	.882	.648	.645	1.08754	1.366	.410

a. Predictors: (Constant), PAt

c. Dependent Variable: CubeRT_AUC

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