UNIVERSITY OF CAPE TOWN
FACULTY OF HEALTH SCIENCES
DEPARTMENT OF LOGOPAEDICS

DEVELOPMENTAL LIMB APRAXIA IN DEAF CHILDREN: AN OBJECTIVE ASSESSMENT

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A study submitted to the University of Cape Town, Faculty of Health Sciences, Department of Logopaedics, in fulfilment of the requirements for the Degree of Master of Science in Speech and Language Pathology. 2000

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DEDICATION

In loving memory of my father,
Who is the inspiration in my life!

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"You were my strength when I was weak
You were my voice when I couldn't speak
You were my eyes when I couldn't see
You saw the best there was in me
Lifted me up when I couldn't reach
You gave me faith because you believed
I'm everything I am
Because you love me!"
(Dianne Warren, 1996;
Sung by Celine Dion, 1996)

DECLARATION

I, ANGELA KINSELLA, hereby declare that the work on which this thesis is based is my original work (except where acknowledgements indicate otherwise), and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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Signature

30.10.2000

Date

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ABSTRACT

This study determines the presence of developmental limb apraxia in deaf signing children and in an oral hearing-impaired child who presents with oral apraxia. The VICON 370 Motion Analysis System was adapted to objectively assess the presence of this disorder and to illustrate differences in patterns of movement between the experimental and control subjects. The execution of motor performance of praxic functioning was analysed on a continuum of complexity across signs, gestures and a meaningless movement sequence. Quantitative measures of kinematic abnormalities, spatial parapraxias, temporal qualities, quantitative elbow joint angles, resultant trajectories of elbow position and wrist joint centre were obtained. This study differed from previous research in that it incorporated the use of three movement parameters i.e. signs, gestures and a meaningless movement sequence, in one assessment protocol. This study revealed praxic deficits in the signing deaf and the oral hearing impaired experimental subjects that were not evident in their matched control subjects. It revealed deficits in movement kinematics and spatial parapraxias in the signing deaf experimental subjects as well as the oral hearing-impaired subject, providing a possible explanation for the inability of the acquisition of the expression of sign and/or spoken language. The measures of this study provide preliminary findings in the context of explorative research. Further research of a larger scale, with a larger sample size, is indicated to determine the validity for the use of this tool in the identification of developmental limb apraxia.

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SECTION ONE

1. INTRODUCTION

To answer the many unanswered questions in the study of developmental limb apraxia, there exists a dire need for more sophisticated and meticulous methodology than that traditionally used in apraxia research (Rothi, Ochipa and Heilman, 1991). In clinical descriptions of developmental limb apraxia, quantitative data on motor characteristics are not commonly reported. To date, no published tests or standardised assessment procedures exist to assess developmental limb apraxic characteristics or to establish a differential diagnosis. There are no diagnostic criteria to characterise developmental limb apraxia or to differentiate it from motor disorders.

In this study, explorative research is undertaken in an attempt to improve on this methodology. Furthermore by conducting this research within a unique population, the deaf population, who use sign language as a primary means of communication, hopefully more light will be shed on the long existing debate as to the theoretical underpinnings of apraxia. In addition numerous clinical implications for deaf children acquiring sign language may emerge.

> "Apraxia provides a special window into higher motor function, since it is a high level motor execution in subjects with intact sensation and motor capacity. Movement impairment of these subjects cannot be explained by weakness, incoordination, sensory deficits, impaired comprehension, or lack of attention to commands" (Poizner and Kegl, 1992, p. 246).

Apraxia is historically and currently central to neuropsychology and neurolinguistics and as with most areas of contemporary neuropsychological science, is characterised by controversy reflecting its state of evolution. Apraxia is an impairment in the ability to perform purposeful, voluntary movements although the patient has no neuromuscular disorder. It is understood traditionally as an impairment in the planning, the initiation and the coordination of an action sequence in the absence of neuromuscular impairment (Code, 1998).

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Liepmann (1908 in Pramstaller and Marsden, 1996) described three varieties of apraxia: limb-kinetic apraxia, ideational apraxia and ideomotor apraxia. A fourth type of apraxia, labelled "apraxia of speech" appears to have been named by Darley and his colleagues in the late 1960s and 1970s (Helm-Estabrooks, 1992).

Limb-kinetic apraxia is "a loss of motor engrams for skilled movement of a single limb" (Pramstaller and Marsden, 1996). Furthermore, Heilman and Rothi (1985) described subjects with limb-kinetic apraxia as being incapable of making fine, precise finger movements. Characteristically, the subject produces movements that, although lacking precision, are accurately selected sequences correctly orientated in space.

Ideational apraxia is considered to be a higher level disorder in which the patient fails to execute complex movement and has difficulty in sequencing a series of acts with objects (Heilman, 1973), or misuses objects despite the preservation of component movements (e.g. combing the face instead of the hair) as described by DeRenzi and Lucchelli (1988).

There is not a universally accepted, empirically supported unique definition of *ideomotor apraxia.* All definitions in current use incorporate one or more claims about the nature of ideomotor apraxia that are not completely accepted. There is, however, a thread of general agreement around the definition of ideomotor apraxia. Geschwind (1975) defined ideomotor apraxia as a disorder of 'learned movements' despite intact mobility, sensation, co-ordination, attention and comprehension. Therefore, apraxia can be diagnosed only if the patient understands the task and has the physical capacity to perform gestures but fails to execute them in the normal manner (Helm-Estabrooks, 1992).

Developmental apraxia of speech is a neurologically based disorder in the programming of sequential articulatory movements (Crary, 1993). Darley, Aronson and Brown's (1975) definition comprises two distinct elements to apraxia of speech: positioning and sequencing of articulatory muscle movements. This definition implies that the apraxic symptoms are incorrect positioning of articulators resulting in incorrect speech production in an inaccurate order. Buckingham (1991) suggested that the patient presenting with apraxia of speech has no problems with muscular strength or control. However, the groping or articulatory searching suggests that these patients have the

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underlying phonological form in mind and it is the articulatory programme that the patient is searching for (Buckingham, 1991).

There are two forms of ideomotor apraxia: oral ideomotor apraxia and limb ideomotor apraxia. Oral apraxia involves purposeful, learned movements of the oral/respiratory structures. It may be associated with problems in verbal communication. However, limb apraxia involves purposeful, learned movements of non-paralysed fingers, wrist, elbow and shoulder. It may be associated with problems in non-verbal, gestural communication (Helm-Estabrooks, 1992).

Two alternate models of the neural basis of apraxia and their predictions of motor performance in apraxic subjects have been a source of debate for a number of years. The debate has centred on whether the undelying core deficit is of a symbolic or motor nature.

Liepmann (1905, cited in Pramstaller and Marsden, 1996) essentially denied the existence of locally confined brain centres ('praxis centres'), which would generate complex movements on their own. However, he noted that there are loci or systems in the brain concerned with the organisation of higher order behaviour, which are interconnected by important cortico-cortical pathways, and that damage to these discrete structures, which enable sensory association and motor areas to work together, can cause disconnection and thus apraxia. Although he did not accept the view of praxis centres, he admitted that lesions in different locations could cause different patterns of apraxia. Liepmann (1908, in Pramstaller and Marsden, 1996, p. 320) thus concluded that "the patient is not apraxic due to the impairment of the sensory-receptive functions...the motor part of the action, the control of the motor expression is defective". Therefore, he essentially defined apraxia as a movement disorder rather than a symbolic disorder (Pramstaller and Marsden, 1996).

Liepmann's (1905, in Pramstaller and Marsden, 1996) proposal of the nature of apraxia stemming from a motoric disorder, gained support from researchers such as Kimura and Archibald (1974); Kimura, Battison and Lubert (1976); Kimura (1982) and Poizner and Kegl (1992) who considered the left hemisphere to be primarily specialised for the motor control of changes in the position of both oral and manual articulators.

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Kimura and Archibald (1974) and Kimura (1976; 1977; 1982) proposed that the reason for the apparent close relationship between speech and praxic impairment is explained in terms of the finding that both formal linguistic aspects of language and praxic functions are processed by the left hemisphere, that speech processing is highly dependent on praxic skills and that the development of the capability to speak is based on a phylogenetically earlier capacity for action and gesture. Serial control of behaviour is a vital component in Kimura's hypothesis: both the sounds of language and the sequences of action are temporally organised (Code, 1998).

Kimura and Archibald (1974) suggested that limb apraxia is a non-symbolic motor sequencing disorder and found that left hemisphere-damaged patients had impairments in imitating meaningless hand and arm movements compared to right hemisphere-damaged patients. In addition, Kimura (1976) suggested "the left hemisphere is particularly well adapted, not for symbolic function per se, but for the execution of some categories of motor activity which happen to lend themselves readily to communication" (Kimura, 1976, p. 154).

Conversely, the disconnection theory of apraxia as proposed by Geschwind (1965) explained motor behaviour by using a neural substrate similar to that proposed by Wernicke (1874, in Clark, Merians, Kothari, Poizner, Macauley, Rothi and Heilman, 1994) to explain language processing. Furthermore, he emphasised the 'disconnection' of motor centres from the stimuli-processing cortical association areas (auditory association cortex for verbal commands, visual association cortex for movement carried out to written commands or on imitation, and somaesthetic association areas for movements performed under tactile control) (Pramstaller and Marsden, 1996). Support for the disconnection theory, is derived from authors such as Goldstein (1948); Poizner, Klima and Bellugi (1987); Corina, Poizner, Bellugi, Feinberg, Dowd and O'Grady-Batch (1992) who considered the nature of apraxia to be a symbolic disturbance.

In summary the study of apraxia appears to stimulate much theoretical debate and clearly much controversy still exists regarding the theoretical underpinnings of apraxia. Furthermore, although researchers have considered apraxia, especially limb apraxia to be a neuropsychological syndrome only of theoretical importance (Basso, Capitani, Della Sala, Laiacona and Spinnler, 1987; Poeck, 1985), the researcher strongly believes that

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indeed limb apraxia would be of clinical significance for the deaf population who use sign language as their primary mode of communication. The clinical implications of limb apraxia is of particular interest in deaf persons with acquired brain injury and hence the dissolution of language and in children who display developmental difficulty in the acquisition of the expressive use of sign language.

Sign language is the primary, natural language of deaf children, no matter what the spoken language of his/her hearing parents may be (Mbeki, 1997). It is proposed that sign language constitutes the central focus of the human rights of deaf individuals. Hickok, Say, Bellugi and Klima (1996) stated that sign language is a true language in its own right, using the modality of space in place of the modality of sound used in spoken languages. Sign language is the natural language of the Deaf community. It is the language of the hands and eyes and is considered a language of movement and space. Similar to that of spoken language, it is creative and arbitrary, changing and abstract, complex and rule-governed (Penn, 1992). It is acknowledged that sign language is becoming far more accepted as the primary mode of communication for deaf children.

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Languages in the visual-gestural modality use varying hand configurations and types of arm movements to locations on, near or in front of the body, as well as facial expressions and body movements that combine to form signs (Poizner and Kegl, 1992). Each sign consists of five parameters which serve to delimit its meaning. These parameters include hand-shape(s), movement of the hand(s), position and location of the hand(s), orientation of the palm(s) as well as facial expression and other non-manual behaviours (Penn, 1992).

Bellugi and Klima (1985) described sign language as a fully autonomous language with complex syntactic structure based on the modality. Therefore, sign language is a multilayered linguistically organised system and uses the structured use of space for its grammatical markers (Tabor, 1988). Since sign languages use a communication modality different from that of spoken languages, the study of sign languages and gestures offer a unique opportunity for insight into the nature of neural mechanisms for language and motor behaviour.

Sign languages display complex linguistic structures and spatial relations. Because of these dual properties, it is possible to study sign languages as they host the special

properties of the visual-gestural modality in exploring brain and language relationships. The interplay between linguistic and spatial relations is one such property; while another is the relationship between control of arm movements and linguistic expression. Since movements of the articulators in sign are clearly visible, it is possible to investigate signing as a linguistic behaviour as well as a motor behaviour. Furthermore, it is possible to directly contrast linguistic-representational and motor-execution disorders of signing (Poizner and Kegl, 1992).

Hence, the study of sign language offers a unique opportunity into the nature of the brain for linguistic and non-linguistic gestural systems. Since sign language and gesture are transmitted in the same modality, the breakdown of the two can be directly compared (Corina et al, 1992). The study of visual-gestural languages can provide insight not only about the brain function for language, but can provide an understanding of the relationship of the brain's control for language and of movement. The study of signers with distinct motor disorders can provide clues to the neural substrate underlying language as a motor behaviour (Poizner and Kegl, 1992). The movements of the articulators in sign language are directly observable and are thus available for non-invasive measurement. It is, therefore possible to study signing not only as a linguistic behaviour but also as a motor behaviour. As noted by Poizner and Kegl (1992), the study of the breakdown of sign languages and the breakdown of non-linguistic gesture offers new ways of investigating apraxia in terms of its underlying symbolic or neural substrate, since the expression of language and gesture does not intersect transmission modalities.

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Previous research in the study of limb apraxia has been conducted within the deaf aphasic adult population, see Kimura (1977); Coelho and Duffy (1987, 1990); Poizner, Mack, Verfaellie, Rothi and Heilman (1990); Kegl and Poizner (1991); Harrington and Haaland (1992) and Neiman, Duffy, Belanger and Coelho (1994). There has been considerable controversy as to whether the impaired communicative content of pantomime is related to the language deficit of aphasia rather than to a general impairment of purposeful movement (Wang and Goodglass, 1992).

There are major differences between sign language and communicative pantomimic gestures. These differences might be rudimentary in determining whether limb apraxia is motor-governed or language-governed. As noted by Corina et al (1992), the

strongest case for the existence of independent neural processes mediating linguistic gesture (sign language) from non-linguistic gesture (pantomime) may come from functional dissociations in brain-damaged deaf signers.

Findings from studies that investigated limb apraxia in the deaf aphasic adult population are conflicting. Duffy and Duffy (1981); Poizner et al (1987); Wang and Goodglass (1992); Coelho and Duffy (1990) reported findings which revealed that limb apraxia is not detrimental to successful acquisition of a significant repertoire of signs or gestures by severely impaired deaf aphasic adult subjects. Furthermore, these researchers noted that the left hemisphere is specialised for language, spoken or signed, and that this language specialisation is not based on the physical form of the signal, but rather on the linguistic function it subserves (Poizner et al, 1987).

However, contrary to this, findings of other studies have indicated that the impairment of pantomime production is a manifestation of apraxia - a high level disturbance of movement formulation and execution. Studies conducted by Goodglass and Kaplan (1963); Kimura (1974; 1982; 1987; 1988); Kimura (1974); DeRenzi, Motti and Nichelli (1980); Kertesz, Ferro and Shewan (1984) and Poizner and Kegl (1992) revealed that the nature of movement breakdown in apraxia elucidates how the brain acts when representations of the controlled skilled movements are damaged. Kimura (1976) proposed that disturbances of sign language in the deaf population are associated with left hemisphere damage. The left hemisphere's specialised functions may be related to the control of complex motor behaviour. Disturbance of sign language and of speech are seen as disorders of certain motor functions in which the linguistic impairment is secondary. Kimura (1987) further noted that the pervasiveness of such motor-programming deficits in most aphasic individuals predicts that aphasic patients' use of gestures or signs would generally not be successful. In other words, the patient's deficit is one of motor sequencing. Kimura (1988) further stated, "the alternative interpretation, that signing and non-signing manual behaviours are carried out by totally separate neural systems, is so improbable that it does not warrant serious consideration" (p. 378).

Hence, from a review of the literature much controversy regarding the precise definitions and the neural basis of apraxia still remains. Methodological issues including the difficulties involved in the measurement of apraxia and especially limb apraxia seem

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to have contributed to conflicting findings. This appears to be largely due to the lack of objective and standardised assessment tools. "Unlike aphasia, no standardised battery of tasks is available for the clinical evaluation of motor apraxia. The diagnosis is made largely on the basis of personal experience and intuition" (Poeck, 1986, p. 130).

Past literature has documented two major difficulties in the measurement of limb apraxia: Firstly, difficulties in the type of technique used; and secondly, the types of tasks and stimuli used to elicit target movements. Previous researchers have indicated that it is impossible to discern the precise parameters of three-dimensional movement patterns from subjective evaluation or from judging videotaped recordings (Poizner et al, 1990). Although neurologists have noted the problems that apraxic subjects have in controlling limb movement, there have been few quantitative analyses of the nature of their movement disorder. If it is found that aspects of the timing patterns and three-dimensional spatial patterns have been disrupted, such quantitative analyses are critical to understanding the nature of the limb control deficits, which could ultimately lead to a better understanding of the neural control of limb movement (Poizner and Kegl, 1992) and resolve the controversy regarding the underlying basis of this movement disorder (Clark et al, 1994).

Although, Poizner et al (1990) stated that it is impossible to uncover precise patterns of timing and spatial relations in three-dimensional trajectories from observation or from viewing of videotaped recordings, such precise information on temporal and spatial trajectory variables is essential for uncovering the nature of any movement disturbances in apraxic subjects. "One of the great disadvantages which clinical investigations suffer is difficulty in recording and measuring observations accurately by such methods as physiologists employ" (Holmes, 1939, in Clark et al, 1994, p. 1095).

Recently, in an attempt to overcome these difficulties, the use of three-dimensional computergraphic analyses has been employed in studies to investigate kinematic abnormalities and spatial parapraxias in hearing subjects with acquired brain damage, presenting with a limb apraxia. Kinematic abnormalities, as defined by Hermsdörfer, Mai, Spatt, Marquardt, Veltkamp and Goldenberg (1996), are the deficits seen in the lack of precision of a movement trajectory, together with evidence of deficient joint co-ordination (Poizner et al, 1990). Hermsdörfer et al (1996) defined spatial parapraxias when a subject fails to reach the correct final target hand position.

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In addition to the lack of precise use of techniques, previous research has inconsistently considered the complexity of the task items. As has been noted by Belanger, Duffy and Coelho (1996), the use of relatively simple items for apraxic testing has limited value in the differential diagnosis of limb apraxia. In addition, these authors also caution clinicians regarding the modes of elicitation and the types of movement elicited in testing for limb apraxia.

Poizner et al (1990) provided a detailed kinematic analysis of apraxic movements in adults with lesions to the left hemisphere. In their study, gestures of the type traditionally used to test for apraxia were selected for the three-dimensional movement analysis. In addition, these researchers investigated the pantomime of object use by verbal command in two apraxic patients (Poizner et al, 1990). In a further study conducted by Clark et al (1994), the gesture 'slicing bread' was conducted under different contextual conditions (with and without the object or/and tool present), including the actual object and tool use.

However, Hermsdörfer et al (1996), criticised such previous research as their results did not permit a definite conclusion as to the level of gesture production at which kinematic abnormalities arise. Therefore, Hermsdörfer et al (1996) investigated both the movement kinematics and spatial parapraxias during the imitation of meaningless gestures. The imitation of familiar and meaningful gestures could be mediated by existing knowledge about the form and the meaning of the gestures and could therefore be affected by degradation of this knowledge. In contrast, imitation of novel and meaningless gestures appears to include a direct route from perception to execution of the movement (Rothi et al, 1991; Roy and Hall, 1992). Therefore, errors in the imitation of meaningless movement gestures should permit for a better understanding into apraxia as a disorder of a motor execution (Hermsdörfer et al, 1996).

In summary, further research is clearly needed in the study of developmental limb apraxia. It is hoped that an increased understanding will be achieved by incorporating the use of carefully selected signs, gestures and a meaningless movement sequence into one objective assessment procedure. Furthermore, spatio-temporal aspects, movement kinematics and spatial parapraxias across the signs, gestures and the meaningless movement sequence needs to be determined in order to provide more knowledge regarding limb apraxia.

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As was previously mentioned, research in the deaf population has been conducted in the deaf aphasic adult population. To the best of the researcher's knowledge no previous research has been conducted in children with limb apraxia. This population is thought to be of particular clinical importance due to the effects limb apraxia may have on their expressive use of sign language. Recently there have been numerous clinical reports from teachers and language therapists working with deaf children regarding some children displaying difficulty in the acquisition of the expressive use of sign language. Expectantly, further investigation in limb apraxia, or more particularly, developmental limb apraxia, may provide some insight into the nature of their difficulties.

As has been suggested by Byers-Brown and Edwards (1989), the lack of research within children may be as a result of language in dissolution lending itself more easily to analysis than language in development, and furthermore, one can obtain clearer information from the damaged brain than from the developing one, when subjected to neurological investigation.

However, with increasing sophistication of technology, hopefully increased insight into developmental disorders and the implications thereof will emerge despite there being no simple or direct relationship between developmental and acquired disorders. Certain parallels are evident between acquired and developmental disorders, but the impairment of development and the breakdown of function need to be analysed in different contexts. In the case of an adult with an acquired disorder, the breakdown is likely to occur in the context of a previously normal functioning system (e.g. linguistic) so that the remnants of this will still be evident in varying degrees. When impairment is developmental there is no such background of experience. The progress of the condition also varies. Natural processes of maturation will influence the development, however impaired, so that the pattern of the deficit may then change (Byers-Brown and Edwards, 1989). The distinction in classifying these disorders is important, as the clinical implications are vastly different for acquired versus developmental disorders (Crystal and Varley, 1993).

In summary, there is still a dire need for further development of objective assessment tools to examine limb apraxia. In addition, little research has been conducted in the deaf population. The scant research that has been conducted in this population has been concentrated in acquired neurogenic disorders and to the best of the researcher's knowledge, none in developmental limb apraxia in deaf signing children.

Hence, the purpose of this study was to investigate developmental limb apraxia in deaf signing children as well as in an oral hearing-impaired child, by developing an objective assessment tool, to determine the effectiveness and the nature thereof, in the clinical diagnosis of developmental limb apraxia. The rationale develops from the fact that if deaf children display difficulty in the acquisition of the expressive use of sign language, they may indeed be presenting with a developmental limb apraxia, which would have far reaching communicative and educational implications.

This study has three primary aims: Firstly, to develop an objective assessment tool, using the VICON Motion Analysis System for the objective analysis of developmental limb apraxia; secondly, to investigate developmental limb apraxia in deaf children who use sign language as their primary mode of communication; and thirdly to investigate the possibility of developmental limb apraxia in an oral hearing-impaired child who presents with oral and/or verbal apraxia.

A hearing impaired child who primarily uses the oral mode of communication was also included in this study as his teachers had not only reported on a possible oral and/or verbal apraxia which accounted for his difficulties in spoken language apart from the degree of his hearing loss, but also that the movements noted in his gestural system appeared to be "awkward" in comparison to his peers. Therefore, it was believed that his inclusion might reveal some interesting findings regarding the co-occurrence of apraxia, that is oral, verbal and limb apraxias.

De Renzi (1966 in Code, 1998) found that the majority of hearing patients with verbal apraxia presented with oral apraxia as well as a high co-occurrence of oral and limb apraxia. However, while it is understood that some subjects present with a co-occurrence of the various apraxias, it is also possible that dissociations also exist: there are subjects who present with developmental limb apraxia who do not present with oral

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apraxia (Code, 1998). Hence, in this study a comprehensive battery of tests of the oral, verbal, constructional and limb apraxias are included.

This study, unlike previous research, incorporated the use of carefully selected signs, gestures and a meaningless movement sequence into one objective measurement of the VICON Motion Analysis System. In assessing the presence of limb apraxia, this study included simple as well as complex task items in the limb apraxia test battery. The guidelines suggested by Ogilvy (1995) consisted of a continuum of formational complexity in sign language. Hence, items were selected to represent the continuum of complexity i.e. " from less complex to more complex". Furthermore, careful consideration was given to the modes of elicitation. This was conducted by way of imitating movements (to exclude receptive variables) presented by a deaf native signer (to ensure signs and movements were presented accurately). In addition, thorough deliberation was provided to the types of movement elicited. Therefore, each selected sign was carefully analysed using the criteria of: unfamiliar, proximal, distal, representational, non-representational, complex, sign, gesture, movement, transitive or intransitive.

The results using multiple movement tasks and the VICON Motion Analysis System promise to yield quantitative measures of kinematic abnormalities, spatial parapraxias and temporal qualities in the form of resultant trajectories of elbow position and wrist joint centre as well as elbow joint angle values.

An advantage of the introduction of the VICON Motion Analysis System into this study is that it might provide more objective assessment techniques that may contribute towards the development of more sophisticated analyses of limb apraxia. Furthermore, the use of this sophisticated technology as a method of analysis in developmental limb apraxic patients is in accordance with current worldwide research trends in the field of apraxia. This proves to be advantageous in the assessment of the deaf population where no studies of deaf signing children presenting with developmental limb apraxia are available.

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Numerous theoretical and clinical implications may evolve from this study. Hopefully, the results from this study may provide preliminary findings towards the development of more accurate and objective measures of limb apraxia. In addition to providing a description of the experimental subjects' praxic functions, further insight may be shed on an explanation for the difficulties in the acquisition of sign language by deaf signing children with developmental limb apraxia. Furthermore, by conducting this study from a clinical diagnostic perspective, it will hopefully provide speech-language therapists and other relevant professionals with the necessary assessment tools for the correct identification of developmental limb apraxia in deaf children. This in turn may have far reaching clinical and educational implications. Moreover, the results from this study may provide further evidence for the theoretical underpinnings of apraxia and more particularly limb apraxia.

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SECTION TWO

2. METHODOLOGY

This section outlines the aims, methodological design, subject selection criteria and description of subjects used in this study. Furthermore, the diagnostic test battery, methods of data collection and methods of analysis are described.

2.1 AIMS

The primary aims of this study were as follows:

(a) To develop an assessment tool for the objective analysis of developmental limb apraxia.

(b) To investigate the possibility of developmental limb apraxia in deaf signing children.

(c) To determine whether developmental limb apraxia is evident in a hearing-impaired child, with oral apraxia, who uses the spoken modality.

More specifically

(d) To assess the effectiveness of the use of this assessment tool in the diagnosis of developmental limb apraxia.

(e) To investigate the relationship between kinematic abnormalities and spatial parapraxias, by way of analysis of spatio-temporal characteristics.

(f) To examine the co-occurrence of oral, verbal, limb and constructional praxic functions.

(g) To investigate the evidence of developmental limb apraxia in sign language, transitive and intransitive gestures and/or non-representational movements.

2.2 RESEARCH DESIGN

This study uses a descriptive multiple case study design. Four experimental subjects and four matched controls are employed. The results are not pooled and averaged, but rather each case is analysed separately and differences and/or similarities are highlighted. This design was chosen, as it has been debated that the only valid research methodology with neurologically impaired patients is based on single patient studies (Caramazza, 1986; Caramazza and McCloskey, 1988 and Caramazza, 1991). In addition, group studies involving averaged subjects' performance are only valid if the functional lesions of the

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groups of patients are similar (Caramazza, 1986). Furthermore, the use of a heterogeneous sample of patients may complicate the interpretation of research results (McReynolds and Kearns, 1983). The employment of a descriptive multiple case study design allows for a more thorough investigation evaluating the uniqueness of individual subjects, rather than a cursory examination of trends to be made. In addition, it provides insight into phenomena that may be overlooked in a group analysis (Ventry and Schiavetti, 1980).

2.3 SUBJECTS

2.3.1 Sample Size

Four deaf experimental subjects, with evidence of possible developmental limb apraxia, were assessed in this study. Four controls, matched for age, sex, age of onset of deafness, degree of deafness, handedness and language spoken, were included in this study. The inclusion of these matched controls allowed for the validation of the assessment procedures and results obtained.

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2.3.2 Subject Selection Criteria

The following criteria were applied in the process of subject selection:

2.3.2.1 Developmental Limb Apraxia

Subjects were required to present with a possible suggestion of developmental limb apraxia as was demonstrated by their difficulties in imitating gestures, signs and movements in sign language. Reported difficulties in the acquisition of expressive sign language were required to be made by the teachers and other professionals in the child's educational setting.

2.3.2.2 Age

In an attempt to avoid normal variance of movement noted in children below the age of 5 years, children above the age of 5 years were selected as subjects in this study.

Furthermore, children who had attended deaf schools for a minimum of three years were included in this study, as three years would have allowed for sufficient time in which the children were able to master some skills of sign language.

Subjects were required to be between the ages of 5 years to 12 years. Research suggests that the sequence of development is predictable and similar for all children, but the rate at which specific changes take place varies from one child to another. The first five years of life are generally regarded as a time during which fundamental motor patterns emerge as the child deals with problems of locomotion and as he/she learns to manipulate objects in the environment (Wickstrom, 1983).

The relatively predictable rate and orderly sequence of sensory-motor development, which appear to be fairly consistent across children and which is responsible for the ability to obtain norms, is attributed to maturation of the central nervous system. The maturational theory states that the emergence of behaviour is dependent on a sufficient level of development in areas of the central nervous system that regulates and mediates behaviour. In addition to maturation, movement experiences are necessary for motor development. Opportunity for movement and play provides the experience necessary for sensory-motor development in infancy. Early stages of the sensory-motor development sequence provide the experiences that prepare the infant for later, more advanced stages; therefore, specific training associated with learning motor skills at older ages is not necessary (Krus, Bruininks and Robertson, 1981).

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2.3.2.3 Deafness

(a) Age of Onset: The subjects were required to be congenitally deaf or prelingually deaf with a maximum onset age of 2 years since the cut-off age for the critical definition of prelingual deafness is often set at 2 years (Meadow, 1980).

(b) Degree of hearing loss: Subjects were required to have a bilateral severe-profound hearing loss (i.e. greater than 70 dBHL), since this population may rely to a greater extent on sign language (Ogilvy, 1995).

2.3.2.4 Communication Mode

The subjects of this study were required to be involved in a deaf educational programme using the signed and/or spoken modality.

2.3.2.5 Education

All children were required to attend a school for the deaf/hearing impaired. The schools were required to use sign and/or spoken language.

2.3.2.6 Handedness

Subjects were required to be right hand dominant. This was evaluated by means of the subjects' handed preference for drawing (Poizner and Kegl, 1992). Research findings on hemispheric specialisation of sign language, indicate left hemisphere lateralisation for sign language among the right-handers (Vaid, Bellugi and Poizner, 1989). Right-handers have verbal abilities in the contralateral left hemisphere and spatial abilities in the right hemisphere, however, left-handers seem to show a pattern of cerebral organisation that is either the same as the right-handed pattern or less well defined (Sheehan and Smith, 1986). Levy (1984, in Sheehan and Smith, 1986) suggested that individuals with verbal abilities in both the cerebral hemispheres and spatial abilities in the right hemisphere are inferior in visuospatial performance tasks to those with verbal abilities in the left hemisphere and spatial abilities in the right hemisphere. Therefore, only right-handers were included in this study as verbal and visuo-spatial abilities are pertinent in this study. Furthermore, auditory stimuli are processed via the auditory pathways, by the primary auditory cortex and from there relayed to the posterior part of the auditory association cortex. To the left of this is Wernicke's area, which is responsible for language comprehension. This area is connected to the motor association cortex by the arcuate fasciculus and the motor association area on the left is connected to the primary motor area on the left. When the subject is verbally instructed to carry out a command using his right hand, he uses this pathway (Clark et al, 1994). Geschwind (1965) postulated that in order to carry out a verbal command with the left hand, information is processed by the right motor cortex.

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2.3.2.7 Visual

Subjects were required to have no evidence of sensory-visual impairment, as was reported by their teachers following annual eye tests.

2.3.3 Subject Consent

Written consent with regard to the subjects' participation in the study was obtained prior to testing. The purpose of this study and the procedures undertaken were fully explained to the subjects, their families and caregivers.

2.3.4 Location of the Subjects

The researcher approached the schools for the deaf/hearing impaired in the Western Cape. A brief presentation on developmental limb apraxia was conducted at each school. The lecture highlighted all the pertinent symptoms of developmental limb apraxia and how one would identify evidence thereof. All teaching staff who were involved with children, aged five to twelve years, were invited to attend. Documentation and a summary of the criteria were left with the teachers after the presentation (see Appendix I). Those children, who were suspected to have evidence of possible developmental limb apraxia i.e. those children who were unable to correctly imitate and initiate limb movements and who were demonstrating difficulties in accurate imitation of the signs and the development of expressive sign language skills as reported by the teachers and other professionals in the school, were selected for this study.

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2.3.5 Subject Description

Prior to administration of the test battery, information pertaining to the subject selection criteria was obtained. In addition, information regarding medical, educational and social history was obtained. This information was obtained from caregivers, medical records and perusal of all reports written by teachers, speech therapists, psychologists, neurologists and paediatricians. All biographical and clinical information for the experimental subjects and the matched control subjects is presented in Table 2.1.

Table 2.1 Case History Details of the Subjects

	ES 1	ES 2	ES 3	ES 4	CS 1	CS 2	CS 3	CS 4
Age	7.11 yrs	10.7 yrs	7.4 yrs	8.5 yrs	7.11 yrs	10.7 yrs	7.5 yrs	9.0 yrs
Sex	M	M	F	M	M	M	F	M
Age of onset of deafness	Congenital	Congenital	Congenital	Congenital	Congenital	Congenital	Congenital	Congenital
Degree and type of hearing loss	Severe to Profound sensorineural hearing loss	Severe to Profound sensorineural hearing loss	Severe to Profound sensorineural hearing loss	Moderate to Severe sensorineural hearing loss	Severe to profound sensorineural hearing loss	Severe to Profound sensorineural hearing loss	Severe to profound sensorineural hearing loss	Moderate to severe sensorineural hearing loss
Primary mode of communication	Sign and/or Spoken	Sign and/or Spoken	Sign and/or Spoken	Spoken English	Sign and/or Spoken	Sign and/or Spoken	Sign and/or Spoken	Spoken English
School Attending	Deaf Residential School	Deaf Residential School	Deaf Residential School	Deaf Residential School (oral)	Deaf Residential School	Deaf Residential School	Deaf Residential School	Deaf Residential School (oral)
Current School Phase	Foundation	Foundation	Foundation	Foundation	Foundation	Foundation	Foundation	Foundation
Amplification	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral
Significant Medical History	Waardenberg Sydrome assoc. Hirschsprung's Disease	None	None	None	None	None	None	None
Use of Language: spoken and/or sign	Uses predominantly sign language and some speech	Uses predominantly sign language and some speech	Uses predominantly sign language	Uses spoken language	Uses predominantly sign language and some speech	Uses predominantly sign language and some speech	Uses predominantly sign language	Uses spoken language

ES – Experimental Subject; CS – Control Subject
Foundation Phase = Primary School (the first three years of formal South African schooling)

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As can be seen from Table 2.1, the control subjects were matched to the experimental subjects with regard to age, sex and deafness i.e. age of onset, degree and type of hearing loss and primary mode of communication. The four experimental subjects were reported to demonstrate difficulties in accurate imitation of signs. Furthermore, ES 4 was reported to present with marked articulatory errors thought not to be exclusively due to the degree of his hearing loss. In addition, ES 4, presented with evidence of developmental limb apraxia in his natural gesture system. Moreover, as is noted in Table 2.1 above, ES 1, ES 2, ES 3 and CS 1, CS 2 and CS 3 all use the sign and/or spoken modalities, while ES 4 and CS 4 only use spoken language. The control subjects had neither suspected neurodevelopmental deficits nor any evidence of defective motor movements, as identified by their teachers and language therapists, which included no muscle weaknesses, incoordination, sensory deficits, impaired comprehension or lack of attention to instructions.

2.4 TEST CONSTRUCTION

In order to address the aims of this study a battery of apraxia tests was modified and developed.

2.4.1 Description of Test Construction

A description of those tests that were modified and translated and those specially developed is discussed.

A summary of the tests that were modified and translated and those that were specifically developed is presented in Table 2.2.

Table 2.2 Tests Modified and Translated, and Developed

MODIFIED & TRANSLATED	Formal Oral and Limb Apraxic Test - Normed Edition (TOLA)	**ORAL APRAXIA** • Nonrespiratory • Respiratory **GESTURED PICTURES** • Proximal • Distal • Oral
DEVELOPED	Formal Limb Apraxia Tests	**VICON MOTION ANALYSIS SYSTEM** • Copying of Formationally Complex Signs • Gestured Pictures • Demonstrated Use of Objects (Ideational)

2.4.1.1 Sub-tests from the Test of Oral and Limb Apraxia - Normed Edition (TOLA) (N. Helm-Estabrooks, 1992).

Modification of the sub-tests was found to be necessary to ensure that the test items were culturally relevant and age appropriate to the subjects. The researcher undertook the modifications, after observation of the subjects' natural environment and routine. All modifications made to the TOLA are indicated in Table 2.3.

Table 2.3 The Modified Version of the TOLA

Item No.	ORIGINAL	MODIFICATION
ORAL APRAXIA		
Oral Nonrespiratory		
3	Lick a lollipop	Lick an ice-cream
5	Lick milk off upper lip	Lick upper lip
GESTURED PICTURES		
Proximal		
1	Meat Grinder	Axe
2	Automobile Jack	Tennis Racquet
3	Paint Roller	Paint Brush
4	Spatula	Spoon
5	Vacuum Cleaner	Knife
Distal		
1	Dart	Peg
2	Tweezers	Pen
3	Faucet	Scissors
5	Hand calculator	Gun
ORAL		
3	Water Fountain	Bubbles
5	Party Favour	Not replaced i.e. not tested

As is seen in Table 2.3, modifications were undertaken to ensure age appropriateness and cultural relevance for the subjects in this study. The complete modified version is documented in Appendix II.

2.4.1.2 The Test for the Copying of Formationally Complex Signs

This test formed part of the Apraxic Test Battery and was constructed using the guidelines proposed by Ogilvy (1995). The guidelines suggested by Ogilvy (1995) consisted of a continuum of formational complexity in sign. This was devised using six aspects of sign in which hierarchies of complexity have been proposed, either in relation to their acquisition or to their specific visual, linguistic or motor properties (Ogilvy, 1995). A four-point scale was devised to rate signs on each aspect from easy to complex. The test was slightly modified to allow for additional signs to be assessed (i.e. the addition of 'less complex' signs and 'more complex' signs). These changes resulted in the inclusion of ten signs in the completed version of the test, to represent the continuum of complexity. A summary of these scales and of the signs selected is tabulated in Tables 2.4a and 2.4b.

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Table 2.4a Numerical Values Allocated to Represent the Complexity of the Six Aspects of Sign

ASPECT	NUMERICAL VALUE
A Handshape	1
Stage 1	2
Stage 2	3
Stage 3	4
Stage 4	
B Nature of Feedback	
Within field of vision	1
Outside field of vision	4
C Complexity of Sign Action	
Repetitive touching motion	1
Interchanging action	4
D Continuum of Iconicity to Opaqueness	
Iconic	1
Transparent	2
Translucent	3
Opaque	4
E Concreteness versus	1
Abstractness	4
F Conventional versus	1
Unconventional	4

This table is reproduced by permission granted from Ogilvy (1995).

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Table 2.4b Numerical Values Assigned to the Twenty Signs Selected for the Copying of Formationally Complex Signs Test

Signed Test Items	Aspects						Total
	A	B	C	D	E	F	
"stupid"	1	1	1	1	1	1	6
"shout"	1	1	1	1	1	1	6
"saw"	1	1	1	2	1	1	7
"smell"	2	1	1	2	1	1	8
"yes"	1	1	1	3	1	1	8
"yellow"	3	1	1	2	1	1	9
"brush teeth"	4	1	1	1	1	1	9
"key"	4	1	1	1	1	1	9
"hook"	4	1	1	2	1	1	10
"snake"	3	1	1	3	1	1	10
"like"	2	1	1	2	4	1	11
"Z"	1	1	1	1	4	4	12
"weird"	2	1	1	4	4	1	13
"aeroplane taking off	3	4	4	1	1	1	14
"submarine"	2	4	4	2	1	4	17
"good morning"	2	3	4	3	4	1	17
"starfish"	2	3	4	3	1	4	17
"bridge"	3	4	4	3	1	4	19
"bad luck"	3	4	4	4	4	1	20
"non-represenational	2	2	4	4	4	4	20

KEY

A: Hand-shape
B: Nature of Feedback
C: Complexity of Sign Action
D: Continuum of Iconicity to Opaqueness
E: Concreteness versus Abstractness
F: Conventional versus Unconventional

Table 2.4b above is placed on a continuum from simple to complex. A score of 6 is considered simple in signing nature while a score of 20 is considered complex in signing nature.

Figure 1 illustrates the movement tasks developed for measurement purposes using the objective VICON 370 Motion System Analysis Assessment Protocol.

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Figure 1.1. "stupid"

Figure 1.2. "shout"

Figure 1.3. "saw"

Figure 1.4. "smell"

Figure 1.5. "yes"

Figure 1.6. "yellow"

Figure 1.7. "brush teeth"

Figure 1.8. "key"

Figure 1.9. "hook"

Figure 1.10. "snake"

Figure 1.11. "like"

Figure 1.12. "Z"

Figure 1.13. "weird"

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Figure 1.14. "airplane taking off"

Figure 1.15. "submarine"

Figure 1.16 "Good morning"

Figure 1.17. "star fish"

Figure 1.18. "bridge"

Figure 1.19. "bad luck"

Figure 1.20. "non-representational"

Figure 1: Photographs illustrating the movement tasks used during the objective VICON Motion Analysis of developmental limb apraxia

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2.4.1.3 The Test of Demonstrated Use of Objects

Clark et al (1994) stated that if the "disconnection" model of apraxia, as previously discussed, is correct, then apraxic individuals should display difficulties with completing tasks to verbal command, however, they should show no difficulty with the manipulation of objects and tools, since this process does not require language comprehension. Therefore, a test designed by the researcher, to assess the presence of ideational apraxia, was included in the battery of apraxia tests. The test procedure involved the objective analysis of the demonstrated use of the following objects: a peg; a toothbrush; a whistle and a brush, by the subjects.

2.4.1.4 The VICON 370 Motion Analysis System Procedure

An assessment tool was developed, for the purposes of this study, to assess the presence of developmental limb apraxia, through the use of motion capture, using the VICON 370 Motion Analysis System. The rationale for its development was based on the need for an efficient objective measure of developmental limb apraxia and that no such assessment battery was readily available in South Africa. As De Renzi (1989 in Hermsdörfer et al, 1996, p. 1575) noted, "the riddle of apraxia is posed by the observation that the occurrence of abnormal movements depends on the condition of testing". The principles of the methodological procedures from research conducted by Poizner et al (1990), Clark et al (1994) and Hermsdörfer et al (1996) were adopted in order to meet the requirements outlined by this study. The researcher developed the VICON 370 Motion Analysis System Procedure for the assessment of developmental limb apraxia in conjunction with the personnel from the Department of Biomedical Engineering, University of Cape Town. A detailed description of the procedure will follow at a later stage.

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2.5 THE BATTERY OF DIAGNOSTIC TESTS

2.5.1 The Standard Battery of Apraxic Tests

This battery of tests was used to assess the various types of apraxia. A list of the types of apraxia as well as the tests used to assess the respective types of apraxia is displayed in Table 2.5.

Table 2.5 Battery of Apraxic Tests

Type of Apraxia	Tests Used
VERBAL	• The evaluation section of the "Terapieprogram vir Verbale Ontwikkelingsapraksie" (Test of Verbal and Oral Developmental Apraxia)
ORAL	• The Test of Verbal and Oral Developmental Apraxia • A subtest from the TOLA (Oral Apraxia)

CONSTRUCTIONAL	• Copying – The Beery Visuo-Motor Integration Test
	• Two-dimensional construction
	    • Stick construction
	    • Block design
	    • Form-boards
	• Three-dimensional construction
	    • Block design

LIMB **1. Ideomotor** **2. Ideational** **3. Limb-Kinetic**	**The VICON Motion Analysis System:** • "Gestured Pictures" subtest from TOLA • Demonstrated Use of Objects • Copying of Formationally Complex Signs

2.5.1.1 Verbal Apraxia

The verbal apraxia sub-test from the Test of Verbal and Oral Developmental Apraxia was employed in the assessment battery of this study, as it assesses aspects such as: consonant-vowel combinations; phonetic repertoire for consonants in isolation; phonetic repertoire for vowels and diphthongs in isolation and phonetic repertoire for combinations of consonants in isolation. Many researchers have described verbal apraxia as a motor speech timing limitation and it has often been ascribed to brain damage involving the left hemisphere (Towne and Crary, 1988). The resulting speech production error patterns

seem to reflect an underlying deficit in the ability to plan appropriately, sequence or execute movements of the articulators during speech production (Towne and Crary, 1988).

2.5.1.2 Oral Apraxia

The assessment procedures for oral apraxia involved the use of the oral apraxic sub-tests of the Test of Verbal and Oral Developmental Apraxia as well as the sub-tests adapted from the TOLA (Helm-Estabrooks, 1992). These sub-tests included exercises such as the protrusion and retraction of the tongue; lateral tongue movement; the puffing up the cheeks, blowing out a candle and licking an ice-cream.

Jackson (1932, in Rothi, Raade and Heilman, 1994) defined oral apraxia as an inability to perform learned skilled movements of the lips, facial muscles, tongue, pharynx, larynx and respiratory muscles and is based on the exclusion of other neurological deficits that impair motor activity. The most important parameter in classifying types of oral apraxia relates to the involvement of the respiratory apparatus. If the target gesture does not involve respiration, it is called non-respiratory oral gesture. An example of this is pretending to lick an ice-cream. If the target gesture does involve respiration, it is called respiratory oral gesture, an example of this is pretending to sniff a flower.

2.5.1.3 Constructional Apraxia

The researcher devised an assessment protocol to determine the presence of constructional apraxia in the subjects. The assessment procedures included: freehand drawing; copying; block design; match-stick copying and timed completion of form-boards (Lezak, 1983). The full rationale and development of this assessment procedure is documented below.

Constructional apraxia "denotes an impairment in combinatory or organising activity in which details must be clearly perceived and in which the relationships among the component parts of the entity must be apprehended if the desired synthesis of them is to be achieved" (Benton, 1967, p. 1 in Lezak, 1983). This deficit emerges in tasks for which individual parts must be arranged in a given spatial relationship to form a unitary structure. Patients with constructional apraxia have difficulty with copying, drawing and constructing designs in two and three dimensions (Lezak, 1983).

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Benton (1967) postulated two types of constructional activities (graphic and assembly tasks) and noted that both types should be included in an evaluation of constructional apraxia (in Lezak, 1983). The most common example of a graphic task is copying. Copying activities should include copying geometric shapes (from simple to complex) and drawing without a model (Quintana, 1995).

Assembly tasks include such activities such as stick arrangement, two and three-dimensional block designs. Common errors on stick arrangement include failing to reproduce parts of the model (especially the lateral), making lines more oblique than the model indicates, tending to remove part of the model to make the copy, and "crowding in" (Critchley, 1966 in Quintana, 1995).

Generally, these tasks are not standardised and rely on subjective judgement for the results. It is important to note the patient's method of completing the task; the patient's comments; any emotional display, hesitancy, indecision, and change of mind; and the type of errors made (Quintana, 1995).

(a) Copying

The Beery Visuo-Motor Integration Test was administered in order to assess this area.

(b) Two-dimensional Construction

- **Stick construction**

Stick construction of a two-dimensional task in which the patient arranges sticks together in patterns. The stick test (Benson and Barton, 1970; Butters and Barton, 1970), was included as part of the evaluation of constructional apraxia in this study.

This version of the stick construction task includes a rotation condition as well as a standard copy condition. This ten-item test is first administered as a copying task. The clinician remains seated next to the patient throughout the first "match condition" part of the test. The examiner then gives the patient four wooden match sticks and then makes a practice pattern with two other sticks, instructing the patient to copy this pattern exactly.

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The clinician does not proceed until satisfied that the patient understands and can perform this two-stick problem. The examiner then administers the test by constructing each design in numbered order (see Figure 2) and requesting that the patient make a copy directly under that of the examiner. On completing the ten copy items, the clinician moves to the opposite side of the table (i.e. sits opposite the patient). After constructing the same two-stick practice pattern made previously, the examiner now instructs that patient to "make your pattern look to you like mine looks to me." If the patient does not understand the examiner demonstrates the right-left and up-down reversals with the practice pattern. Once again, once the examiner is satisfied that the patient understands what is required, the items of the test are given in the same order as the first time. There is no time limit; rather, patients are encouraged to take as much time as they feel they need to be accurate. Each condition is scored for the number of failed items. On the reversal condition, the test is discontinued after five consecutive failures.

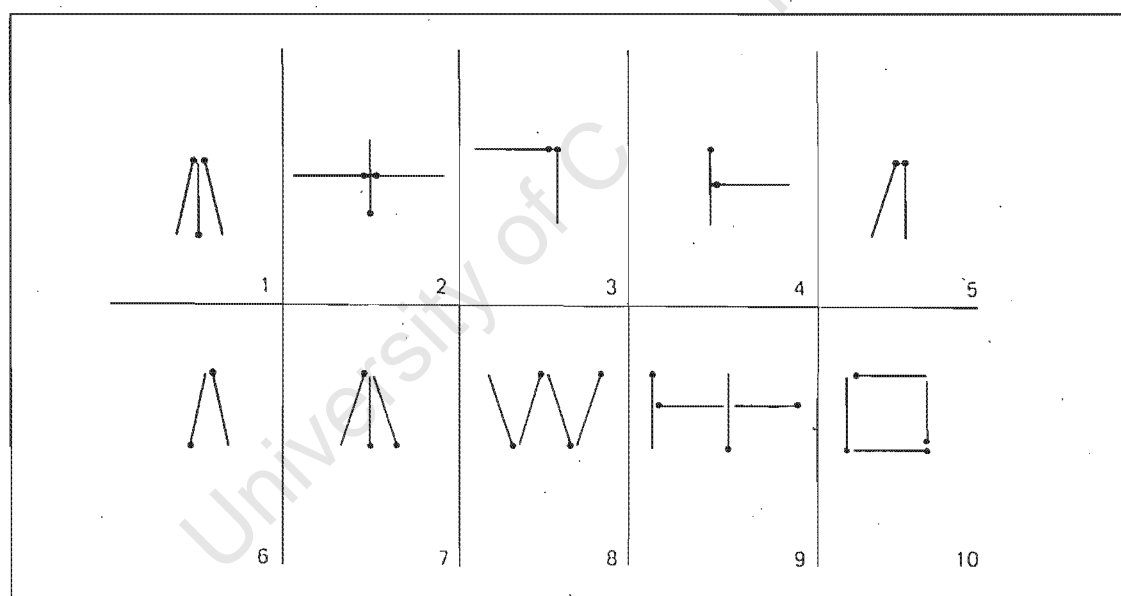

Figure 2: The ten stick designs employed in the match and rotation conditions (Butters and Barton, 1970 in Lezak, 1995)

- **Block Design**

This is a construction test in which the subject is presented with 7 "tangram" shapes. The task is to use the shapes to construct replicas of those designs printed in smaller scale. The order of presentation differs from simple to complex. The ease and rapidity with which the subjects relate the individual blocks to the design pattern give some indication of their level of visuo-spatial conceptualisation. The highest level attained occurs when the subject comprehends the design problem at a glance (forms a "gestalt" concept) and

barely looks at it again while assembling the shapes together rapidly and quickly. Subjects taking a little longer to study the design, who perhaps try out a block or two before proceeding without further hesitancy, or who refer back to the design continually as they work, function at a slightly lower level of conceptualisation. Trial and error performances contrast with the "gestalt" performance. In these, subjects work from shape to shape, trying out and comparing the positioning of each block with the design before proceeding to the next one, is typical of subjects performing in the average range (Wechsler, 1955, 1981 in Lezak, 1995).

- **Form-boards**

The child is requested to complete a form-board as quickly as possible. This is timed and errors, hesitancy and any additional conditions are noted.

(c) **Three-dimensional Construction**

- **Block Design**

The simple block construction tasks described here are designed to elicit three-dimensional visuo-constructive deficits. The level at which age-graded tasks are failed provides a useful indicator of the severity of the disability. The 1960 revised edition of the Stanford-Binet battery contains two simple block construction tasks: Tower at age level II is a simple four-block-high structure; bridge at age level III consists of three blocks, two forming a base with the third straddling over them. At age 3, most children can copy a four-block train (three blocks in a row with the fourth placed on one of the end blocks). Most four year olds can build a six-block pyramid and a five-block gate composed of two two-block "towers", less than 2.5 cm apart, with each top block set slightly back from the bottom block's edge, allowing adequate space for a middle block to rest at a 45° angle. Most five-year-old children can copy six-block steps (Taylor, 1959 in Lezak, 1995).

Benton (1969, cited in Lezak, 1983) suggested that constructional disorders are disturbances "in formulative activities such as assembling, building, drawing, in which the spatial form of the product proves to be unsuccessful without there being an apraxia of single movements" (p. 32). Lezak (1983) proposed that constructional disorders are

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actually not apraxias in the strict sense of the concept and are often associated with lesions of the non-speech hemisphere and may accompany spatial perceptual deficits. Benton (1969) distinguished two different kinds of constructional impairments that often, but not always, co-occur, one having to do with problems in making two-dimensional constructions and the other concerned with three-dimensional building tasks (in Lezak, 1983).

2.5.1.4 Limb Apraxia

Liepmann (1905, in Pramstaller and Marsden, 1996) described three types of limb apraxia: limb-kinetic; ideational and ideomotor apraxia, as discussed in Section 1.

(a) Ideomotor Apraxia

The modified version of the Test of Oral and Limb Apraxia (TOLA) (Kinsella, 1999) as well the Test for the Copying of Formationally Complex Signs (Ogilvy, 1995) was used to assess this area. These tasks were administered only to imitation. In addition, the TOLA Gestured Pictures sub-test probed proximal transitive, distal transitive, oral non-respiratory, and oral respiratory gestures. These tests were analysed under the VICON Motion Analysis System Procedure so as to eliminate subjective bias, as is discussed in detail under Section 2.9.

(b) Ideational Apraxia

The researcher developed the test employed to assess this area. The test procedure involved handing the subjects four objects: a peg; a toothbrush; a whistle and a brush. These items were chosen as they were felt to be age appropriate for the subjects of this study i.e. rather than the use of 'bread knife', as was used in the Clark, et al (1994) study. The demonstrated use of the objects was analysed objectively by using the VICON Motion Analysis System Procedure. The analytical procedures for this test are discussed in detail under Section 2.9.

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(c) Limb-Kinetic Apraxia

As was previously mentioned, two tests, the Test of Copying of Formationally Complex Signs and the Gestured Pictures sub-test from the Test of Oral and Limb Apraxia (TOLA), were modified and analysed using the VICON Motion Analysis assessment tool.

2.6. LANGUAGE TESTS

Formal expressive and receptive language tests were not conducted on the research subjects for the following reasons: Firstly, there are no standardised tests available for the deaf population; secondly, those that are available are not culturally sensitive to the population of South Africa; thirdly, the tasks required from the subjects in this study, were only that of imitation, therefore, if a possible receptive language delay was unknowingly present, it would not have affected the aims of the study. However, in-depth interviews regarding the subjects' language level were conducted with their teachers and parents/caregivers.

2.7. DATA COLLECTION

The researcher, together with a Deaf native signer, administered the apraxic tests in this study.

2.7.1 Data Collection Procedure

All tests were administered in the appropriate testing environment. The testing conducted in this research was videotaped and later scored and analysed by the researcher. The standardised tests were administered according to the instructions given in the test manual. Subjects were tested individually. The time taken to complete testing with each subject varied between one to two hours.

The tests were video recorded using a Fisher FMC P880 video camera. Technical issues, which received specific attention, were as follows:

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2.7.1.1 Seating

The subjects stood while the limb apraxic tests were administered in order to ensure that their limb movements were not restricted while seated. The oral and verbal apraxic tests were administered while the subject was seated at a table, and the chair positioned in the appropriate position. The apraxic test battery was video recorded.

2.7.1.2 Lighting and Background

To eliminate the possibility of shadows, caution was taken to ensure that the correct background and sufficient lighting was available during testing.

2.8. ANALYSIS OF DATA

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The videotaped data were subsequently scored and analysed as follows:

2.8.1 Formal Apraxic Tests

2.8.1.1 Verbal Apraxia

The Test of Verbal and Oral Developmental Apraxia was scored according to the manner prescribed in the test manual. This test was scored and analysed by the researcher. It revealed a profile of Verbal and Oral Apraxic Symptoms for all the subjects.

2.8.1.2. Oral Apraxia

As mentioned above, the researcher scored the Test of Oral and Verbal Developmental Apraxia, according to the manner prescribed in the manual. It revealed profiles of the subjects' Verbal and Oral Apraxic repertoires. Furthermore, the oral sub-tests from the Test of Oral and Limb Apraxia (TOLA) were also scored in the manner prescribed in the manual and the results thereof are incorporated into the aforementioned verbal and oral apraxic repertoires.

2.8.1.3 Constructional Apraxia

(a) Copying

As previously mentioned, the Beery Visuo-Motor Integration test was administered to assess the subjects' visuo-spatial and visual integration abilities. This test was administered by the researcher; scored and interpreted by a clinical neuropsychologist.

(b) Two- and three-dimensional Construction

The researcher and two colleague speech therapists scored the videotaped recordings. The results were scored as a percentage value and the time taken to complete each task was recorded in seconds across all tasks for each subject.

2.8.1.4 Limb Apraxia

Ideomotor, ideational as well as limb-kinetic apraxia were objectively analysed using the VICON Motion Analysis System.

2.9. THE VICON 370 MOTION ANALYSIS SYSTEM FOR THE OBJECTIVE ASSESSMENT OF DEVELOPMENTAL LIMB APRAXIA

2.9.1 Piloting and Modifications

Subsequent to the initial test construction a pilot investigation was conducted on three deaf children with no known suggestion for developmental limb apraxia. Different subjects were used from the control subjects used for the main study. The full battery was administered to all three subjects. The purpose of this pilot investigation was as follows:

- To determine if any errors or inconsistencies with regards to test construction and adaptation were evident,
- To determine the suitability of the test material for deaf children and
- To refine methodological and analysis aspects.

Following this pilot investigation, modifications were made to test material, procedural aspects and aspects of analysis.

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Table 2.6 below summarises the Tests objectively measured by the VICON Motion Analysis System Assessment Protocol.

Table 2.6 Tests Administered and Analysed using the Objective Measures offered by the VICON Motion Analysis System

TESTS ADMINISTERED AND ANALYSED USING THE VICON 370 MOTION ANALYSIS SYSTEM
The Practice Item
The "Gestured Pictures" sub-test from The TOLA
The Test of Formationally Complex Signs
The Demonstrated Use of Objects

2.9.2 Movement Patterns and Parameters

The movement patterns and their parameters are summarised in Table 2.7. These issues are discussed in detail below.

Table 2.7 Movement Patterns and Parameters

MOVEMENT / CRITERIA	STUPID	SHOUT	SAW	SMELL	YES	YELLOW	BRUSH TEETH	KEY	HOOK	SNAKE	LIKE	Z	WEIRD	AEROPLANE	SUBMARINE	GOOD MORNING	STARFISH	BRIDGE	BAD LUCK	NON-REP
1 Unfamiliar	√	√	√	√	√	√	x	x	√	√	√	√	√	√	√	√	√	√	√	√
2 Proximal	√	√	√	x	x	x	x	√	√	√	x	x	x	√	√	√	√	√	√	√
3 Distal	√	√	x	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
4 Representational	x	x	√	√	x	x	√	√	√	x	x	√	x	√	x	x	√	x	x	x
5 Non-representatonal	√	√	x	x	√	√	x	x	x	x	√	x	√	x	√	√	x	√	√	√
6 Complex	x	x	x	x	x	x	x	x	x	√	√	√	√	√	√	√	√	√	√	√
7 Sign	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	x
8 Gesture	x	x	√	√	x	x	√	√	x	√	x	x	x	x	x	x	x	x	x	x
9 Movement	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	√
10 Transitive	x	x	x	x	x	x	x	x	x	√	x	x	x	x	x	x	x	x	x	x
11 Intransitive	√	√	√	√	√	√	√	√	√	x	√	√	√	√	√	√	√	√	√	√

From the above table it is seen that "√" denotes that the movement parameter is present while "X" indicates that it is absent.

The movements chosen for the analytical purposes in the VICON 370 Motion Analysis System Procedure were selected according to strict criteria. The criteria selection is detailed in the discussion below. Poizner et al (1990) found that the apraxic subjects used in their study, showed impairment in four aspects of their control of movement: spatial orientation; distal joint control; movement imitation and timing and space-time relations (velocity). Therefore, these four aspects of the control of movement were considered when choosing the signs/gestures/movements to be analysed in the VICON Motion Analysis System Procedure. These aspects of movement control are now discussed in detail.

2.9.2.1 LIMB APRAXIA

(a) Distal versus Proximal Limb Gestures

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The most important parameter in the classification of types of limb apraxia most likely relates to the extent that finer hand/finger movements versus grosser hand/arm/shoulder movements are required to produce the target gesture. Gestures involving fine hand/finger movements are referred to as distal gestures. An example of this is snapping the fingers. Gestures involving gross hand/arm/shoulder movements are referred to as proximal gestures. An example of this is "saluting".

Motor articulators of apraxic subjects appear to be controlled from the proximal joints with little or no distal control of fine motor articulations (Poizner and Kegl, 1992). Neuroanatomical information suggests that distal musculature, particularly the fingers, may have more independent control for the two sides than is the case for the proximal musculature. The left hemisphere selection system may also be less critical for control of finger movements than for wrist and elbow movements (Kimura, 1981). As previously mentioned, many skilled movements require not only the correct joint to be used, but that two or more joints are used simultaneously. If they are not, then the spatial component of the trajectory will be incorrect (Poizner et al, 1990).

Therefore, movements that rely mostly on the proximal execution of the movement as well as those movements that rely mainly on distal execution of the movement were included as areas to assess within this test.

(b) Intransitive versus Transitive Limb Gestures

A second important parameter in classifying limb apraxia relates to whether the target gesture requires the pretended use of a tool or object. Gestures that do not involve pretended object use are referred to as intransitive gesture. An example of this is waving "goodbye" (a proximal intransitive gesture). Gestures that do not involve the pretended use of an object are referred to as transitive gestures. An example of a transitive gesture is dialling a telephone (a distal transitive gesture).

2.9.2.2 Spatial Errors: Impairments in Spatial Orientation of Movement

To be taught how to use an instrument is learnt for use in a specific spatial relationship to the body. The apraxic subjects often produced movements improperly orientated with respect to the body, lacking proper control over the spatial orientation of movement. This has important implications for sign language acquisition, as the use of spatial aspects has linguistic meaning for signers (Poizner and Kegl, 1992). Poizner et al (1990) concluded that apraxic subjects orient movement laterally in the transverse plane, whereas the control subjects orient movement in the sagital plane.

2.9.2.3 Impairments in Joint Control

In order to use an instrument correctly, the individual must stabilise certain joints and move others. If the incorrect joints are moved, the spatial trajectory (movement pattern) will be incorrect. Apraxic subjects in earlier literature were documented to generate the movement proximally at the shoulder, whereas the control subject generated the movement distally, from a point axis at the elbow. Many skilled movements require not only the correct joint to be used, but also the simultaneous use of two or more joints. If they are not, then again, the spatial trajectory will be incorrect. The apraxic subjects, in previous studies, were found not to co-ordinate shoulder and elbow motion properly. Data have revealed that distal movement is more impaired than the proximal movement in apraxia and that the distal aspects of a movement representation may be more lateralised than the representation of proximal aspects (Poizner et al, 1990). However, Kimura (1981) has documented that the praxis system in the left hemisphere controls the movements of both the left and right arms, and appears to be as critical for proximal as for distal control (Kimura, 1981). Therefore, it was necessary to include both proximal and

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distal features of movement in the VICON Motion Analysis System Procedure. Control over temporal variables such as movement initiation, movement fluidity and movement timing are also disrupted in apraxic subjects. It has been noted that there was often an initial hesitation before the movement is begun, and then a searching or groping behaviour for the appropriate movement (Poizner et al, 1990). Hence, the inclusion of this parameter was indicated in the assessment task.

Poizner et al (1990) remarked on the interesting aspect of the nature of space-time (velocity) representations for learned movement. This lies in the interrelation of spatial and temporal representations. They proposed that the space-time coupling is disrupted in apraxia (Poizner et al, 1990). They concluded that the right hemisphere does not, by itself, contain all the information to program the spatial or temporal aspects of skilled movement. Therefore, movement tasks that involved spatial-temporal orientation were included as part of this diagnostic assessment protocol.

2.9.2.4 Unfamiliar Movements

- **Movement Copying**

The task is to imitate multi-component movements of the hands and arms in unfamiliar and meaningless sequences. The subject sees three movements to be imitated, each involving only one hand and arm. Subjects with left hemisphere damage who may not have difficulty with the single hand postures may be impaired in copying a series of movements. The test procedure involved presenting a practice item; for the practice and subsequent test item, the examiner presents the entire movement, after which the patient copies it from memory. If the patient fails to make a perfect reproduction of the movements, the sequence is repeated a second time in exactly the same way. The patient again copies from memory. No further trials are given.

Kimura (1981) reported that a deaf aphasic appeared to have significant difficulty imitating non-linguistic movements as well as linguistic movements. In addition, a deaf aphasic may have difficulty in imitating unfamiliar manual movements. She proposed that the very familiar over-practised movements by which apraxia is typically tested are simply not adequate to uncovering a moderate movement control defect. Furthermore, Wang and

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Goodglass (1992) postulated that the imitation of non-meaningful movements served as a measure of apraxia, uncontaminated by symbolic or linguistic factors. Therefore, unfamiliar movements were included in the assessment battery.

2.9.2.5 Representational versus Non-representational Movements

In order to investigate the relationship between apraxia and aphasia for a gestural language, tests of production and imitation of both representational and non-representational movements are usually included in the tests for investigating for the possible presence of apraxia (Poizner and Kegl, 1992). Impairments in motor control are not limited to representational meaningful movements, but can be demonstrated in meaningless, unfamiliar arm movements (Kimura and Archibald, 1974). Therefore, both representational and non-representational items were included in the test.

2.9.2.6 Repetitiveness

The praxis system in the left hemisphere controls the movements of both the left and right arms and appears to be just as critical for proximal as for distal control. It is particularly important for carrying out movements requiring several changes in posture but not for movements that are simply repeated over and over, even if the repetitious movement involves fairly fine finger control (Kimura, 1977).

Therefore, for the purposes of this study, the aim was to investigate several changes in posture as they occur in a movement pattern. Hence movement tasks that are repetitive in nature were excluded from this assessment procedure.

2.9.2.7 Complexity

As previously mentioned, it was essential to include signs that consisted of several changes in posture in order to exclude signs that were repetitive in nature. Therefore, the movements of the Test of Copying of Formationally Complex Signs were included in this section, as they were considered to have an adequate representation of several changes in posture. Furthermore, as previously mentioned, they were scored as complex on the

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continuum of formational complexity and included in the VICON 370 Motion Analysis System for objective measurement.

2.9.2.8 Signs versus Gestures

Previous research has found that deaf aphasic patients showed marked sign language deficits, but displayed preserved expression and comprehension of gesture (Poizner and Kegl, 1992). Thus, gestures and signs as well as gestures/signs were included as part of the test assessment. Both transitive and intransitive gestures were included since, as mentioned previously, the main symptoms of apraxia are described as body-part-as-object in intransitive (without objects) actions. For example, where the patient uses his/her fist to pantomime a hammering action or the forefinger to pantomime a toothbrush or a teaspoon. Spatial inaccuracy of actions, substitution of similar actions for intended actions, clumsiness in execution and perseveration of actions also characterise the disorder. Therefore, it was essential to include both transitive and intransitive actions in the apraxic assessment protocol (Code, 1998).

Literature documents the importance, at the abstract level, of distinguishing between a conceptual system, which provides a schema of action, and a production system responsible for the planning, generation and implementation of action. The conceptual system carries three types of knowledge: knowledge of action of function (e.g. cutting) associated with objects and tools – transitive movements (e.g. knife, scissors); knowledge of actions which are independent of objects or tools – intransitive movements (e.g. hammering) but into which objects and tools may be incorporated (e.g. using a hammer) and knowledge concerning the ordering of single actions into a sequence. Apraxic symptomatology can be attributed to impairment to one or both of these systems (Roy, 1983; 1986).

2.9.3 Equipment and Set-up: Oxford Metrics Camera System using the Body Builders Software.

VICON 370 is a three-dimensional motion measurement and analysis system comprising specialised hardware, a PC, and application software. The system tracks the trajectories of retro-reflective markers in the field view of 6 cameras. The measured quantities are processed by the software producing an output file with the extension .C3D. which

contains three-dimensional motion data. The hardware components of the system comprise two main systems: a data station; and a workstation. The procedures involved in the development and implementation of the VICON Motion Analysis System are depicted in Figure 3.

2.9.4 Measurement

The following procedure was adopted in using the Body Builder for Biomechanics when processing data:

- The purpose of the measurement was decided and the model and marker set were selected.
- The physical parameters of objects were measured and marker sets attached.
- The data was collected using VICON 370.
- The trajectories were reconstructed and identified.
- A C3D file was produced.
- The Body Builder software was started and the C3D file opened.
- The data was "cleaned-up" using the editing tools.
- The models were loaded and the parameters checked.
- The models were run and the results examined.
- The suitable output format was selected and saved.

(Oxford Metrics Ltd, 1997; 1998).

2.9.5 Administration of the VICON 370 Motion Analysis Assessment Tool

Some individuals have difficulty in copying single hand postures, however, many do not (Kimura, 1987). This test is always given prior to the VICON Motion Analysis System Assessment. A practise item is presented. This practise item establishes that the individual understands what he/she is to do. For the practise and subsequent test items, there is first a brief presentation by the examiner, after which the individual copies the posture from memory. If the individual does not correctly perform the posture, the examiner demonstrates and sustains the posture, and the individual copies it while the posture is visible (Kimura, 1987).

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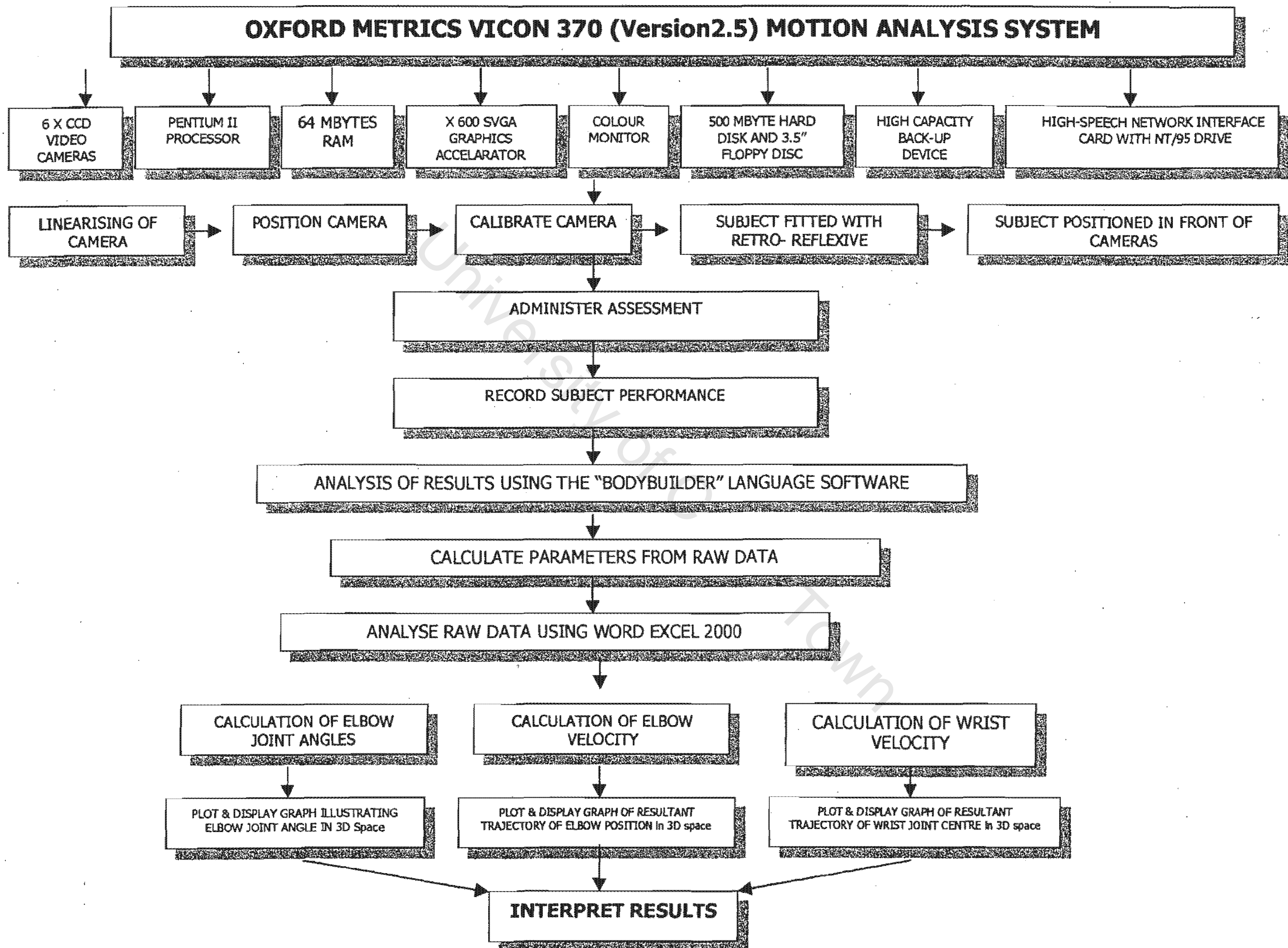

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Figure 3: **Flow diagram illustrating the VICON Motion Analysis System Procedure**

Figure 4: A photograph illustrating the camera set-up used in the VICON Motion Analysis System

Figure 5: A photograph illustrating the placement of the reflective markers

A deaf native signer administered this test. The examiner instructed the subjects to imitate the movement patterns conducted by her. The entire sequence of the movement patterns was repeated three times to obtain measures of movement variability (Poizner et al, 1990). The subjects' responses were captured and later analysed. The details of the administration of the test battery for the VICON 370 Motion Analysis System procedure are as follows:

- **Instructions to the subjects**: "All you have to do is copy exactly what I do!"
- **Practice Item**: "Hold up hand as in a 'Stop'- like gesture"

- **Test of Formationally Complex Signs**

Each sign is shown three times. A ten second pause occurs after each sign. Table 2.8 below displays the movements used (as discussed earlier).

Table 2.8 The Movements used during the VICON Motion Analysis Test

1. "stupid"	11. "like"
2. "shout"	12. "Z"
3. "saw"	13. "weird"
4. "smell"	14. "aeroplane taking off"
5. "yes"	15. "submarine"
6. "yellow"	16. "good morning"
7. "brush teeth"	17. "star fish"
8. "key"	18. "bridge"
9. "hook"	19. "bad-luck"
10. "snake"	20. "non-representational"

- **Gestured Pictures**

Instructions to the subject: "Please could you show me how you would use these objects?" A ten second pause occurs after each picture is shown.

The following pictures were used in this assessment battery and are tabulated in Table 2.9 below.

Table 2.9 Pictures used in the VICON Motion Analysis

NAME OF PICTURE USED	
Axe	Tennis racquet
Painter	Spoon
Knife	Peg
Pen	A pair of scissors
Key	A Gun
A toothbrush	

- **Test of Ideational (Object) Apraxia**

Instructions to the subject: "Show me how you would use these objects - you only need to gesture".

The following objects were used in this assessment battery and are tabulated in Table 2.10.

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Table 2.10 Objects used in the VICON Motion Analysis

PEG TOOTHBRUSH WHISTLE (to pick up from chair) BRUSH

As previously mentioned, the researcher adopted the underlying principles of the methodological procedures of Poizner et al (1990); Clark et al (1994) and Hermsdörfer et al (1996) and devised an alternative method of analysing the purposeful, skilled movement patterns. In summary, the VICON Motion Analysis System Procedure determines the **kinematics of movement** i.e. it objectively analyses the "smoothness" of the movement trajectories, as well as processing the existence of any possible deficiencies of joint co-ordination. Furthermore, it determines if the presence of **spatio-temporal parapraxias** is evident.

2.10. MEASURES OF RELIABILTY

"Reliability should be a central concern because it is a necessary, although not sufficient, prerequisite to the validity of scores" (Strong and Shaver, 1991, p. 95). If the assessment battery is not reliable, that is, if the results of the measurement are not consistent and repeatable, then the scores lack meaning (Strong and Shaver, 1991). Therefore, measures of reliability regarding some of the apraxic evaluations were undertaken by the use of matched control subjects.

Inter-rater reliability for part of the apraxic assessment battery, i.e. The Test of Verbal and Oral Developmental Apraxia, the sub-tests from the TOLA and the Constructional Apraxia Test Battery were determined as follows. All the aforementioned tapes were scored by three qualified speech therapists and checked for inter-rater reliability using point-to-point ratings. The average agreement was 90 % and any differences were resolved.

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SECTION THREE

3. RESULTS AND DISCUSSION

In this section, the results of the experimental and the control subjects' performance on the apraxic test battery are presented. A description of the nature of the experimental subjects' movement patterns as compared to that of the control subjects is provided. Furthermore, the findings of this research are compared to that of previous research.

3.1 RESULTS OF THE TEST OF DEVELOPMENTAL VERBAL AND ORAL APRAXIA

A qualitative profile of the oral and verbal apraxic repertoires for all subjects is presented below in Tables 3.1 – 3.4.

Table 3.1 Subjects' Oral and Verbal Apraxic Repertoire (ES 1 & CS 1)

SYMPTOM	ES 1		CS 1	
	YES	NO	YES	NO
• Oral groping	X			X
• Limited phonetic repertoire	X		X	
• Oral apraxia for isolated movements	X			X
• Oral apraxia for a sequence of movements	X			X
• Discrepancy between voluntary & spontaneous non-verbal oral movements (with spontaneous movements being better)	X			X
• Discrepancy between receptive & expressive language abilities (with receptive language abilities being better)	X		X	
• Vowel difficulties		X	X	
• Production quality worsens with increased utterance length	X			X
• Adaptation occurs: production improves with repeated attempts	X			X
• Placement confusions within word (metathesis)		X		X
• Articulatory substitution errors	X		X	
• Voiced/voiceless substitutions	X		X	
• Articulation distortion errors	X		X	
• Sounds produced correctly in isolation, not correctly carried over to longer sound combinations	X			X
• Abnormal prosodic characteristics	X		X	

Table 3.2 Subjects' Oral and Verbal Apraxic Repertoire (ES 2 & CS 2)

SYMPTOM	ES 2		CS 2	
	YES	NO	YES	NO
• Oral groping	X			X
• Limited phonetic repertoire	X			X
• Oral apraxia for isolated movements	X			X
• Oral apraxia for a sequence of movements	X			X
• Discrepancy between voluntary & spontaneous non-verbal oral movements (with spontaneous movements being better)	X		X	
• Discrepancy between receptive & expressive language abilities (with receptive language abilities being better)	X			X
• Vowel difficulties	X			X
• Production quality worsens with increased utterance length	X			X
• Adaptation occurs: production improves with repeated attempts		X		X
• Placement confusions within word (metathesis)	X			X
• Articulatory substitution errors	X			X
• Voiced/voiceless substitutions	X			X
• Articulation distortion errors	X			X
• Sounds produced correctly in isolation, not correctly carried over to longer sound combinations	X			X
• Abnormal prosodic characteristics	X		X	

Table 3.3 Subjects' Oral and Verbal Apraxic Repertoire (ES 3 & CS 3)

SYMPTOM	ES 3		CS 3	
	YES	NO	YES	NO
• Oral groping	X			X
• Limited phonetic repertoire	X		X	
• Oral apraxia for isolated movements	X			X
• Oral apraxia for a sequence of movements	X			X
• Discrepancy between voluntary & spontaneous non-verbal oral movements (with spontaneous movements being better)	X			X
• Discrepancy between receptive & expressive language abilities (with receptive language abilities being better)	X		X	
• Vowel difficulties	X		X	
• Production quality worsens with increased utterance length	X			X
• Adaptation occurs: production improves with repeated attempts		X	X	
• Placement confusions within word (metathesis)	X			X
• Articulatory substitution errors	X		X	
• Voiced/voiceless substitutions	X		X	
• Articulation distortion errors	X		X	
• Sounds produced correctly in isolation, not correctly carried over to longer sound combinations	X			X
• Abnormal prosodic characteristics	X		X	

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Table 3.4 Subjects' Oral and Verbal Apraxic Repertoire (ES 4 & CS 4)

SYMPTOM	ES 4		CS 4	
	YES	NO	YES	NO
• Oral groping	X			X
• Limited phonetic repertoire		X		X
• Oral apraxia for isolated movements	X			X
• Oral apraxia for a sequence of movements	X			X
• Discrepancy between voluntary & spontaneous non-verbal oral movements (with spontaneous movements being better)	X			X
• Discrepancy between receptive & expressive language abilities (with receptive language abilities being better)	X		X	
• Vowel difficulties		X		X
• Production quality worsens with increased utterance length	X			X
• Adaptation occurs: production improves with repeated attempts	X			N/A
• Placement confusions within word (metathesis)		X		X
• Articulatory substitution errors	X			X
• Voiced/voiceless substitutions		X		X
• Articulation distortion errors		X		X
• Sounds produced correctly in isolation, not correctly carried over to longer sound combinations	X			X
• Abnormal prosodic characteristics	X			X

As can be seen from Tables 3.1 – 3.4, the experimental subjects appear to present with evidence of both verbal and oral apraxia. The degree of severity, however, cannot be deduced from these results. Furthermore, it is evident from these qualitative profiles that the experimental subjects unlike the control subjects appear to present with oral apraxia. All subjects seem to display an indication of the presence of verbal apraxia such as limited phonetic vowel difficulties, vowel difficulties and articulation distortion errors. However this should be carefully interpreted as all subjects, both experimental and controls, are severe to profoundly deaf, and as a result of deafness present with articulatory disturbances. This highlights the difficulty in assessing the presence of verbal apraxia in deaf children.

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3.2 RESULTS FROM THE TEST OF ORAL AND LIMB APRAXIA (TOLA). Normed Edition. (Helm-Estabrooks, 1992); Modified Version – (Kinsella, 1999).

The performance of the experimental and control subjects on the oral apraxia and gestured pictures sub-tests of the TOLA are reflected in Table 3.5. The "imitation" component of this test and not the "to command" was administered in order eliminate the influence of possible affects of poor receptive functioning (Clark et al, 1994).

Table 3.5 Results from the TOLA

SUBTEST NAME & SCORES	ES 1	ES 2	ES 3	ES 4	CS 1	CS 2	CS 3	CS 4
• Oral Apraxia – imitation only								
Raw Score	27	25	17	23	25	26	29	28
Percentage Score	90	83	57	77	83	87	97	93
• Gestured Pictures:								
Raw Score	12	11	5	9	11	11	12	12
Percentage Score	100	92	42	75	92	92	100	100

Percentile ranks, standard scores and the TOLA composite score could not be calculated as only sub-tests were employed. However, from the raw scores and calculated percentages, only ES 3 and ES 4S' overall performance was poorer than that of the matched controls. The reader is cautioned regarding the interpretation of the results, as due to the previously mentioned modifications made to this test, the normative data may not necessarily apply to this population group.

3.3 RESULTS FROM THE VICON MOTION ANALYSIS SYSTEM

As previously mentioned in Section 2.9, the subjects' signs, gestures and movement patterns were analysed using the Oxford Metrics VICON 370 (Version 2.5) Motion Analysis System and the "Body Builder" language software programme. The final results yield graphs indicating objective measures of elbow joint angles, elbow and wrist velocity and wrist rotation angles.

Graphs illustrating the resultant trajectories of elbow position and wrist joint centre as well as the elbow joint angle for the various movements investigated in the VICON 370 Motion Analysis System will follow. The resultant trajectories are plotted against displacement (how the movement changes over time) and cycle (a standard calculated to allow for a direct comparison between experimental and control subjects).

Although the movement patterns of the experimental and control subjects are formally plotted using objective measures, for the purposes of this research which is exploratory in nature, the interpretation of the results are restricted to observing differences in movement patterns as depicted on the graphs. In future research, which includes a larger sample size and has as its purpose the validation of such measuring techniques, quantification of the results using statistical analyses such as variance ratios should be undertaken.

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As mentioned previously in the methodology section, meaningless movement sequences, signs and gestures were employed in this study. The graphs obtained from the VICON Motion Analysis System are displayed in these three "categories" for each experimental subject. Specific examples have been selected to allow a sign/gesture, a transitive and intransitive gesture, a sign and a non-representational movement to be illustrated.

3.3.1. GRAPHS ILLUSTRATING THE RESULTS FROM THE MEANINGLESS MOVEMENT SEQUENCE

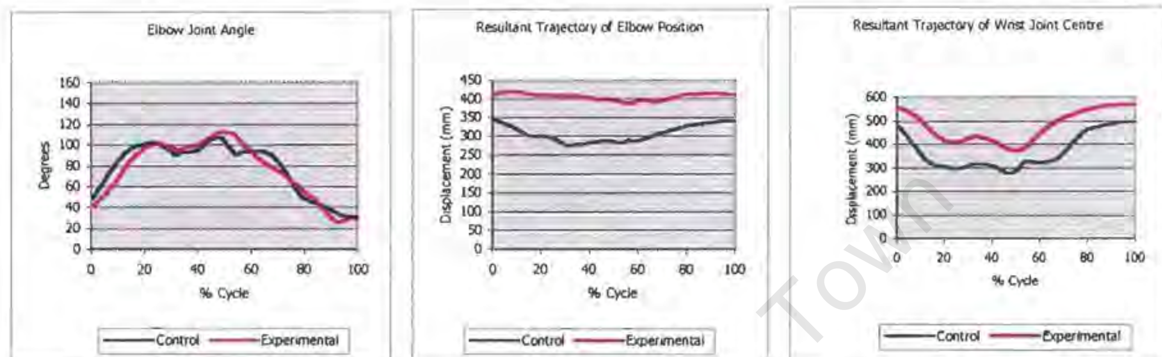

Figure 6 Graphs illustrating the movement trajectory of the movement "non-rep" of ES1 and CS1.

As is noted from the above-mentioned graphs, all movement trajectories were measured using x, y and z co-ordinates. This is important in determining movement in space, i.e. in the third dimension. Hence, all movements were captured by methods explained in the methodology of this section. In order to represent the movement trajectories of all subjects in two-dimensions, x- and y-axes have been plotted. The x-axis represents the percentage cycle so as to allow a standard of comparison across graphs in that all movement trajectories are interpreted according to one movement cycle. Furthermore, percentage cycle includes the temporal component of the movement trajectory. The y-axis in the first graph represents "degrees" i.e. how the elbow joint angle (angles are measured in units of degrees) increases or decreases. In the second and third graphs, the y-axis is represented by "displacement". Displacement is defined as distance in a particular direction. In addition, both the percentage cycle and displacement were calculated in the third-dimension i.e. measuring x, y and z co-ordinates in space, hence the graphs (both the x- and y-axes) of the resultant trajectories have captured the spatio-temporal characteristics of the subjects' movement trajectories.

As is seen in Figure 6 "elbow joint angle", CS 1 displays more of an angle change than does ES 1. This movement requires a marked change in the elbow joint angle value for the movement to be carried out correctly. Conversely, in graphs displaying the resultant

trajectories of elbow joint centre and wrist joint centre, ES 1 shows less of a spatio-temporal change compared to CS 1.

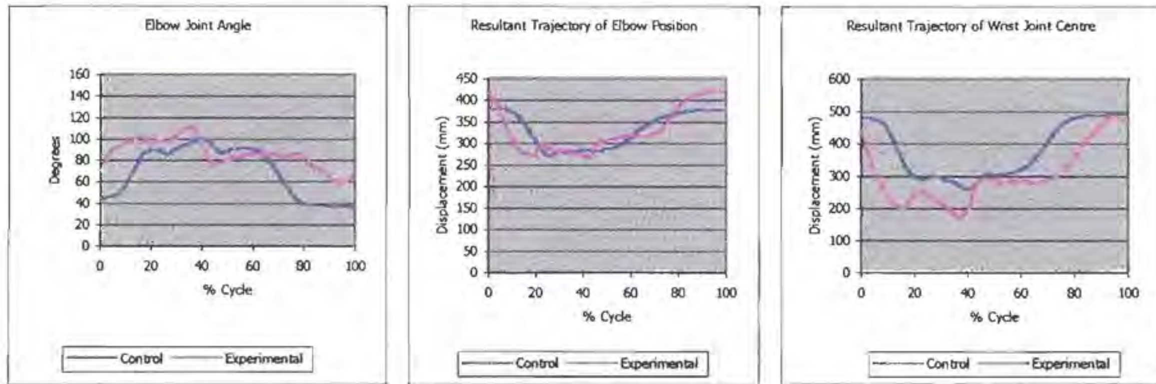

Figure 7 Graphs illustrating the movement trajectory of the movement "non-rep" for ES2 and CS2.

As is seen in Figure 7, ES 2 appears to present with a deficient joint co-ordination, as can be observed by a sharp change in elbow joint angle value versus the smoother transition in elbow joint angle values of CS 2. In the graphs representing the resultant trajectories of elbow position and wrist joint centre, ES 2's movement trajectories do not appear to be as smooth of the movement trajectories of CS 2. This may be suggestive of disrupted spatio-temporal aspects for this particular movement.

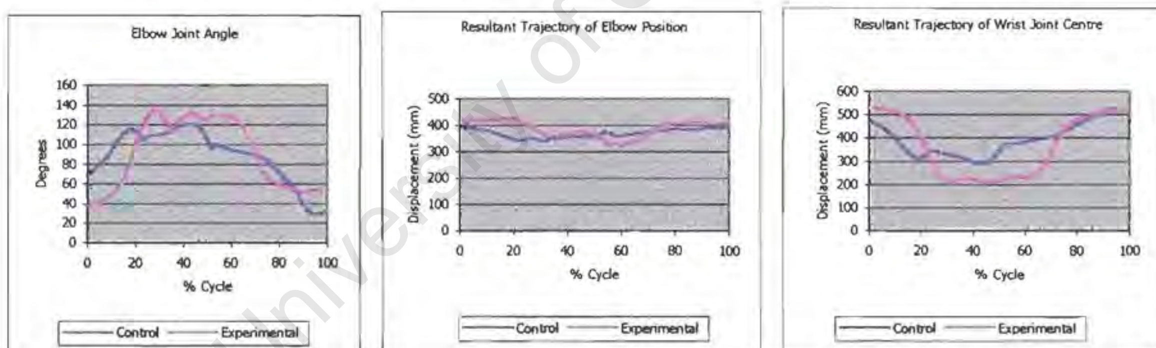

Figure 8 Graphs illustrating the movement trajectory of the movement "non-rep" for ES3 and CS3.

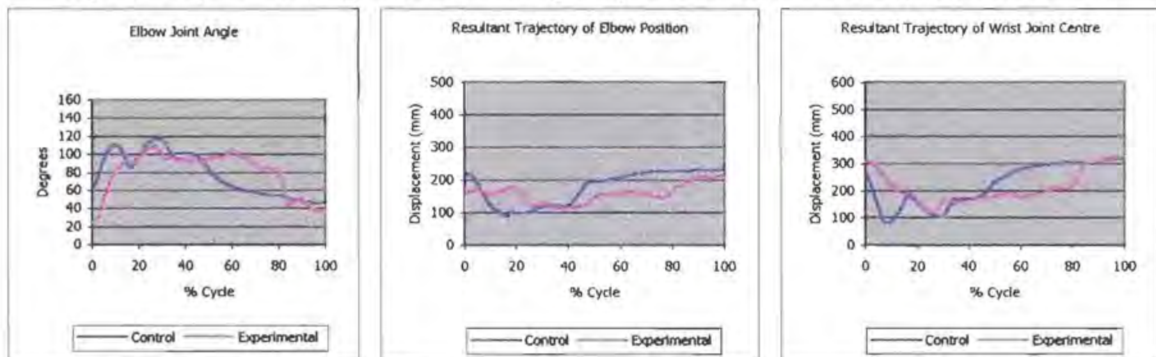

Figure 9 Graphs illustrating the movement trajectory of the movement "non-rep" for ES4 and CS4.

As is seen in Figures 8 and 9, the experimental subjects present with abnormal kinematics and spatial parapraxias in carrying out the non-representational movement sequence.

This is particularly evident in the sharp changes in elbow joint angle values seen in ES 3 and ES 4. In addition, the jerkiness noted in the experimental subjects' of ES 3 and ES 4 graphs compared to the smoother graph of the matched control subjects is indicative of disruptive spatio-temporal components measured by the displacement y-values and the percentage cycle x-axis of the resultant trajectories for elbow position and wrist joint centre. An apparent defective movement of a meaningless movement sequence would be indicative that developmental limb apraxia could be attributed to a movement disorder rather than a symbolic disturbance. This finding is in agreement with Hermsdörfer et al (1996) who postulated that the presence of kinematic abnormalities is indicative of a motor programming difficulty.

3.3.2. GRAPHS ILLUSTRATING THE RESULTS OF VARIOUS SIGNS

As mentioned earlier, signs were incorporated into the objective assessment of the VICON Motion Analysis System. Only examples of the signs illustrating marked differences between the experimental subjects and the matched controls have been included in this section. The remainder of the graphs illustrating the signs employed in this study can be viewed in Appendix III.

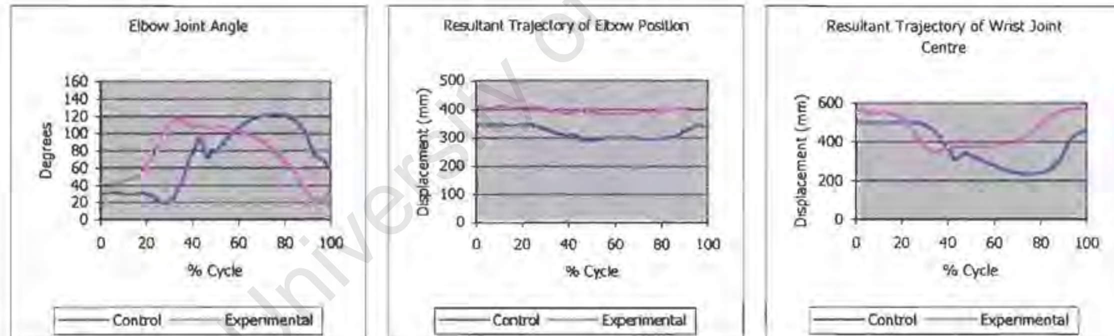

Figure 10 Graphs illustrating the movement trajectory of the sign "good morning" of ES1 and CS1.

As can be seen from Figure 10, the experimental subject presented with abnormal kinematics, spatial kinematics and spatio-temporal abnormalities. It is clear that the experimental subject failed to execute the change necessitated to conduct the sign. The matched control subject's results indicate this change by the notch in the graph. Researchers such as Poizner et al (1992) and Clark et al (1994) have documented that deficient elbow joint angles and spatio-temporal characteristics as indicated by ES 1's lack of variation in displacement, might be characteristic of apraxia.

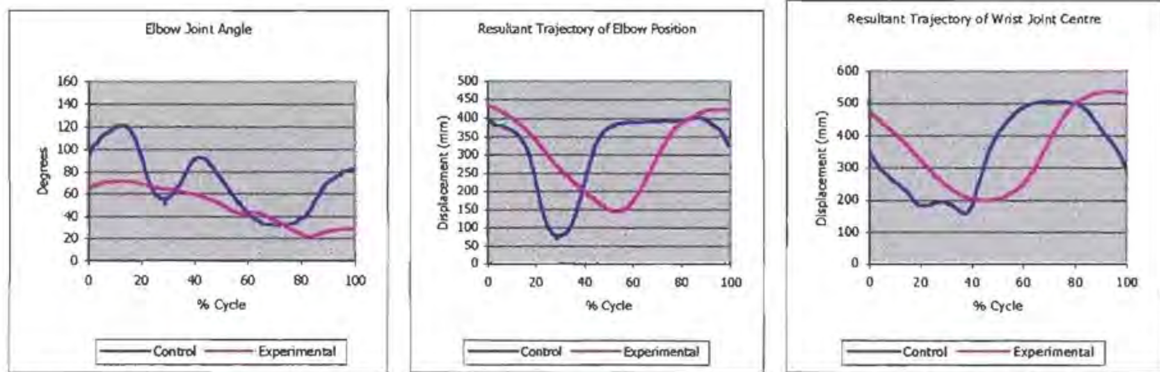

Figure 11 Graphs illustrating the movement trajectory of the sign "aeroplane taking off" for ES2 and CS2.

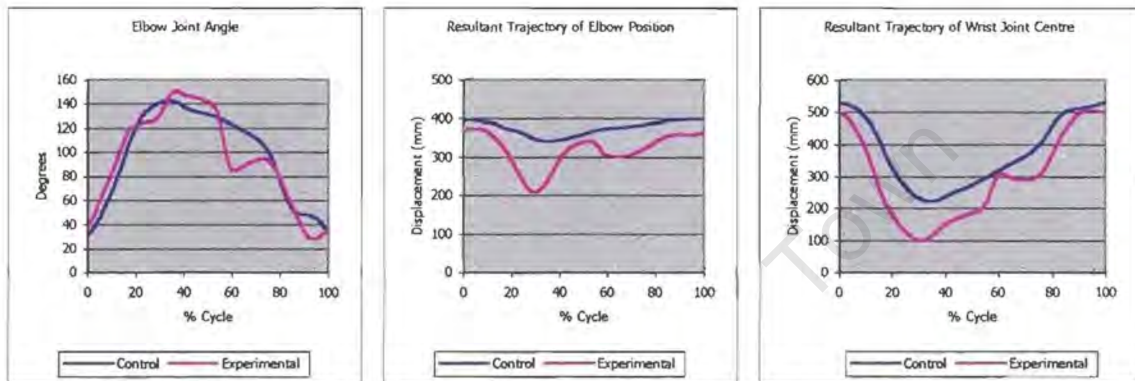

Figure 12 Graphs illustrating the movement trajectory of the sign "submarine" for ES3 and CS3.

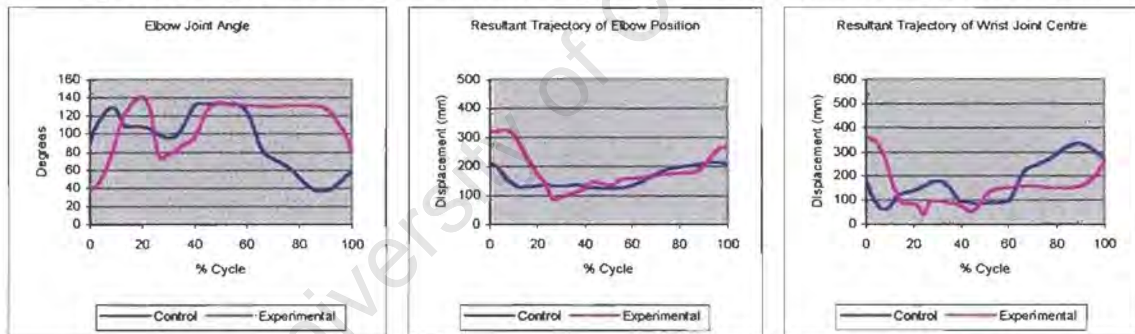

Figure 13 Graphs illustrating the movement trajectory of the sign "bad luck" for ES4 and CS4.

Similarly, as is seen in Figures 11, 12 and 13, ES 2, ES 3 and ES 4, present with abnormal kinematics, spatial kinematics and spatio-temporal abnormalities, in that they do not execute an accurate change in movement to correctly carry out the signs.

3.3.3. GRAPHS ILLUSTRATING THE RESULTS OF THE VARIOUS GESTURES

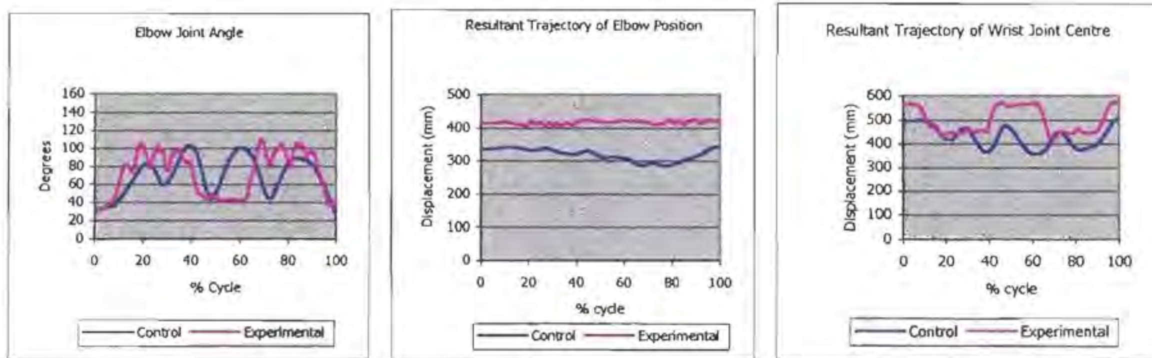

Figure 14 Graphs illustrating the movement trajectory of the gesture "saw" for ES 1 and CS 1

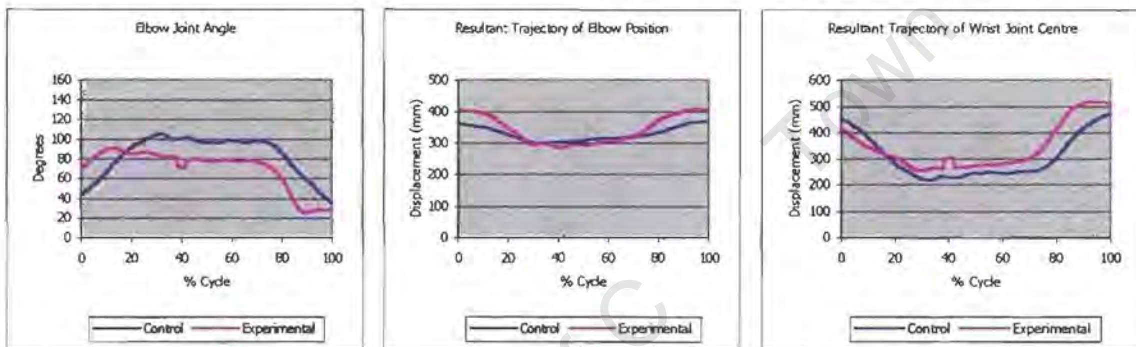

Figure 15 Graphs illustrating the movement trajectory of the gesture "key" for the ES2 and CS2.

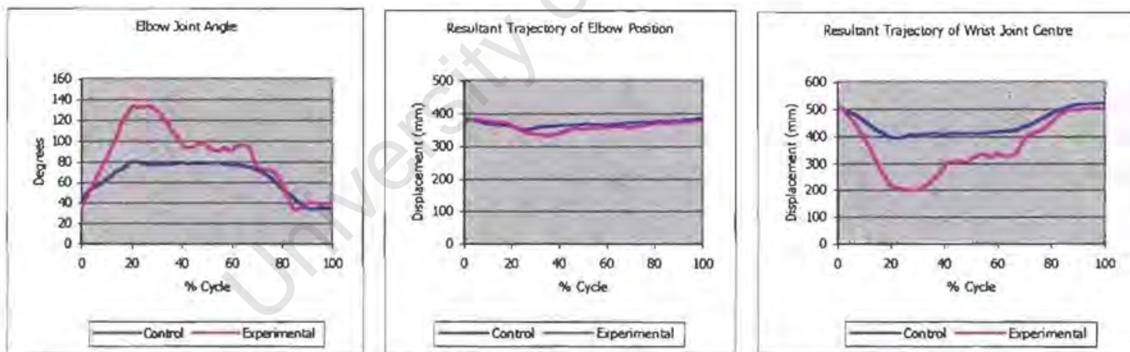

Figure 16 Graphs illustrating the movement trajectory of the gesture "key" for ES3 and CS3.

Figures 14, 15 and 16, clearly illustrate that the experimental subjects present with abnormal kinematics and spatial parapraxias noted in impaired spatio-temporal aspects of the movement patterns for the gestures of "saw" and "key". The jerkiness of movement in the experimental subjects suggests the presence of a developmental limb apraxia. The findings of this research are in support of Rothi and Heilman (1997) who have documented that in addition to making spatial orientation errors, the spatial trajectory of an apraxic's limb when producing a pantomime i.e. a gesture, is often inaccurate. This error in spatial path may be related to incorrect joint use or poor joint co-ordination as is noted in the

sharp changes in elbow joint angle values noted in the experimental subjects compared to that of their controls.

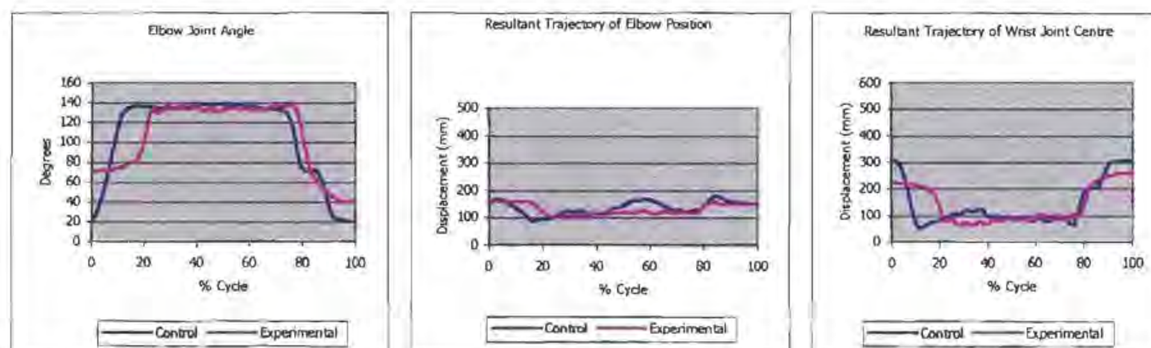

Figure 17 Graphs illustrating the movement trajectory of the gesture "brush teeth" for ES4 and CS4.

In Figure 17 above, the elbow joint angle graphs illustrate jerkiness displayed by the experimental subject. This highlights a deficient joint co-ordination as well as disruptive spatio-temporal components in the resultant trajectory of elbow position in the second graph. Although a "jerky" movement is illustrated in the resultant trajectory of the wrist joint centre both by the experimental subject and the matched control, this is considered normal due to the nature of the wrist movement during this particular movement. However, CS 4's wrist appears to be more controlled relative to ES 4 as the notches are not as prominent.

In the methodology, it was hypothesised that gestured pictures could be objectively evaluated. However, this has proven not to be the case. The gestured picture of "axe" was analysed using the objective methods of the VICON Motion Analysis System. It was found that the experimental and control subjects performed the same movement differently. Observations of the video-recordings, revealed both groups of subjects as having executed the correct and accurate movement. In addition, the VICON Motion Analysis System yielded skewed results in that no kinematic movements were recorded but only two very varied movements. For this reason, the gestured pictures were not analysed further. For the readers' interest, the few examples from the results of the gestured picture of "axe" have been included in Appendix IV.

Overall, the experimental subjects' performance was shown to include defective movement patterns (i.e. kinematic abnormalities) together with the presenting evidence of spatio-temporal parapraxias for the signs and gestures as well as the meaningless movement

sequence. As is seen from the above discussion, the experimental subjects of this study present with evidence of developmental limb apraxia across the meaningless movement sequence, sign and gestures (both intransitive and transitive). This finding supports the results of Poizner and Kegl (1992), Clark et al (1994), Hermsdörfer et al (1996) and Rothi and Heilman (1997).

A mentioned previously, a number of researchers (e.g. Poizner et al, 1990 and Clark et al, 1994) have provided detailed kinematic analyses of apraxic movements. The results of this study are consistent with the findings of Hermsdörfer et al (1996), in which kinematic abnormalities may be interpreted as indicators of deficient motor programming.

The findings of the presence of kinematic abnormalities and the evidence of spatial parapraxias and defective spatio-temporal aspects of the experimental subjects of this study, support the findings of Liepmann (1908, in Hermsdörfer et al, 1996); Poeck (1986) and Code (1998) which stress that a fundamental feature of apraxia is the presence of spatial parapraxias which may affect either the spatial course and the final position of single movements or the temporal sequencing of multiple movements into a coherent motor action. Hermsdörfer et al (1996) predicted that deficient motor programming is the cause of parapraxic errors and that kinematic indications of deficient programming should be detectable in every movement that ends up in with a parapraxic error.

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3.4. RESULTS OF THE CONSTRUCTIONAL APRAXIA TEST BATTERY

As previously mentioned in Section 2.5.1.3, the researcher devised an assessment protocol to determine the presence of constructional apraxia in the subjects. The assessment procedures included: free drawing; copying; block design; matchstick copying and timed completion of form-boards (Lezak, 1983). Patients with constructional apraxia have difficulty with copying, drawing and constructing designs in two- and three-dimensions (DeRenzi, 1985). Table 3.6 illustrates the results of the Beery Visuo-Motor Test. This test assesses visual integration and was scored and interpreted by a clinical neuropsychologist.

Table 3.6 Subjects' Performance on the Beery Visuo-Motor Integration Test

SUBJECTS	QUOTIENT	COMMENTS
ES 1	132	Above average
ES 2	88	Below average
ES 3	55	Very poor visual motor integration
ES 4	87	Below Average
CS 1	167	Superior
CS 2	95	Slightly below average
CS 3	64	Borderline - very poor visual motor integration
CS 4	97	Average

As can be seen from Table 3.6 above, three of the four experimental subjects present with difficulty in visual motor integration abilities as measured on the Beery Visuo-Motor Integration Test. Furthermore, two of the four control subjects also displayed difficulty with visual motor integration abilities.

These findings may suggest a possible explanation for the presence of the deficit seen in the spatial components of the movement trajectories of the signs, gestures and movement patterns of the VICON Motion Analysis Battery. This issue will be discussed in greater depth in Section 4.

Table 3.7 below displays the subjects' performance on the two-dimensional stick construction task. This version of the stick construction task includes a rotation condition as well as a standard copy condition.

Table 3.7 Subjects' Performance on the Stick Construction Task

TEST	ES 1	ES 2	ES 3	ES 4	CS 1	CS 2	CS 3	CS 4
A: STANDARD COPYING CONDITION								
% Correct	80	100	60	80	100	100	80	100
Time (seconds)	225	157	330	300	210	150	240	255
B: ROTATION COPYING CONDITION								
% Correct	60	80	30	40	80	50	40	70
Time (seconds)	300	120	208	350	390	210	150	315

As is noted by the subjects' performance displayed in Table 3.7 above, ES 3 performed poorly on both the standard and rotation copying conditions, while ES 4, CS 2 and CS 3 performed poorly on the rotation copying condition. These results correlate with the poor performances noted by these subjects on the Beery Visuo-Motor Integration Test. The

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weaker results displayed by ES 3, ES 4, CS 2 and CS 3 on the stick construction task may be indicative of a constructional apraxia difficulty.

Table 3.8 below highlights the subjects' constructional ability in terms of two dimensional block design.

Table 3.8 Subjects' Performance on the Block Design Sub-test

SUBJECTS	% CORRECT	TIME (seconds)
ES 1	60	300
ES 2	80	350
ES 3	10	TD
ES 4	50	362
CS 1	70	455
CS 2	80	410
CS 3	40	314
CS 4	50	600

TD = Test Discontinued

Table 3.9 Subjects' Performance on the Three-Dimensional Block Design Sub-test

SUBJECTS	% CORRECT	TIME (seconds)
ES 1	100	180
ES 2	100	120
ES 3	30	195
ES 4	83	160
CS 1	100	150
CS 2	100	180
CS 3	83	190
CS 4	100	63

Table 3.10 Subjects' Performance on the Two-Dimensional Form-board Completion

SUBJECTS	TIME (seconds)
ES 1	98
ES 2	145
ES 3	140
ES 4	60
CS 1	50
CS 2	34
CS 3	60
CS 4	81

As in noted from Tables 3.8, 3.9 and 3.10 above ES 3, ES 4, CS 3 and CS 4 performed poorly on the block design subtest, while ES 3, ES 4 and CS 3 performed poorly on the

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three-dimensional block design sub-test. Furthermore, ES 2 and ES 3 performed poorly on the two-dimensional form-board completion task. ES 3's results display a weak overall performance on the block design sub-test, the three-dimensional block design sub-test and the two-dimensional form-board completion task, indicating a possible presence of constructional apraxia.

3.5. SUMMARY OF THE PRAXIC FUNCTIONS OF THE SUBJECTS

Table 3.11 Subjects' Performances Across Tasks

SUBJECTS	OA	VA	DLAM	DLAS	DLAG	Visuo-motor integration	CA
ES 1	√	?	X	X	X	√	√
ES 2	√	?	X	X	X	X	?
ES 3	X	?	X	X	X	X	X
ES 4	X	?	X	X	X	X	●
CS 1	√	?	√	√	√	√	√
CS 2	√	?	√	√	√	X	√
CS 3	√	?	√	√	√	X	●
CS 4	√	?	√	√	√	√	√

KEY

OA	=	Oral Apraxia
VA	=	Verbal Apraxia
DLAM	=	Developmental Limb Apraxia – meaningless movement
DLAS	=	Developmental Limb Apraxia – signs
DLAG	=	Developmental Limb Apraxia – gestures
CA	=	Constructional Apraxia
√	=	No disorder present
?	=	Unable to conclusively assess the presence of the disorder
●	=	Strong indication that disorder may be present
X	=	Disorder present

As can be seen from Table 3.11 above, all the experimental subjects present with developmental limb apraxia. Furthermore, ES 3 and ES 4 appear to present with disorders in all areas assessed in this study. The assessment of verbal apraxia was found to be unreliable due to the effects on speech, as discussed earlier. ES 1 does not appear to present with an oral apraxia, but does appear to present with a developmental limb apraxia i.e. marked abnormal kinematics, deficient elbow joint angles, spatial parapraxias

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and defective spatio-temporal aspects across the signs, gestures and meaningless movement sequence. However, he presents with above average visuo-motor integration abilities and an absence of a constructional apraxia. Although ES 2's kinematics, elbow joint angle values, spatial parapraxias and spatio-temporal aspects across the signs, gestures and meaningless movement sequence are not as marked as ES 1, his visuo-motor integration abilities have been assessed as below average. ES 2 does not present with an oral apraxia and the researcher was unable to conclusively determine the presence of a constructional apraxia. In addition, ES 3 and ES 4 present with marked abnormal kinematics, deficient elbow joint angle values, spatial parapraxias and defective spatio-temporal aspects across the signs, gestures and meaningless movement sequence as well as very poor visuo-motor integration and below average visuo-motor integration abilities respectively. CS 2 and CS 3 present with poor visual motor integration abilities, while CS 3 also appears to present with evidence for the presence of a constructional apraxia.

Both the experimental and control subjects' visuo-motor integration results correlate with the results obtained on the constructional apraxia tasks with the exception of ES 2, who presents with below average visuo-motor integration abilities, but whose performance on the two-dimensional stick construction and block design tasks and the three-dimensional block design appears to be above average.

It is proposed that the experimental subjects' apraxic disturbances are due to a motor disorder, rather than one of symbolic disruption, based on the examination of the nature of the apraxic errors, showing kinematic abnormalities, deficient elbow joint angle values, spatial parapraxias and defective spatio-temporal aspects across the signs, gestures and meaningless movement sequence. However, ES 2, ES 3, ES 4, CS 2 and CS 3 appear to present with apraxic errors as well as visuo-spatial difficulties, suggesting that the developmental limb apraxia noted in the experimental subjects of this study present with apraxic errors manifested solely due to a movement disorder as seen in ES 1 or apraxic errors manifesting due to a movement disorder compounded by a visuo-spatial deficit seen in ES 2, ES 3 and ES 4.

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SECTION FOUR

4. GENERAL DISCUSSION

In this chapter a discussion of the results of the experimental subjects' praxic performance is undertaken. Trends are highlighted and the experimental subjects' performances are related to that of previous research.

The experimental subjects in this study were impaired in performing non-linguistic as well as linguistic manual movements, which is consistent with the findings of Rothi et al (1991) and Roy and Hall (1992), who proposed that imitation of novel and meaningless gestures appears to involve a direct route from perception to execution of the movement. Errors in the imitation of meaningless movement gestures should, therefore, allow for a better understanding into the disorder of a motor execution (Hermsdörfer et al, 1996).

The study of visual-gestural languages can provide an insight not only about the brain function for language, but can provide an understanding of the relationship of the brain's control of language and of movement. The study of signers with distinct motor disorders can provide clues to the neural substrate underlying language as a motor behaviour (Poizner and Kegl, 1992). The movements of the articulators in sign language are directly observable and are thus available for non-invasive measurement. It is therefore possible to study signing not only as a linguistic behaviour but also as a motor behaviour.

4.1 The Relationship between Kinematic Abnormalities and Parapraxias

The experimental subjects' performance was shown to include kinematic abnormalities and spatial parapraxias noted in impaired spatio-temporal aspects across the meaningless movement sequence, gestures and signs. Furthermore, the experimental subjects presenting with deficient elbow joint angle values is in support of the hypothesis as proposed by Hermsdörfer et al (1996).

As mentioned previously, a number of researchers (e.g. Poizner et al, 1990 and Clark et al, 1994) have provided detailed kinematic analyses of apraxic movements. The results of Poizner et al (1990) do not allow for a definite conclusion as to the level of gesture

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production at which kinematic abnormalities arise. However, the results of this study are consistent with the findings of Hermsdörfer et al (1996), in which kinematic abnormalities have been interpreted as indicators of deficient motor programming.

Kinematic abnormalities in apraxic movements may therefore be a direct indication of insufficient programming of the details of movement execution in apraxia. Alternatively, kinematic abnormalities may be an indirect sequel of conceptual errors in the performance of symbolic gestures: the patients may have performed shapeless movements or may have switched to a strategy of slowed on-line controlled movements because they lacked a clear conceptual representation of the intended target position (Hermsdörfer et al, 1996).

The case against a conceptual source of errors in the imitation of movements appears to be even more convincing if imitation is probed for meaningless movements, the execution of which cannot be assisted by evocation of conceptual knowledge. As was seen from the results of this study, errors in the imitation of meaningless movements have therefore, been a main argument for considering apraxia or, at least a variety of it, as a disorder of movement execution. This would be in support of previous research such as, Liepmann (1908); Morlaas (1928) both in Hermsdörfer et al (1996); Barbieri and DeRenzi (1988) and, Kimura (1993).

The findings of the presence of kinematic abnormalities and the evidence of spatio-temporal parapraxias in the experimental subjects of this study, would be in accordance with current trends such as Poeck (1986), Hermsdörfer et al (1996) and Code (1998), which stress that a fundamental feature of apraxia, is the presence of parapraxias which may affect either the spatial course and the final position of single movements or the temporal sequencing of multiple movements into a coherent motor action. Hermsdörfer et al (1996) predicted that if deficient motor programming is the cause of parapraxic errors, kinematic indications of deficient programming should be detectable in every movement that ends up with a parapraxic error.

It is proposed that the experimental subjects' apraxic disturbances are due to a motor disorder, rather than one of symbolic disruption, based on the examination of the nature of the apraxic errors, showing both kinematic abnormalities and spatio-temporal

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parapraxias across both signs and gestures as well as in a meaningless movement sequence.

4.2 The Possible Relationship between Constructional Apraxia and Visuospatial Involvement

As mentioned in Section Two, visuospatial relations and linguistic structures are intimately combined in sign languages (Poizner et al, 1987). Hence, the examination of the subjects' non-language visuospatial functions may indicate potential abilities for the linguistic use of space in signing. The non-language visuo-spatial functions were examined using visuoconstructional and visuospatial tasks as described in Sections Two and Three, as part of the constructional apraxia assessment.

Tests assessing constructional performance were considered to be a necessary part of the battery as constructional functions combine perceptual activity with motor response and always have a spatial component (Lezak, 1983). Furthermore, constructional functions include two large classes of activities, namely, drawing and building/assembling. The tendency for drawing and building disabilities to occur together is so variable that the two classes of activities need to be evaluated separately (Lezak, 1983).

Three of the four experimental subjects were found to present with visuo-motor integration difficulties. This finding suggests a possible explanation for the presence of the deficit seen in the spatio-temporal components of the movement trajectories of the signs, gestures and meaningless movement sequence of the VICON Motion Analysis System procedure. Therefore, the presence of the experimental subjects' kinematic abnormalities may be explained by a deficient movement programming pattern, while the evidence of the spatial parapraxias, may be partly attributed to the apparent visuospatial disorder in that the experimental subjects in this study do not always show as much displacement across all their movement trajectories as their matched controls do as discussed in Section Three.

The experimental subjects in the current study may reflect an overall deficit in visuospatial functions. Similarly, apraxic subjects produced spatial errors in a study conducted by Leiguarda, Pramstaller, Merello, Starkstein, Lees and Marsden (1997), while Goldenberg, Wimmer, Auff and Schnaberth (1986) described a significant relationship between spatial errors on a motor task and disturbance of visuospatial functions.

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issue was addressed regarding the inclusion of a specific sign, gesture or meaningless movement sequence in the assessment procedures of the VICON Motion Analysis System. This is related to the notion of "task effects".

In a comprehensive review of the issues involved in assessing limb apraxia, De Renzi (1985) suggested that a complete examination would include tasks that differ in the mode of elicitation and the type of movement elicited. Such recommendations are premised on the assumption of the existence of "task effects". "Task effects" refer to the differences in levels of performance that result from selective variations in the features of the tasks used. In addition to variations in the modes of elicitation and response, it has also been proposed that practic performance can be affected by the use of single versus multiple objects or by the complexity of the motor response" (Belanger et al, 1996, p. 385). Therefore, three major underlying issues are evident with regard to "task effects": firstly, the mode of elicitation and response; secondly, the use of actual objects and thirdly, the complexity of the motor response.

In choosing the tasks for the VICON Motion Analysis Test Battery a range of movements were included and various parameters considered for each i.e. unfamiliarity, proximal, distal, representational, non-representational and repetitive. In addition, careful consideration was taken to include more complex items (i.e. a number of movement components), in an attempt to increase the complexity of the motor response elicited. The use of objects was included in this assessment to objectively evaluate the presence of ideational apraxia. Furthermore, this study has used **imitation** of signs, gestures and meaningless movement sequences, to elicit a response. This was implemented in order to exclude the interference of a possible lack of comprehension to verbal command (Clark et al, 1994).

As mentioned above, the VICON Motion Analysis System included the use of signs as well as gestures in the assessment of developmental limb apraxia. It is essential to distinguish between the two. Gestures are non-linguistic in nature, while sign languages are linguistically symbolic (Corina et al, 1992).

The results of the experimental subjects' impaired movements on all the signs, gestures as well as the meaningless movement sequence tasks within the assessment procedure of the

objective VICON Motion Analysis System, would support the hypothesis of Kimura and Archibald (1974) who proposed that the left hemisphere's specialised functions might not be related primarily to language, but rather to the control of complex motor behaviour. Deficits of sign language and of speech are seen in this context, as disorders of certain motor functions in which the linguistic impairment is secondary (Kimura, 1976).

Controversies regarding the presence of "task effects" have been debated in research for a number of years as Pieczuro and Vignolo (1967) found no significant differences between apraxics and non-apraxics on a manual dexterity task, while Heilman (1973) suggested that this discrepancy was associated with the differences between tasks (Heilman, 1973).

The experimental subjects displayed difficulties with movement execution across both simple and complex tasks. These difficulties were noted across all test items i.e. the signs, gestures as well as the meaningless movement sequence. These findings support the results of a study conducted by Belanger et al (1996), who proposed that no significant task effects were evident on tasks involving relatively simple gestures and the use of single objects and therefore concluded that there are no meaningful task effects for limb apraxic subjects resulting from task variations in the modes of elicitation or types of movement elicited. However, their results also suggested that the use of relatively simple gestures (i.e. few movement components), for example, saluting and waving good-bye, might have limited value in the differential diagnosis and appraisal of limb apraxia (Belanger et al, 1996).

This hypothesis is in support of the findings of Kimura (1976), who stated that deaf aphasic subjects might have been able to imitate comparably easy signs correctly, but there is no evidence to suggest how a subject would generate complex non-linguistic hand movements (Kimura, 1976). It thus appears that, Belanger et al (1996) and Kimura (1976) agree that more complex items are needed before imitation of intransitive gestures proves to be of any diagnostic value.

Furthermore, Geschwind (1965) predicted that apraxic subjects should have difficulty in performing tasks to verbal command, but should correctly manipulate objects and tools since these tasks do not require language. However, if apraxia results from the destruction of spatiotemporal movement representations or an inability of these

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representations to influence premotor and motor systems, as postulated by Heilman (1979), then apraxic subjects should make movement errors even when manipulating actual objects (Clark et al, 1994). In contrast, Liepmann (1908) stated that the manipulation of real objects was least likely to be affected since "the objects provide certain reference points for manipulation" (cited by Kimura, 1976 p. 570). As previously mentioned, the inclusion of gestured pictures and objects, was included in this study as it was hypothesised that it might be a useful tool in determining the presence of developmental limb apraxia across all the experimental subjects of this study, indicating the presence of ideational apraxia. However, an accurate objective measure was not achieved since there exists a wide variation in the normal use of gestures. Therefore, the results from these measures were not fully analysed nor included in this study.

Finally, these new lines of research i.e. the three-dimensional computergraphic analysis of Poizner et al (1990); Clark et al (1994) and Hermsdörfer et al (1996) and the VICON Motion Analysis System procedure of this study, not only provide objective measures but also new insight into the nature of the movement disorders in apraxia.

4.4 The Effects of Developmental Limb Apraxia on Sign Language Acquisition

Bellugi (1988) reported that the study of the acquisition of sign language might be fundamental in providing clues to the biological foundation of language in general. Through the study of sign languages, fundamental questions regarding the representation of language and use of space are brought into focus. At the structural level, the surface forms that create a signed language are influenced by the modality in which the language develops, especially in terms of the use of spatial relations in the expression of syntax and discourse. Vast differences in the surface forms of signed and spoken languages exist as well as between visual and auditory processing. Moreover, a language that exists in the visual modality provides greater possibilities for easier, more direct access into a child's linguistic system and allows the educator or parent the opportunity for more direct instruction. However, studies indicate that the acquisition process in both deaf and hearing children are very similar in the course of development, provided the children are exposed to a natural language during the critical period of language acquisition (Bellugi, 1988).

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The young deaf child is presented with a two-fold task in acquiring sign language: spatial perception; spatial transformations; and memory as well as processing of grammatical structures. These all occur in the same visual event. Deaf children develop language in very similar ways to that of their hearing counterparts and they actively analyse the components of the language that they are presented with. Furthermore, evidence indicates that where the modality and the language offer the child choices that are explicit and intuitively obvious, the deaf child disregards this directness and continues to linguistically analyse the language structure in a systematic manner (Bellugi, 1988).

Various parameters play important roles in the acquisition of sign language. Stokoe (1960) proposed that there are three aspects that distinguish any one sign from another. These include: the place where the sign is made (tab); the shape and orientation of the hand(s) (dez) and the action of the hand(s) forming the sign (sigs). These three categories are referred to as location, hand-shape and movement. They have been described as being made up of specific elements that function in ways that are similar to the phonemes of a spoken language. It is understood that these three aspects are recognised as "the basic units of phonological contrast in American Sign Language (ASL) signs" (Coulter, 1990). The syntactic and semantic components of a child's development need to be investigated for its effect on his/her phonological development (Hoffmeister and Wilbur, 1980).

Research regarding motoric constraints on infant sign production has revealed that certain hand-shapes in sign language are easier to acquire than others and developmental stages in hand-shape acquisition have been documented. Further discussion of this area is felt to be beyond the scope of this paper, however, the reader is referred to: Dubuisson, Lelièvre, Parisot and Vercaingne-Ménard (2000); Hoffmeiser and Schick (2000); Meier, Moreland and Cheeck (2000).

Correlated with "hand-shape" is the aspect of movement. This is the way in which the signs of a child move and when this is appropriate and mature, will exemplify the movement seen in adult signs. Bonvillian and Siedlecki (1998) attempted to show the order in which the various movements are acquired. They found that the movement aspect of sign language was produced by children less accurately than the place or location aspect but more accurately than hand-shape. In addition, they found that there

was little improvement with age in the overall accuracy of the movement, however, as the children developed, they were able to produce signs with more complex movements (Bonvillian and Siedlecki, 1996). It is believed that this is correlated with motor development as discussed in Section Two.

Similar to movement is the orientation of a sign or the direction in which the sign faces. This matures as the child develops and becomes a more proficient signer. The errors made by the child offer much insight into the way in which this aspect is acquired and perfected. Furthermore, the aspect of place in the signing of a child is another crucial parameter in their development and acquisition of sign language. In order for the communication partner to understand the sign the child is intending to communicate, the area or place in which the sign is made is vital. This too develops as the child's language and physical dexterity matures, again offering insight into the stage of development at which the child is functioning (Bonvillian and Siedlecki, 1996). As previously mentioned, the experimental subjects of this study presented with difficulty in correctly orientating the hand in the correct final target hand position, indicating a possible spatial parapraxia.

Spatial processes are underlying, prerequisite skills of sign language and as mentioned earlier, spatial parameters were measured with each sign and any presence for spatial parapraxias were documented in the results section of this study. Moreover, research conducted with deaf children of deaf parents indicates that during normal sign language acquisition, spatial marking to indicate verb agreement is acquired by two years of age (Tabor, 1988).

Verb agreement in sign language marks connections between specific spatial points. Hence, final orientation of hand position was included in the analysis of the data of this study as discussed in the results section. Furthermore, as reported earlier, the experimental subjects of this study yielded incorrect final hand orientation and movement implying possible incorrect use of grammatical structures in their sign language, for example, "I give you", "give" moves from the other person towards the self. This requires a verb agreeing form, whereas the child is giving the mimed form.

Sign language displays both complex language structures and complex spatial relations (Poizner and Battison, 1980). Space is used linguistically in sign language and therefore,

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the linguistic distinctions that are marked by spatial devices in sign language occur at all levels of the language structure i.e. lexical, morphological and syntactic (Bellugi, 1988).

Therefore, it could be concluded that the presence of developmental limb apraxia in the experimental subjects, confounded by the suggested visuospatial deficit in some of the experimental subjects, might explain the difficulties experienced by the experimental subjects in acquiring sign language, more particularly their expressive use of sign language. This highlights the need for the identification of developmental limb apraxia in deaf signing children as well as the urgency of remediation thereof to minimise the possible effects of an expressive language delay.

However, the complexity of this notion is highlighted by the case of the hearing-impaired oral experimental subject of this study, who presents with oral and a possible constructional apraxia as well as developmental limb apraxia. This subject might not have benefited from learning a sign language. It may have been speculated that in order to overcome his poor use of oral language, compounded by his oral and verbal apraxia as well as his deafness, that sign language indeed might have been an option for improved communication skills. However, the presence of developmental limb apraxia may have made sign language acquisition as difficult as acquiring the spoken modality has proven to be. This in turn highlights the belief of the importance in determining the co-occurrence of oral/verbal apraxia and developmental limb apraxia in a deaf or hearing-impaired child who needs to acquire a spoken and/or signed language. The mode of communication adopted in teaching the child language will be affected by the presence or absence of one or both these developmental disorders.

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4.5 The Interrelationship between Deafness; Oral, Verbal and Limb Apraxia

Code (1998) proposed that different forms of apraxia often co-occur in the same patient. The results of the experimental subjects' articulation repertoires, as indicated by the test of verbal and oral developmental apraxia could be affected by the presence of verbal apraxia, together with the contributory factor of deafness, which, in itself would have an effect on the production of speech (Kimura, 1981). It would seem reasonable to assume that, in some children, poor auditory functioning stemming from birth might interfere with speech development but that it would not necessarily contribute to oral/verbal apraxia (Ayres, 1985). As mentioned previously, speech and articulatory errors that result from

deafness may mask verbal apraxia. However, in children, poor auditory functioning arising from birth or a prelingual age, might interfere with speech development and it would not necessarily contribute to developmental oral and/or verbal apraxia. However, the assessment of a verbal apraxia in a hearing-impaired oral child may be difficult to detect due to the articulatory errors resulting from the deafness per se, as was indicated in the experimental subjects of this study.

Many researchers believed that "if the motoric programming of the non-speech movements of the mouth goes, so does the speech" (Rosenbek, Kent and LaPointe, 1984, p. 41). However, the relationship is not such a simple one. DeRenzi, Pieczuro and Vignolo (1966 in Rosenbek et al, 1984) studied the relationship of oral apraxia and verbal apraxia. They suggested a strong association between impaired non-verbal movements of the mouth and that of verbal apraxia, but just as importantly, they found that these disorders can occur independently.

Two of the four experimental subjects of this study, were found to present with evidence of developmental oral and limb apraxia. De Renzi (1966 in Code, 1998) found that the majority of hearing patients with verbal apraxia presented with oral apraxia as well as a high co-occurrence of oral and limb apraxia. However, while it is understood that some subjects present with a co-occurrence of the various apraxias such as the third experimental subject of this study, who presented with oral, limb and constructional apraxia, it is also possible that dissociations also exist: there are subjects who present with developmental limb apraxia who do not present with oral apraxia, as is seen in the first and second experimental subjects of this study (Code, 1998).
This has various implications, as mentioned previously. Firstly, verbal apraxia was difficult to assess due to the articulatory errors that may have resulted from the degree of hearing loss and not necessarily as a result of a verbal apraxia. Secondly, one of the experimental subjects who relied primarily on sign language as a mode of communication presented with both oral and developmental limb apraxia, while the fourth experimental subject, who relied primarily on the spoken modality of communication also presented with both oral and developmental limb apraxia. Hence, if either the signed or the spoken modality respectively, had been chosen as their primary mode of communication, difficulties in their acquisition of expressive language may have occurred.

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SECTION FIVE

5 CONCLUSION AND IMPLICATIONS

In this study a tool to investigate the presence of developmental limb apraxia has been devised. This tool was found to be sensitive and it is believed that it may be adopted with confidence, in that it allowed for an objective measurement of developmental limb apraxia. It provided an objective quantitative analysis of elbow joint angle values as well as resultant trajectories of elbow position and wrist joint centre. Furthermore, it provided a detailed objective analysis of kinematic abnormalities and spatio-temporal parapraxias present in limb apraxias. Differences in patterns of movement using the VICON Motion Analysis System, between the experimental and control subjects were noted.

Using the objective measure, the experimental subjects were found to present with developmental limb apraxia. It is felt the developmental limb apraxia of the children seen in this study is due to a breakdown in the motor execution rather than a disruption of the symbolic representation. This disruption of motor execution is hypothesised as abnormal kinematics and spatio-temporal disruptions that were noted across meaningless movements, signs and gestures. Therefore, it is hypothesised that the findings of this study provide insight into the movement disorders that may prevent a deaf child from acquiring the expressive use of sign language.

This assessment procedure was felt to be an effective assessment tool of developmental limb apraxia found in the experimental subjects of this study. The results of the VICON Motion Analysis System procedure support the findings of other researchers, especially regarding joint control (Poizner et al, 1990), the presence of kinematic abnormalities and spatio-temporal parapraxias in limb apraxia (Hermsdörfer et al, 1996). However, within the context of exploratory research, a small subject sample size was employed in this study and future research would clearly require a larger sample size in order to adopt the results of this study with more confidence. Furthermore, the differences noted in patterns of movement between the experimental and control subjects would require further quantification in future research in order to determine validity for the use of this tool in the identification of limb apraxia.

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This study differed from past research in the population tested, the methodology used, as well as the test procedures and equipment employed. This study assessed the presence of developmental limb apraxia in hearing-impaired children, whereas previous research conducted studies on adults with acquired apraxia. It used three types of movement patterns i.e. signs, gestures and a meaningless movement sequence. All items selected in the apraxic battery, were appropriate for the assessment of children and were selected considering previously mentioned factors such as complexity and proximal versus distal parameters.

The identification of developmental limb apraxia in the experimental subjects of this study has numerous implications regarding remediation. It allows for the clearer identification of deaf children who are unable to acquire the expressive use of sign language. In addition, two of the four experimental subjects presented with a co-occurrence of oral, limb and constructional apraxia. This finding plays an important role in the diagnosis of apraxias in children as this may influence the decision regarding the modality of language adopted i.e. sign and/or spoken.

It is also believed that the investigation of developmental limb apraxia in deaf children has been neglected. Furthermore, it is felt that investigations regarding developmental limb apraxia are of vital importance particularly where children are involved in a signing programme. On the other hand, the speech production of a hearing-impaired child presenting with oral apraxia is equally important as this might have implications regarding which modality, spoken or sign should be adopted.

Furthermore, it is believed that appropriate therapies for limb apraxia is required as this may have a direct effect on improved signing abilities. Some research has been conducted in this area as noted in Helm-Estabrooks, Fitzpatrick and Barresi (1982), Helm-Estabrooks, (1992) and Maher and Ochipa (1997).

5.1 THEORETICAL IMPLICATIONS

The findings of this study have provided additional knowledge towards the long-standing debate whether apraxia is a movement or a symbolic disorder. The use of the objective assessment tool to analyse kinematics and spatial temporal parapraxias across a

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meaningless movement sequence, gestures and signs is suggestive towards a motor explanation of apraxia. Through this research, findings further confirm previous descriptions of limb apraxia documenting spatial parapraxias, temporal and kinematic abnormalities. Subjects found with a visuo-spatial disorder were indeed found to present with spatial parapraxias.

The co-occurrences of apraxia found in the two of the four experimental subjects of this study support previously reported studies of co-occurrences such as De Renzi (1966, Trost, 1970, LaPointe and Wertz, 1974, Marquardt and Sussman, 1984 in Code, 1998). Although co-occurrences have been reported and studied previously, little research has looked all four apraxias, that is, oral, verbal, limb and constructional apraxias in children. This had particular significance within the deaf population group when considering the mode of communication to be adopted in the early stages of a deaf child's life.

5.2 CLINICAL IMPLICATIONS

In this study the importance of developing test batteries and methods of analyses for the examination of developmental limb apraxia for clinical as well as theoretical significance is clearly highlighted.

Indeed there are deaf children who may present with developmental limb apraxia, which in turn might affect the development of their expressive sign language skills. When a deaf child, older than five years, displays difficulty in copying, imitating and/or initiating signs and movements in sign, deaf educators and other professionals involved should be aware of the possibility of developmental limb apraxia and should recommend an objective assessment thereof. In addition, possible methods of intervention should be implemented. This study and the use of the VICON Motion Analysis System in the assessment of developmental limb apraxia, as an innovative technique has numerous clinical implications.

Children attending schools for the Deaf, who experience difficulty with the acquisition of expressive sign language, should be able to undergo an objective developmental limb apraxia assessment battery to investigate the possibility of the presence of this movement disorder and suggest possible areas for remediation.

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It is believed that this tool may not only be used in the deaf population but may also be employed in populations such as the neurogenically impaired. Deaf adults with an acquired neurogenic disorder may indeed benefit from such an evaluative procedure to allow for the effective implementation of signed therapy. In addition, hearing persons presenting with an aphasia, especially with an expressive aphasia, also may benefit from such an examination so as to rule out the presence of a limb apraxia, as the presence thereof may effect the type of therapy conducted i.e. acquisition of gestures. Furthermore, this method of objective analysis may be adopted in the clinical diagnosis of other movement disorders such as Parkinson's Disease, to establish whether a limb apraxia is present or not.

The results of this study clearly indicate the need for multidisciplinary collaboration regarding assessment and rehabilitation of developmental limb apraxia. Additional objective research is indicated to determine the precise nature of the implications of developmental limb apraxia and the later language learning abilities of such children and to ensure optimum benefit from therapy.

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5.3 IMPLICATIONS FOR FUTURE RESEARCH

Numerous research implications have emerged from this study. An advantage of this study involved the sophistication of the equipment to calculate and analyse the temporal and spatial components of the movement trajectories in a quantitative manner. In order to obtain comparable results across studies in future research, standardisation in the use of equipment in the three-dimensional analysis of developmental limb apraxia should be undertaken. In addition, normative data should be obtained for both adults and children.

It is clear that future research is required in the area of apraxia and more specifically limb apraxia in the deaf population and various hearing neurogenic population groups. Furthermore, areas of future research in the development and implementation of programmes and appropriate therapies for developmental and acquired limb apraxia is sorely needed. This research may provide the opportunity for interdisciplinary collaboration.

APPENDICES

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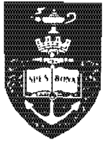

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APPENDIX I

19 April 1999

ATTENTION: The Principle
Name School for the Deaf/Hearing Impaired
Street Address
CITY
Postal Code

MASTER'S RESEARCH

Thank you for the time taken to listen to my discussion on developmental limb apraxia and for kindly agreeing to assist me with my research. As requested please find below a list of the characteristics that the children should possess (please note that the gender of the child is not important):

1. Between the ages of 5 - 12 years.
2. Severe to profound hearing loss (i.e. > 70 dBHL).
3. Congenital deafness.
4. No evidence of neuromuscular weakness.
5. Right handed.
6. English or Afrikaans as a first or second language.
7. Exposure to sign language.
8. No noticeable neurodevelopmental difficulties.
9. No visual impairment.
10. Evidence of developmental limb apraxia, which can be identified by the following guidelines:
    - The actual movement of the sign appears somewhat different compared to other children.
    - The signs that require only small movements such as the fingers or the wrist are not as precise or as accurate as the other children's in the class.
    - The movement of the hand/elbow/shoulder in relation to each other is not well co-ordinated.
    - The entire path of the movement is not as smooth as the other children's i.e. the movement appears very jerky compared to his/her peers.
    - The final hand position, after the sign is completed, is not in a similar position as that of others.

If there are any children that you feel are showing any signs of "developmental limb apraxia", kindly keep a list of their names and I will be in telephonic contact with the school.

Thank you for your kind assistance in this matter. It is much appreciated.

Yours sincerely

ANGELA KINSELLA
Student

DR DALE OGILVY
Thesis Supervisor

"OUR MISSION is to be an outstanding teaching and research university, educating for life and addressing the challenges facing our society."

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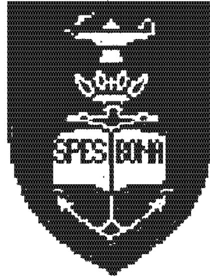
APPENDIX II



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FACULTY OF HEALTH SCIENCES
DEPARTMENT OF LOGOPAEDICS

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MODIFIED VERSION OF THE TEST OF ORAL AND LIMB APRAXIA - TOLA

ORIGINAL NORMED EDITION - Nancy Helm-Estabrooks, 1992.

ADOPTED and MODIFIED BY Angela Kinsella, 1999, for research purposes, South Africa.

ORAL APRAXIA

Test the five items to imitation with the instruction: **"Show me how you would..."** (e.g. **"bite an apple"**). **"Do it like this."** Provide a model for each item.

ORAL NON-RESPIRATORY					
TASK	**To Imitation**				**Notes**
	3	**2**	**1**	**0**	
1. Smile, showing teeth.					
2. Bite an apple.					
3. Lick an ice-cream.					
4. Kiss a baby.					
5. Lick your upper lip.					
	Total				

ORAL RESPIRATORY					
TASK	**To Imitation**				**Notes**
	3	**2**	**1**	**0**	
1. Yawn.					
2. Blow out a candle.					
3. Cough.					
4. Sip through a straw.					
5. Sniff a flower.					
	Total				

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GESTURED PICTURES

Say to the patient, **"Now I'm going to show you some pictures. Each picture shows an object that can be presented with a gesture. For example, here is a picture of a pen. If I were to represent it with a gesture without talking, I would do this."** (Make an appropriate gesture.) **"Now, you make a gesture to represent this picture."** Hold up the picture of the pen so the patient can see it. If the patient makes an appropriate gesture, say. **"Good. Now I'll show you some more pictures and you give me a gesture for each one. Remember, don't talk, do it in silence."** Do not name the test pictures. If the patient cannot produce an appropriate gesture to the picture, proceed to the next item. Do not provide a model for these items.

PROXIMAL					
TASK	**To Picture**				**NOTES**
	3	**2**	**1**	**0**	
1. Axe.					
2. Tennis Racquet.					
3. Paint Brush.					
4. Spoon.					
5. Knife.					
	Total				

DISTAL					
TASK	**To Picture**				**NOTES**
	3	**2**	**1**	**0**	
1. Peg.					
2. Pen.					
3. Scissors.					
4. Key.					
5. Gun.					
	Total				

ORAL					
TASK	**To Picture**				**NOTES**
	3	**2**	**1**	**0**	
1. Whistle.					
2. Toothbrush.					
3. Bubbles.					
4. Ice-cream cone.					
	Total				

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APPENDIX III

REMAINING GRAPHS ILLUSTRATING THE VICON MOTION ANALYSIS SYSTEM'S RESULTS OF THE SIGNS AND/OR GESTURES

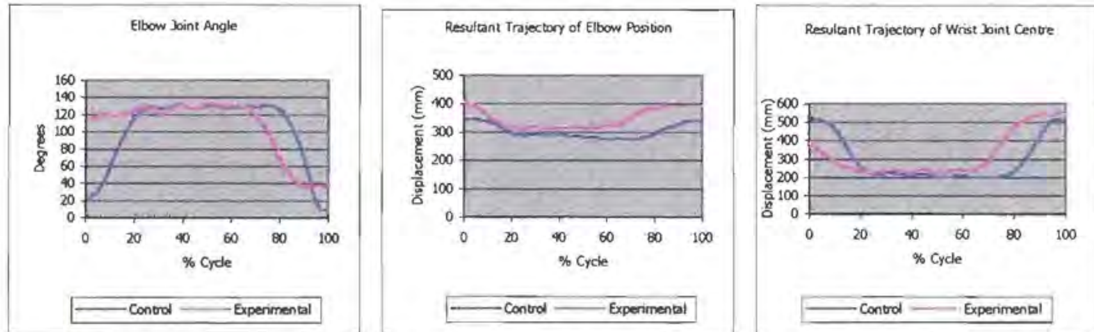

Figure 18 Graphs illustrating the movement trajectory of the sign "stupid" for ES 1 and CS 1

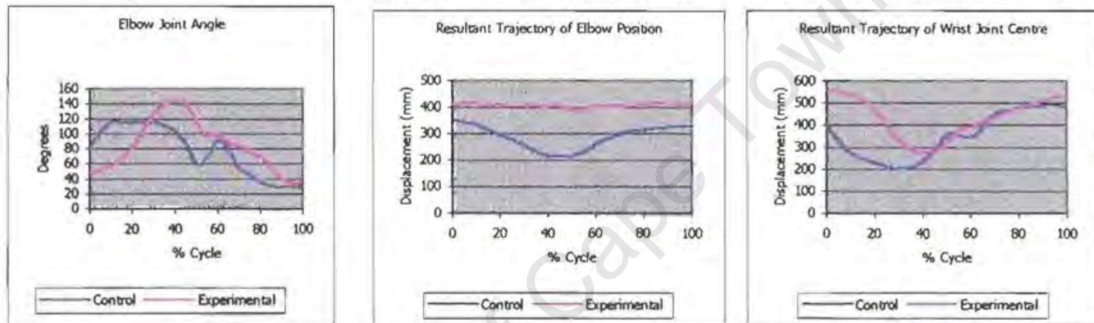

Figure 19 Graphs illustrating the movement trajectory of the sign "aeroplane taking off" for ES 1 and CS 1

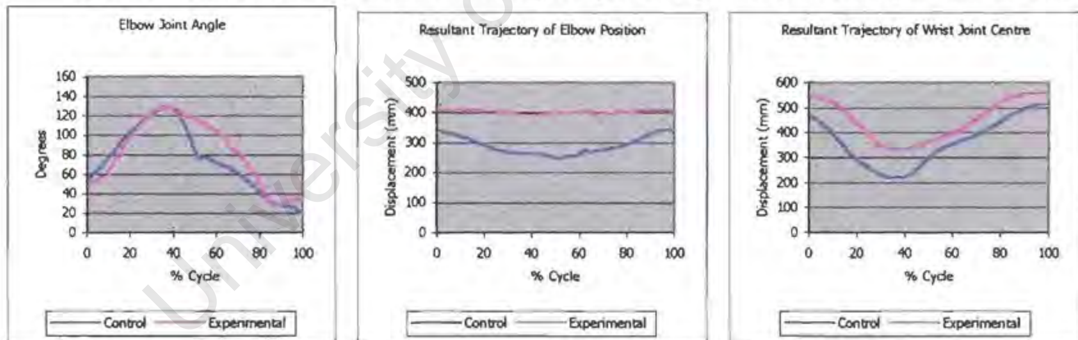

Figure 20 Graphs illustrating the movement trajectory of the sign "shout" for ES1 and CS1.

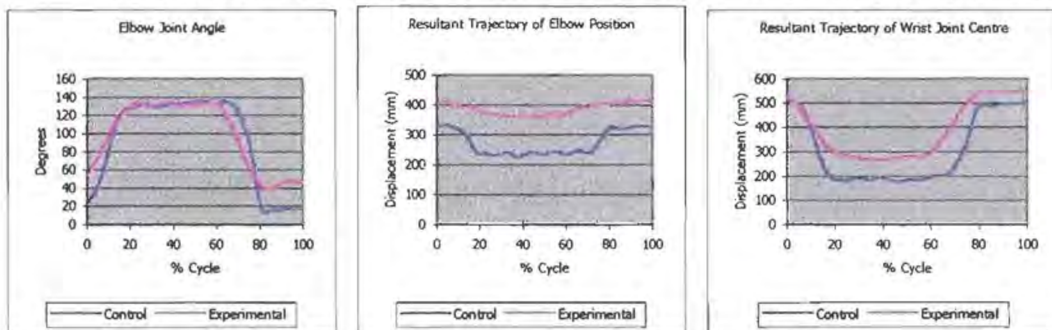

Figure21 Graphs illustrating the movement trajectory of the sign "smell" for ES1 and CS1

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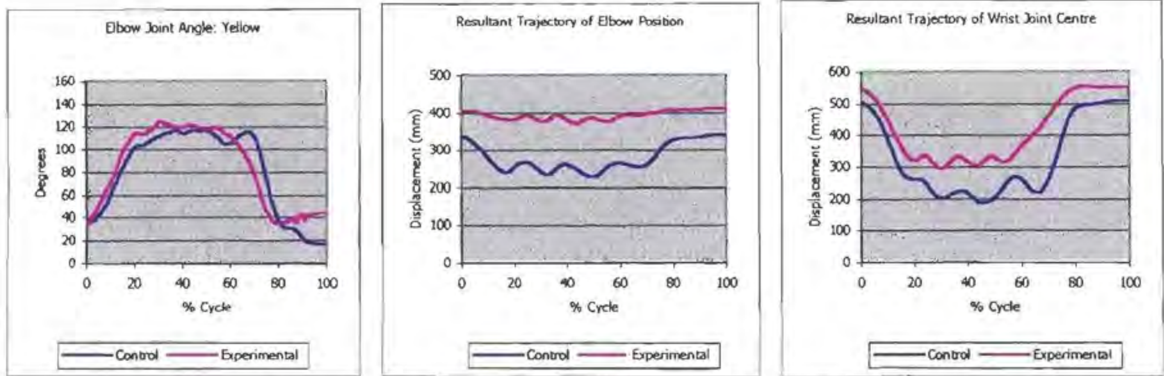

Figure 22 Graphs illustrating the movement trajectory of the sign "yellow" for ES1 and CS1

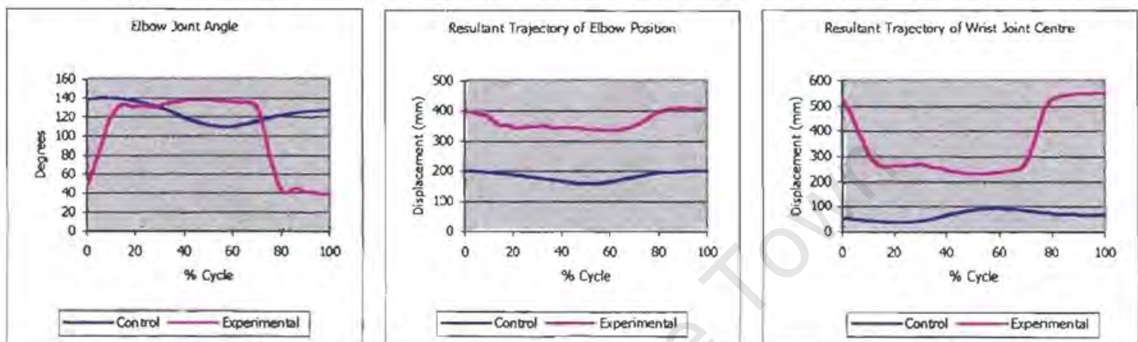

Figure 23 Graphs illustrating the movement trajectory of the gesture "brush teeth" for ES1 and CS1.

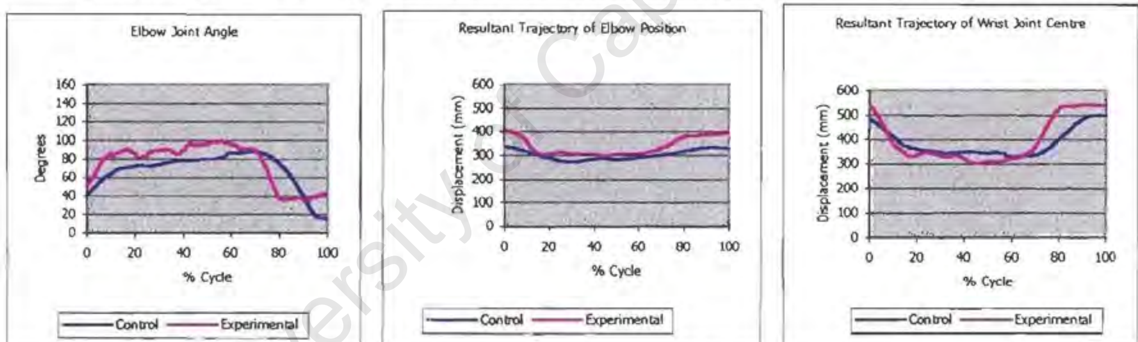

Figure 24 Graphs illustrating the movement trajectory of the gesture "key" for ES1 and CS1.

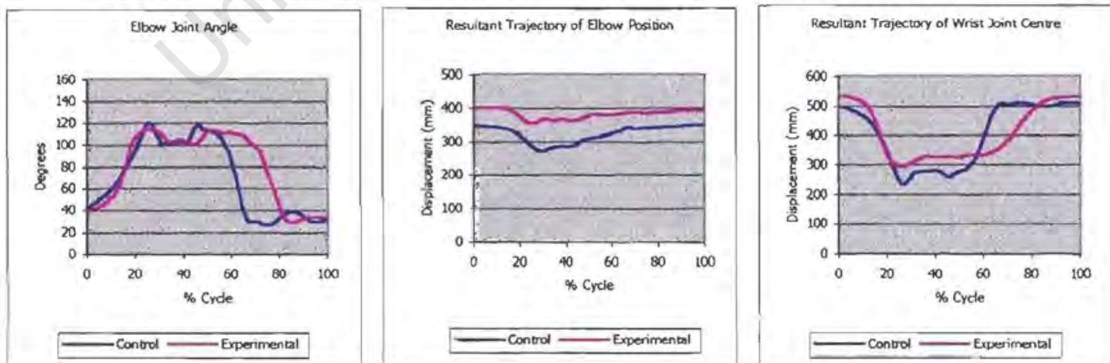

Figure 25 Graph illustrating the movement trajectory of the sign "hook" for ES 1 and CS 1

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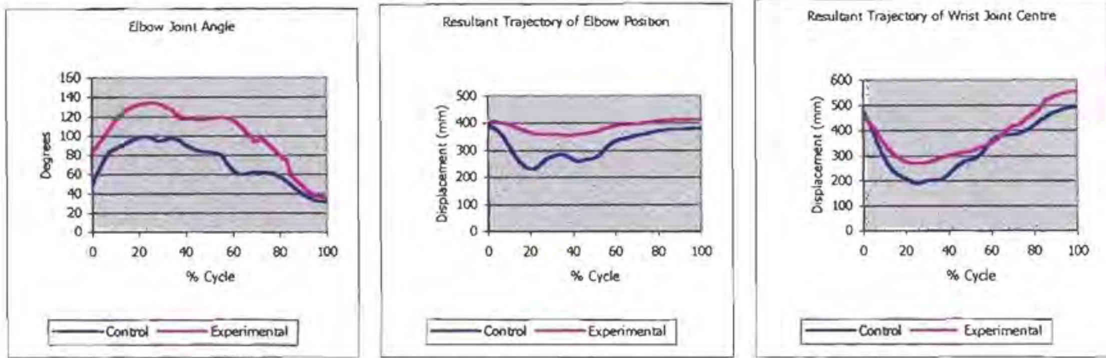

Figure 26 Graphs illustrating the movement trajectory of the sign "snake" for ES1 and CS1.

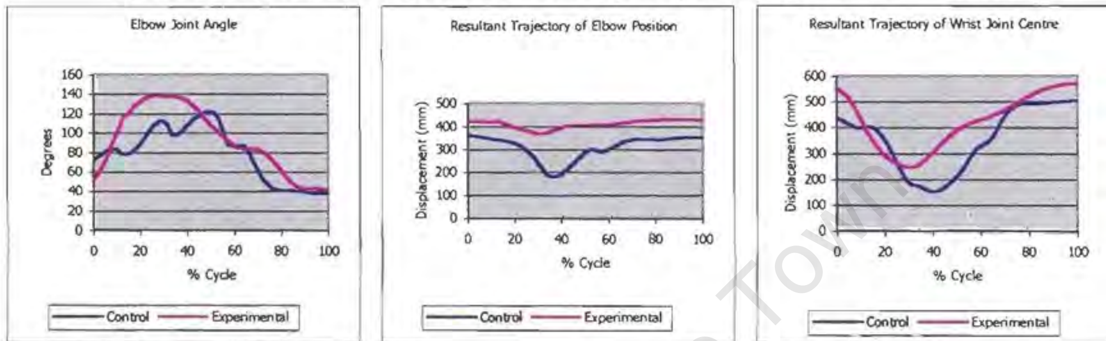

Figure 27 Graphs illustrating the movement trajectory of the sign "submarine" for ES1 and CS1.

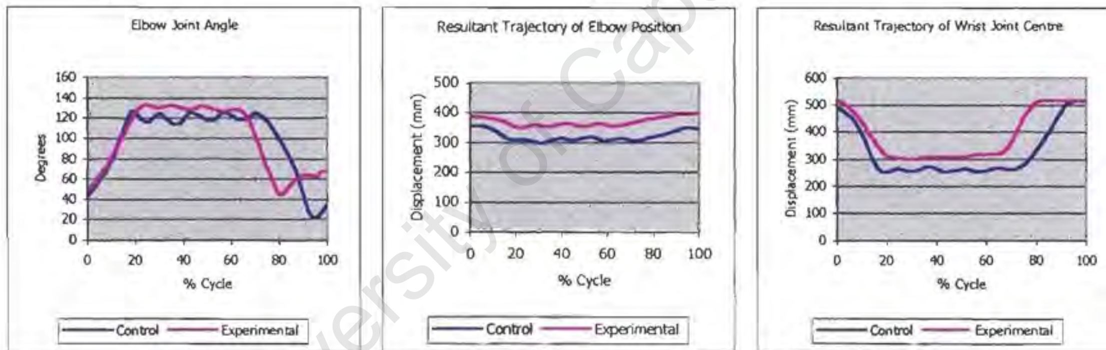

Figure 28 Graphs illustrating the movement trajectory of the sign "like" for ES1 and CS1.

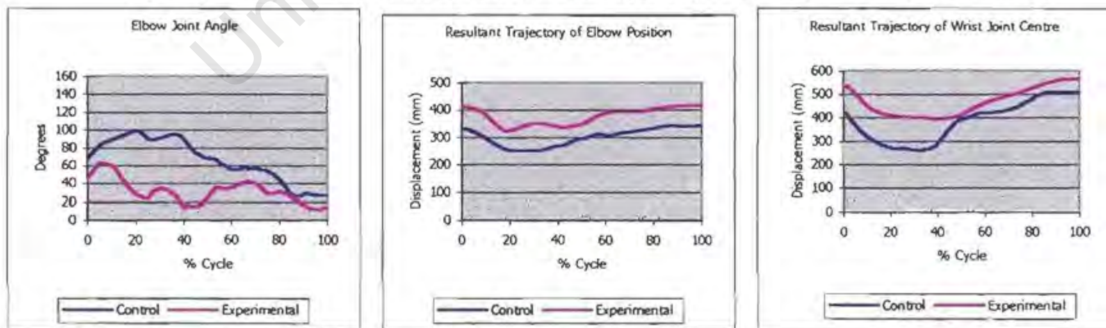

Figure 29 Graphs illustrating the movement trajectory of the sign "z" for ES1 and CS1.

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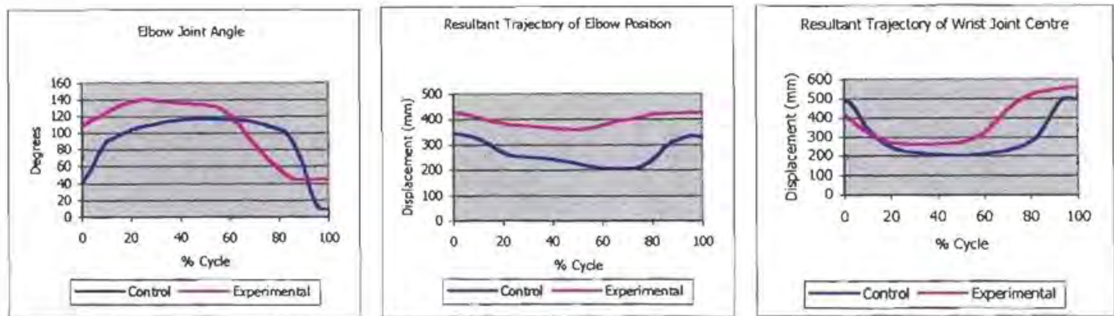

Figure 30 Graphs illustrating the movement trajectory of the sign "weird" of ES1 and CS1.

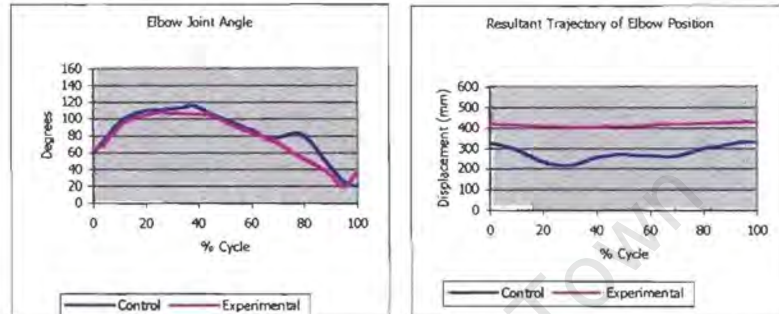

Figure 31 Graphs illustrating the movement trajectory of the sign "starfish" of ES1 and CS1.

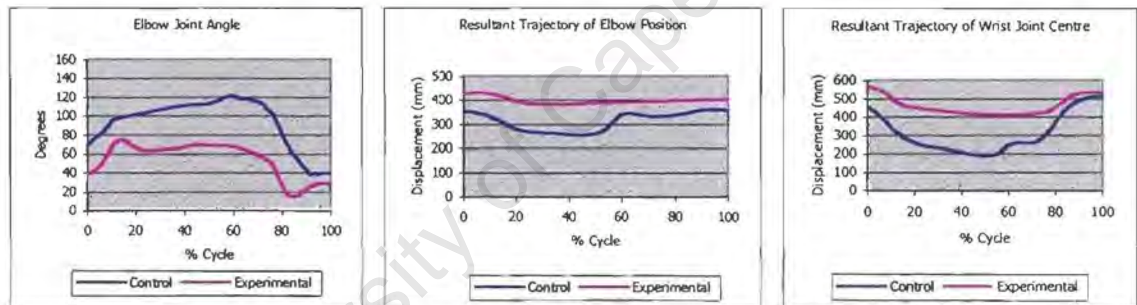

Figure 32 Graphs illustrating the movement trajectory of the sign "bridge" of ES1 and CS1.

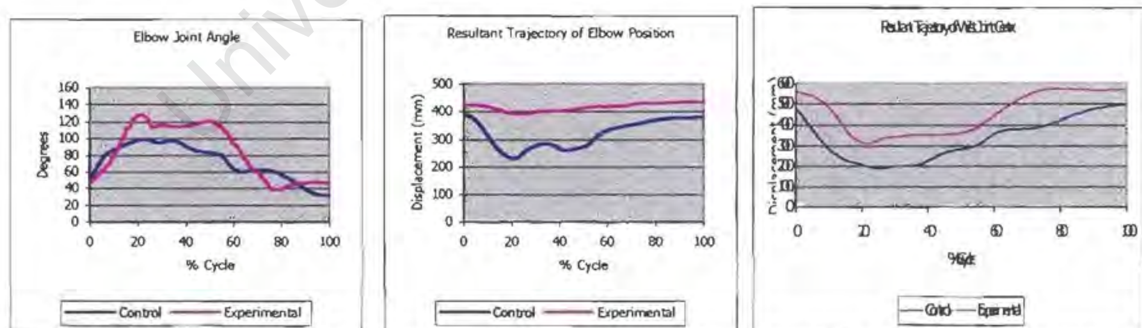

Figure 33 Graphs illustrating the movement trajectory of the sign "bad luck" of ES1 and CS1.

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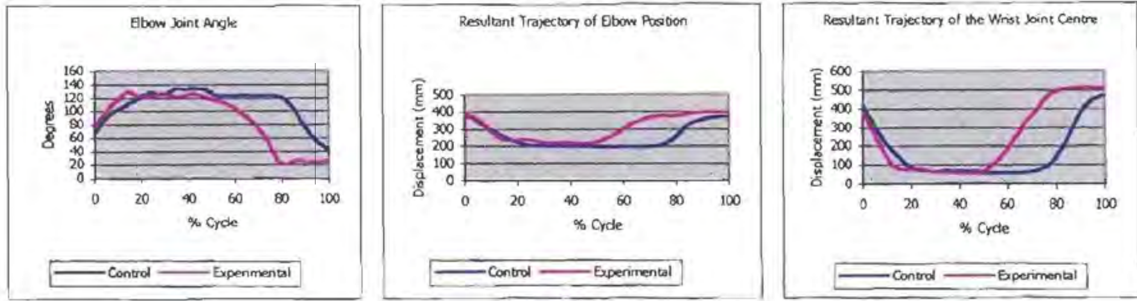

Figure 34 Graphs illustrating the movement trajectory of the sign "stupid" for ES2 and CS2.

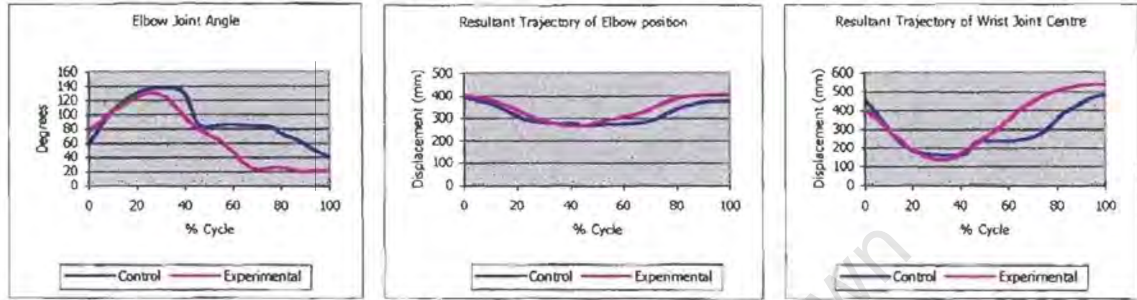

Figure 35 Graphs illustrating the movement of trajectory of the sign "shout" for ES2 and CS2.

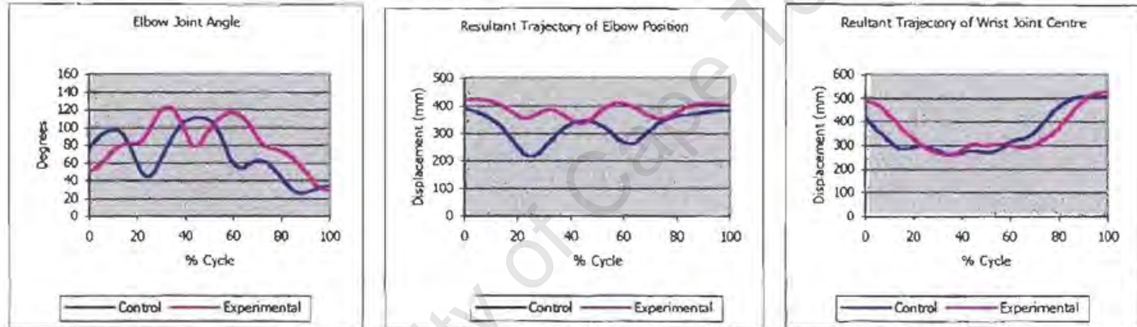

Figure 36 Graphs illustrating the movement trajectory of the gesture "saw" for ES2 and CS2.

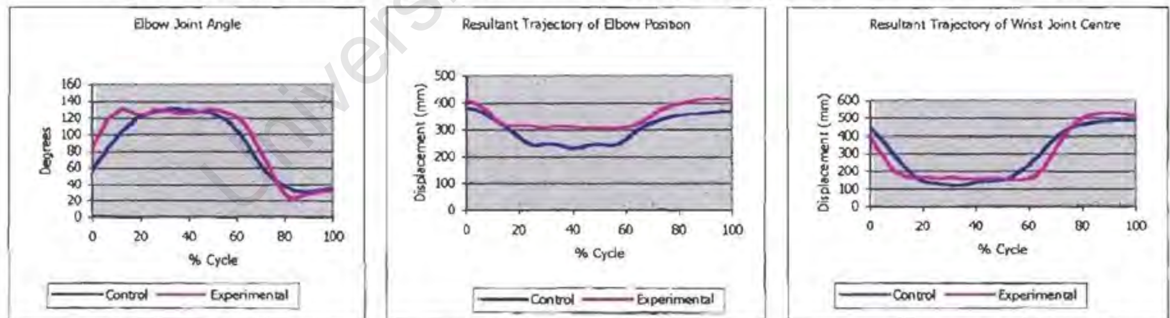

Figure 37 Graphs illustrating the movement of the sign "smell" for ES2 and CS2.

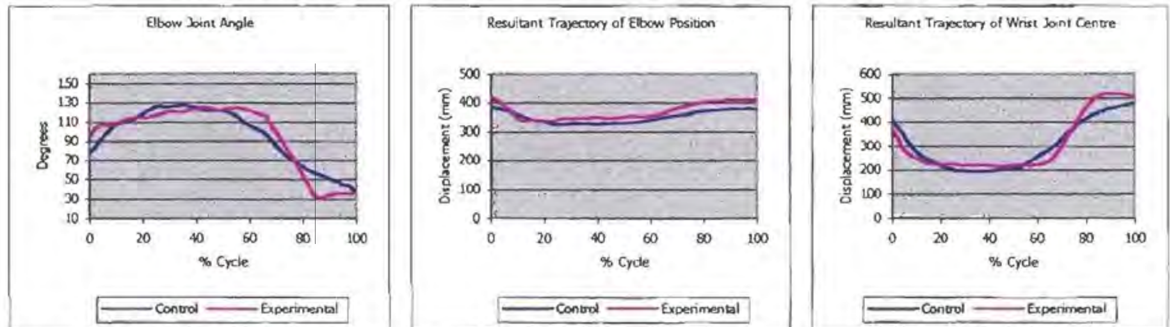

Figure 38 Graphs illustrating the movement trajectory of the sign "yes" for ES2 and CS2.

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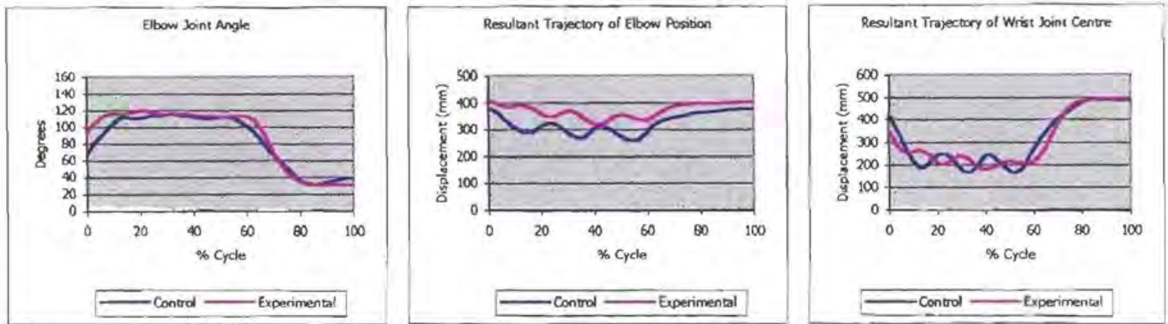

Figure 39 Graphs illustrating the movement trajectory of the sign "yellow" for ES2 and CS2.

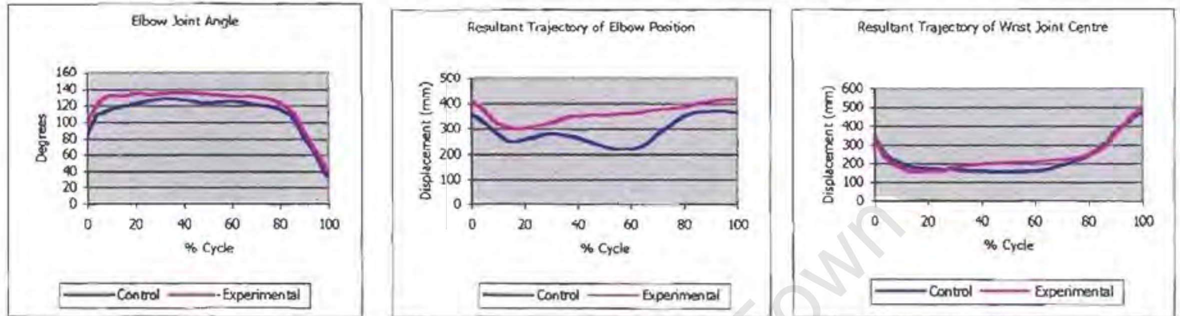

Figure 40 Graphs illustrating the movement trajectory of the gesture "brush teeth" for ES2 and CS2.

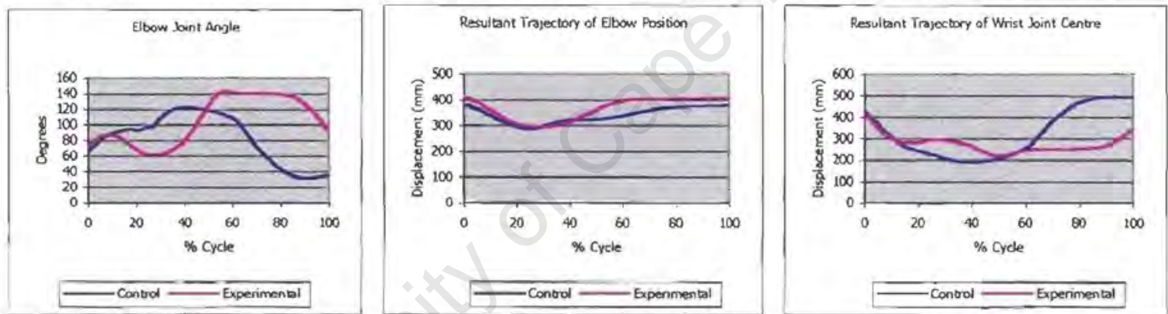

Figure 41 Graphs illustrating the movement trajectory of the sign "hook" for the ES2 and CS2.

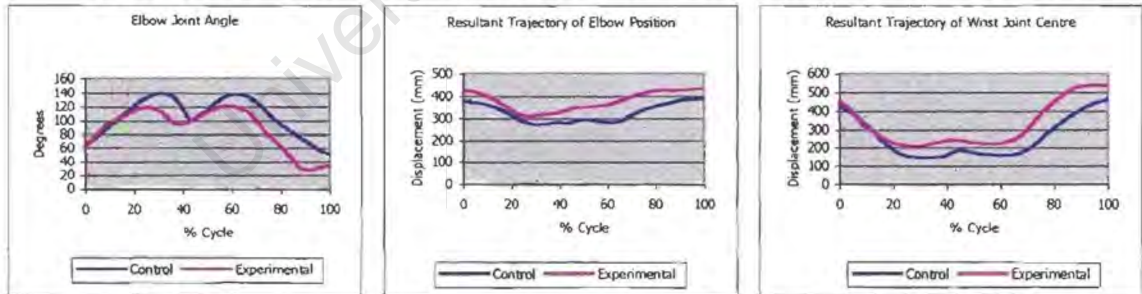

Figure 42 Graphs illustrating the movement trajectory of the sign "snake" for ES2 and CS2.

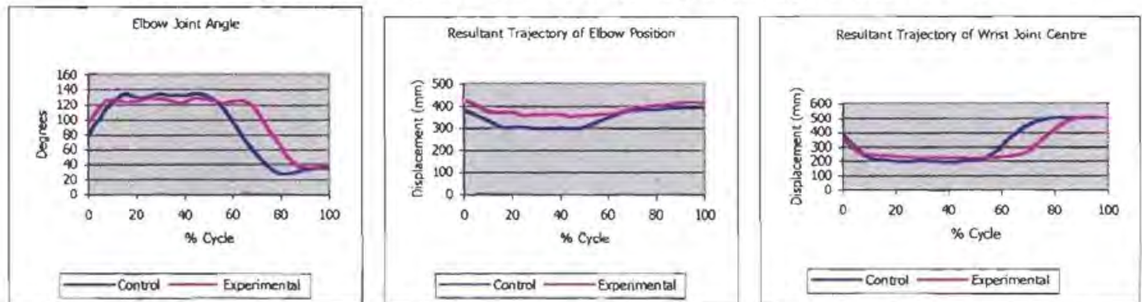

Figure 43 Graphs illustrating the movement trajectory of the sign "like" for ES2 and CS2.

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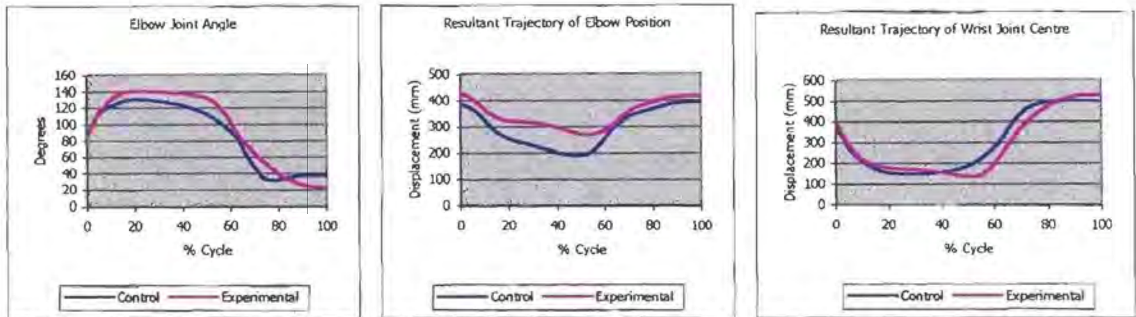

Figure 44 Graphs illustrating the movement trajectory of the sign "weird" for ES2 and CS2.

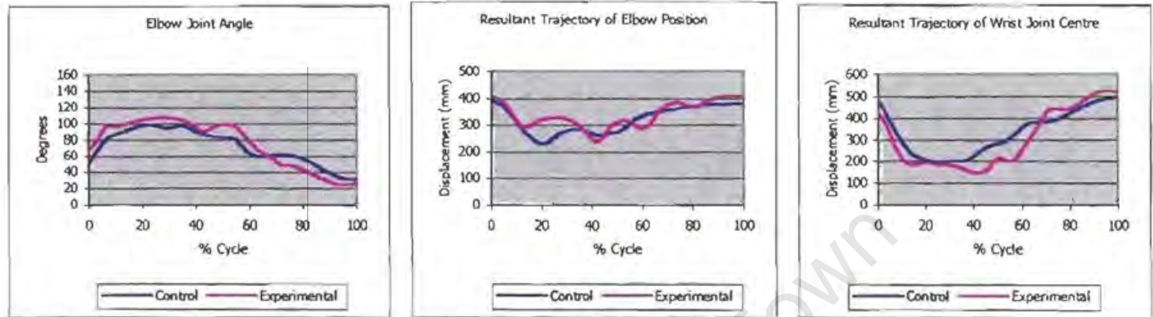

Figure 45 Graphs illustrating the movement trajectory of the sign "z" for ES2 and CS2.

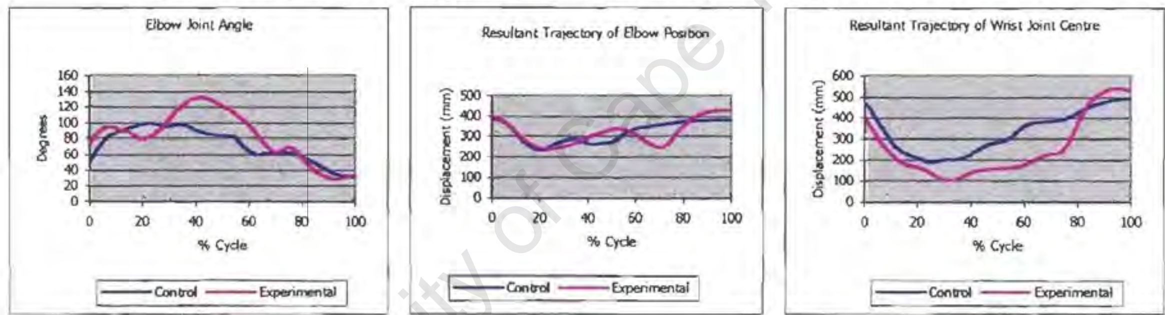

Figure 46 Graphs illustrating the movement trajectory of the sign "submarine" for ES2 and CS2.

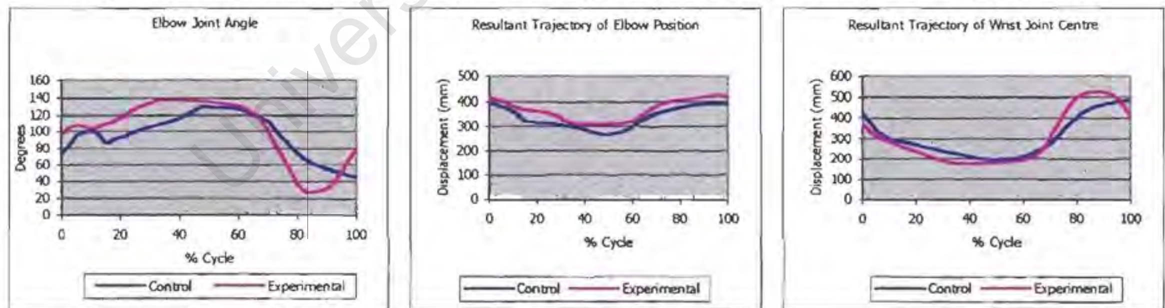

Figure 47 Graphs illustrating the movement trajectory of the sign "good morning" for ES2 and CS2.

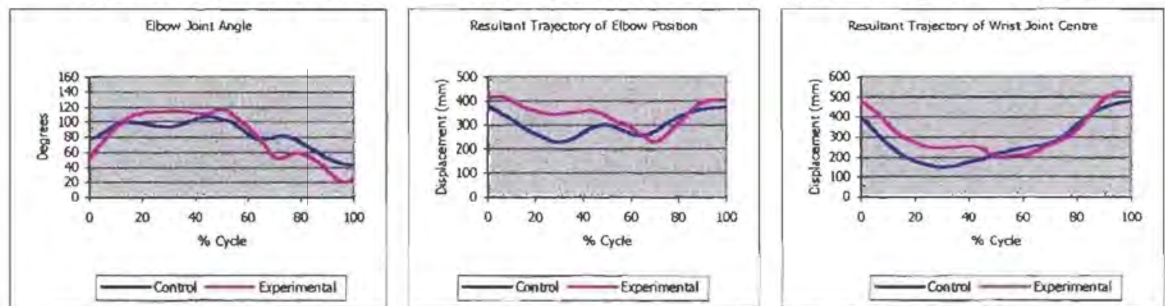

Figure 48 Graphs illustrating the movement trajectory of the sign "starfish" for ES2 and CS2.

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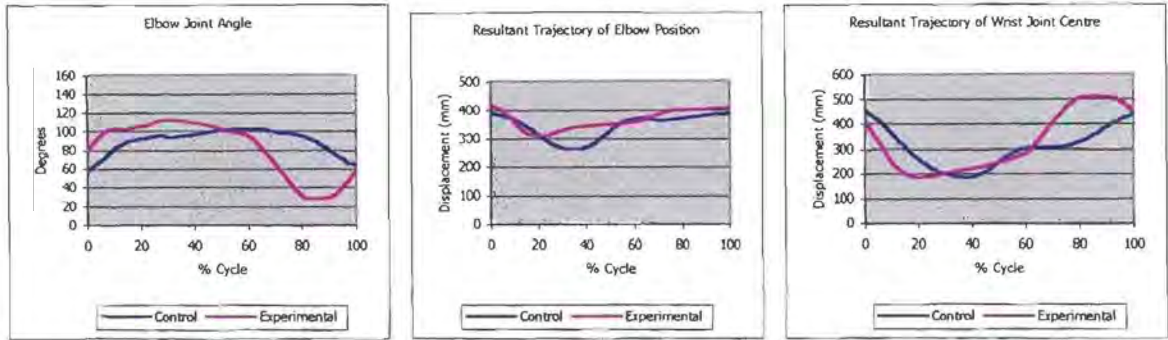

Figure 49 Graphs illustrating the movement trajectory of the sign "bridge" for ES2 and CS2.

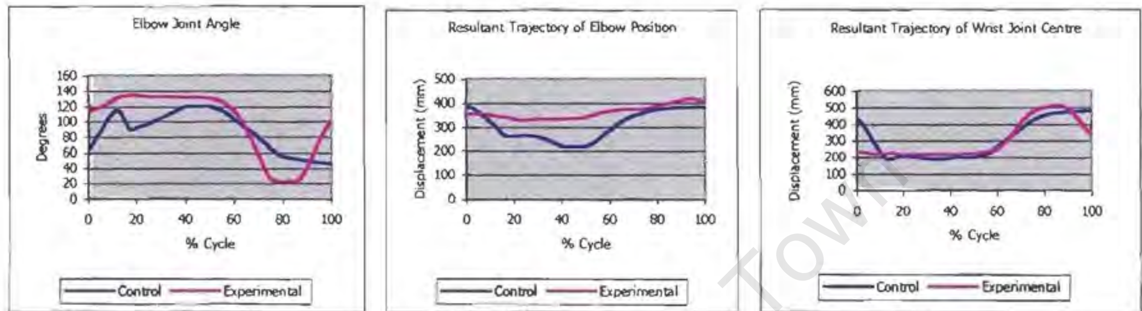

Figure 50 Graphs illustrating the movement trajectory of the sign "bad luck" for ES2 and CS2.

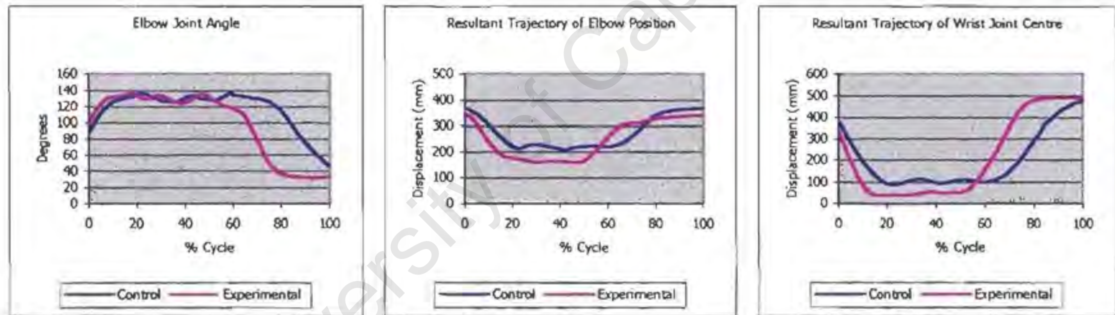

Figure 51 Graphs illustrating the movement trajectory of the sign "stupid" for ES3 and CS3.

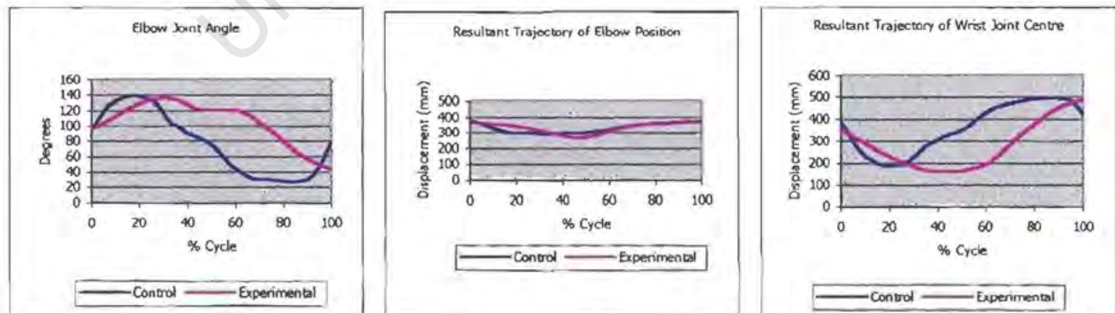

Figure 52 Graphs illustrating the movement trajectory of the sign "shout" for ES3 and CS3.

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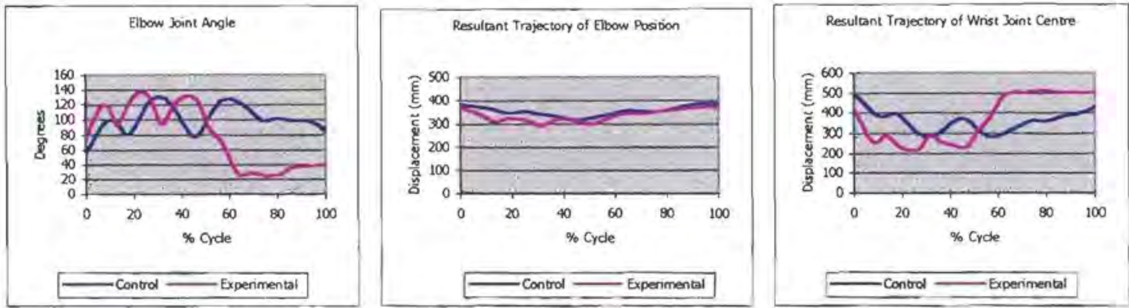

Figure 53 Graphs illustrating the movement trajectory of the gesture "saw" for ES3 and CS3.

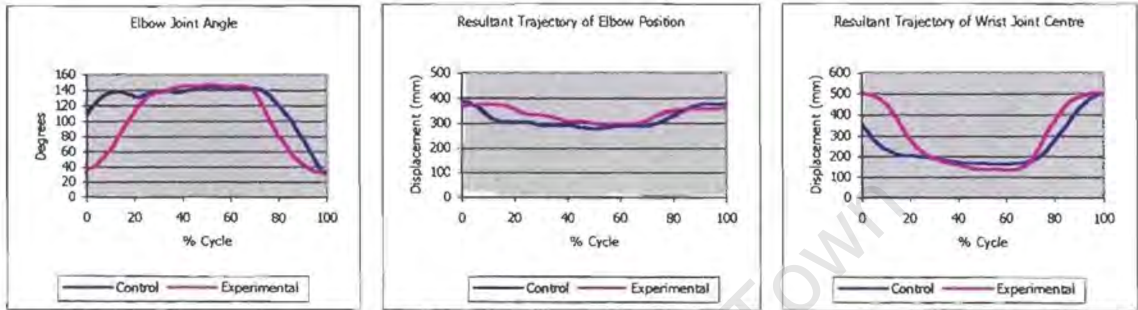

Figure 54 Graphs illustrating the movement trajectory of the sign "smell" for ES3 and CS3.

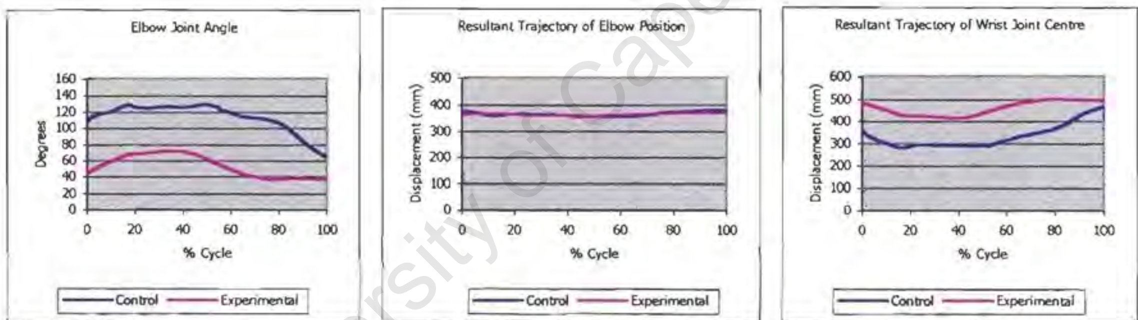

Figure 55 Graphs illustrating the movement trajectory of the sign "yes" for ES3 and CS3.

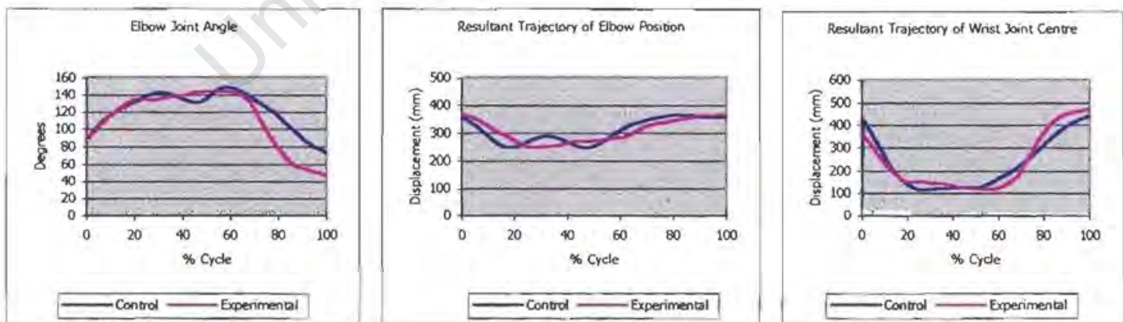

Figure 56 Graphs illustrating the movement trajectory of the gesture "brush teeth" for ES3 and CS3.

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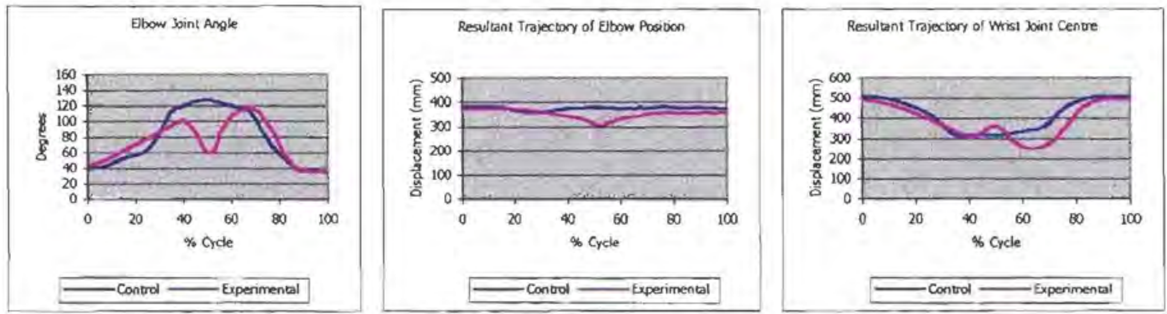

Figure 57 Graphs illustrating the movement trajectory of the sign "hook" for ES3 and CS3.

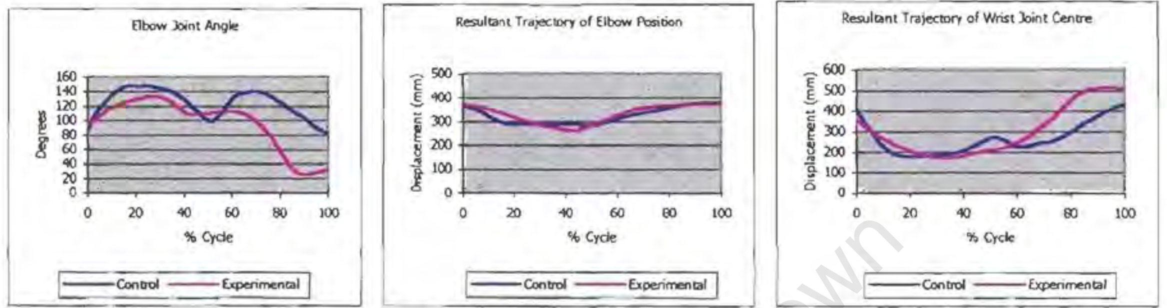

Figure 58 Graphs illustrating the movement trajectory of the sign "snake" for ES3 and CS3.

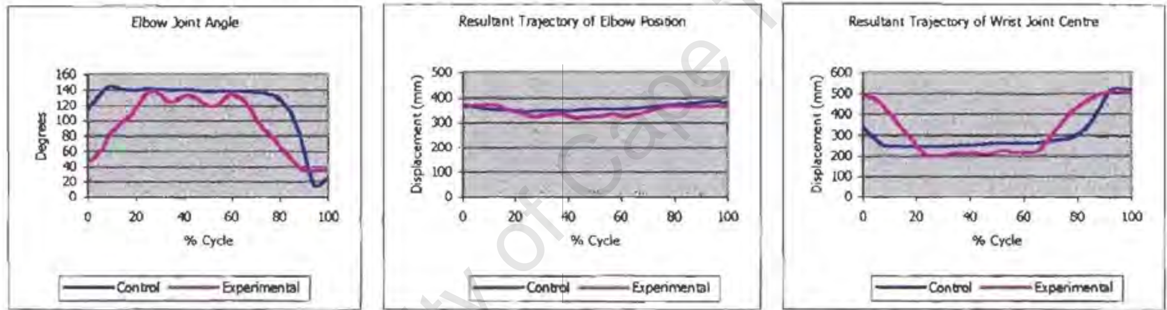

Figure 59 Graphs illustrating the movement trajectory of the sign "like" for ES3 and CS3.

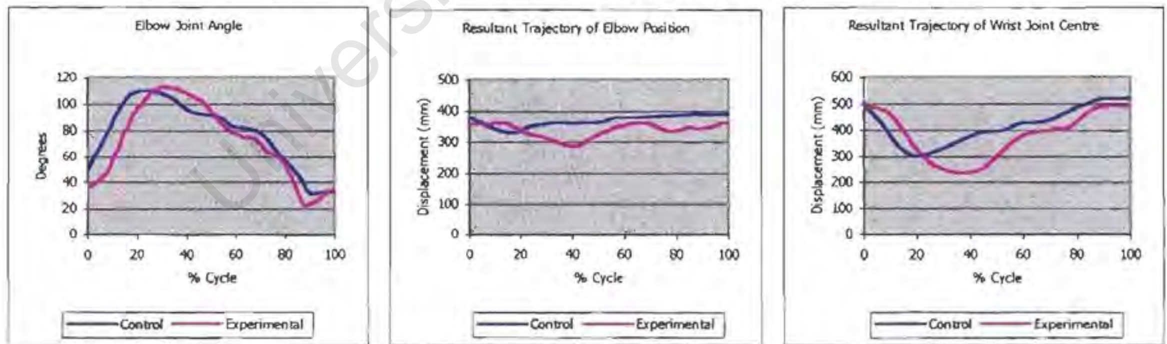

Figure 60 Graphs illustrating the movement trajectory of the sign "z" for ES3 and CS3.

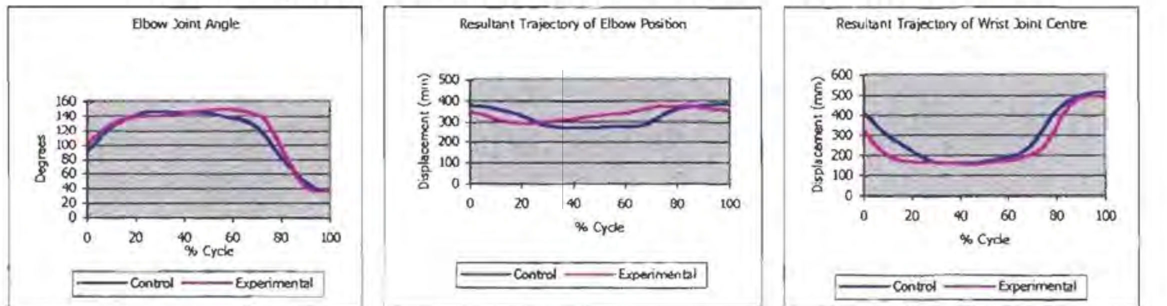

Figure 61 Graphs illustrating the movement trajectory of the sign "weird" for ES3 and CS3.

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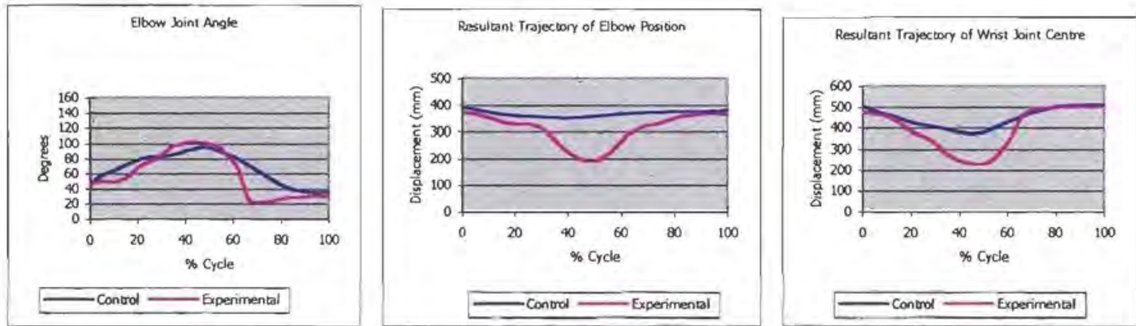

Figure 62 Graphs illustrating the movement trajectory of the sign "aeroplane taking off" for ES3 and CS3.

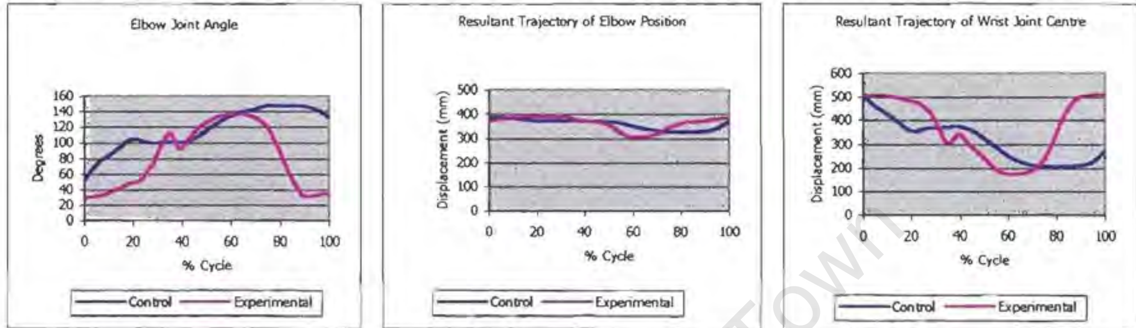

Figure 63 Graphs illustrating the movement trajectory of the sign "good morning" for ES3 and CS3.

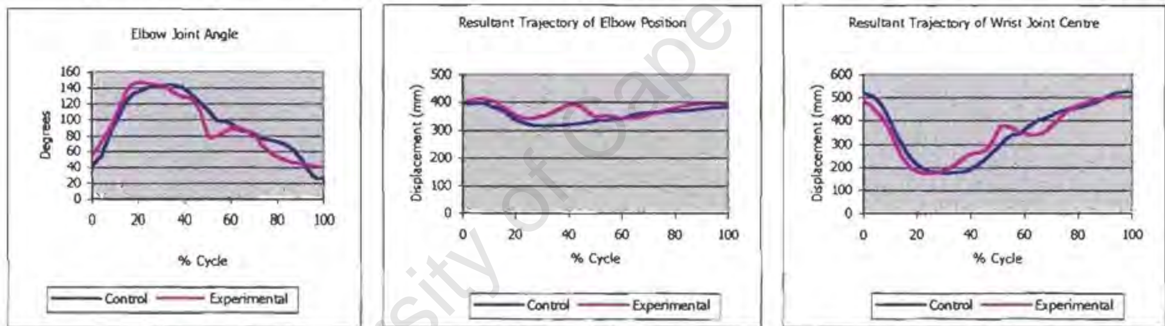

Figure 64 Graphs illustrating the movement trajectory of the sign "starfish" for ES3 and CS3.

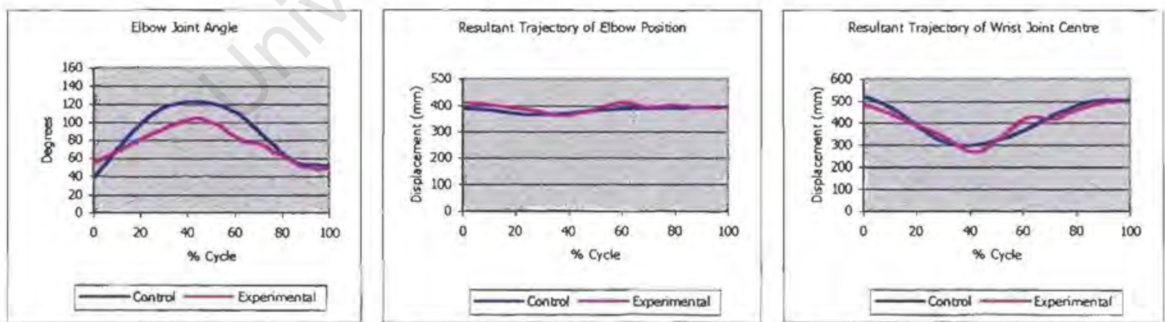

Figure 65 Graphs illustrating the movement trajectory of the sign "bridge" for ES3 and CS3.

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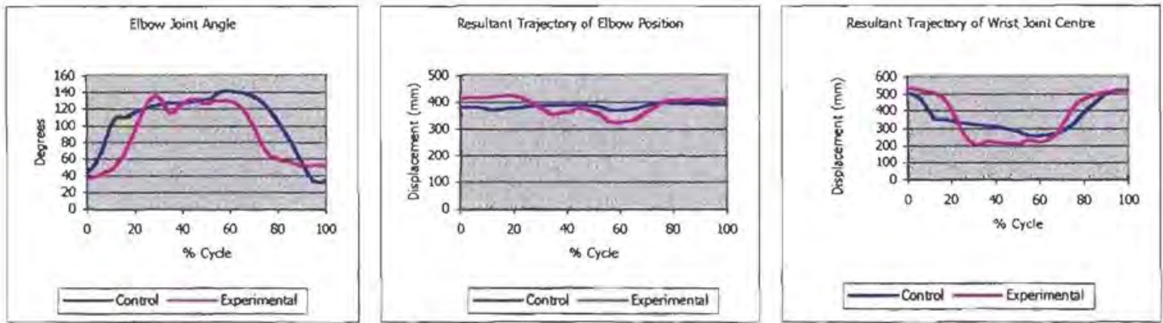

Figure 66 Graphs illustrating the movement trajectory of the sign "bad luck" for ES3 and CS3.

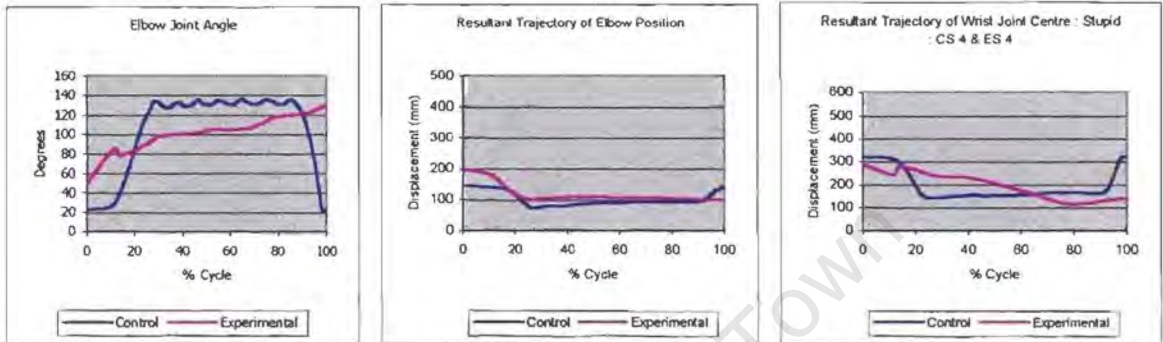

Figure 67 Graphs illustrating the movement trajectory of the sign "stupid" for ES4 and CS4.

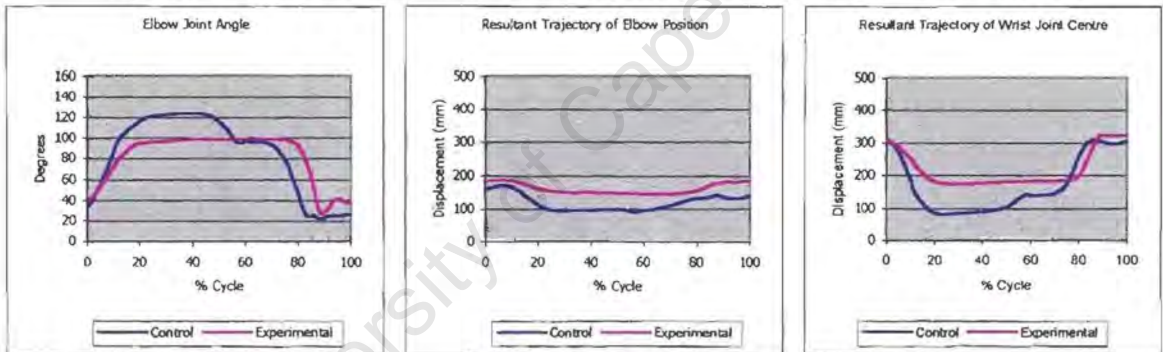

Figure 68 Graphs illustrating the movement trajectory of the sign "shout" for ES4 and CS4.

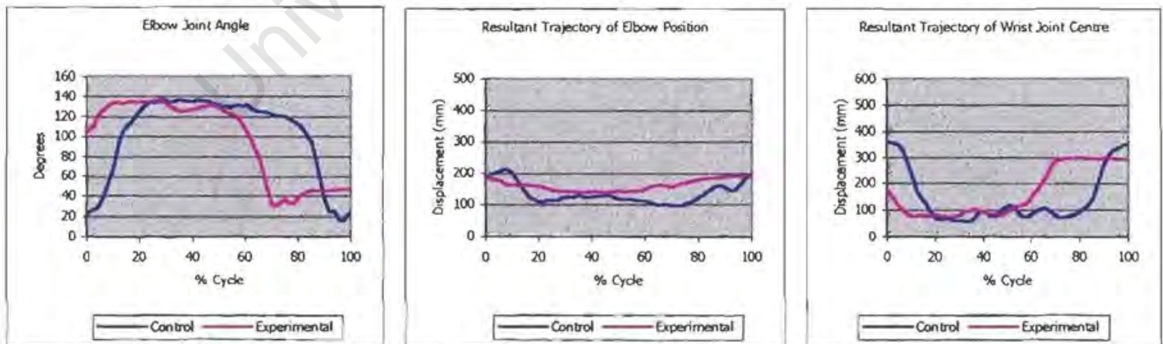

Figure 69 Graphs illustrating the movement trajectory of the sign "smell" for ES4 and CS4.

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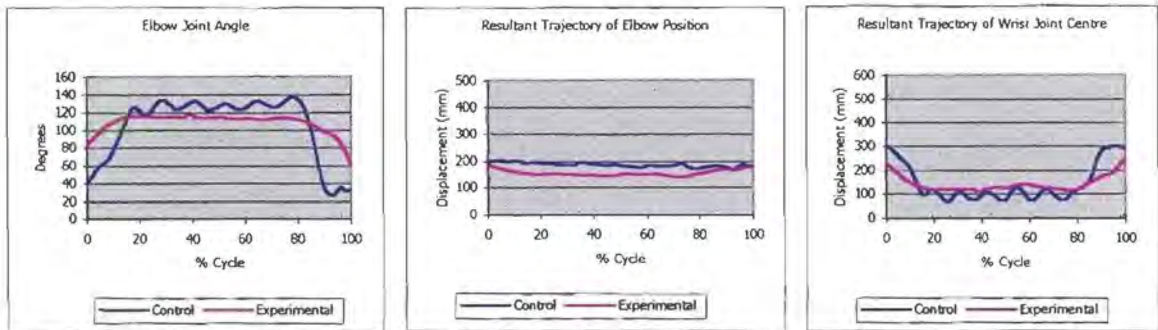

Figure 70 Graphs illustrating the movement trajectory of the sign "yellow" for ES4 and CS4.

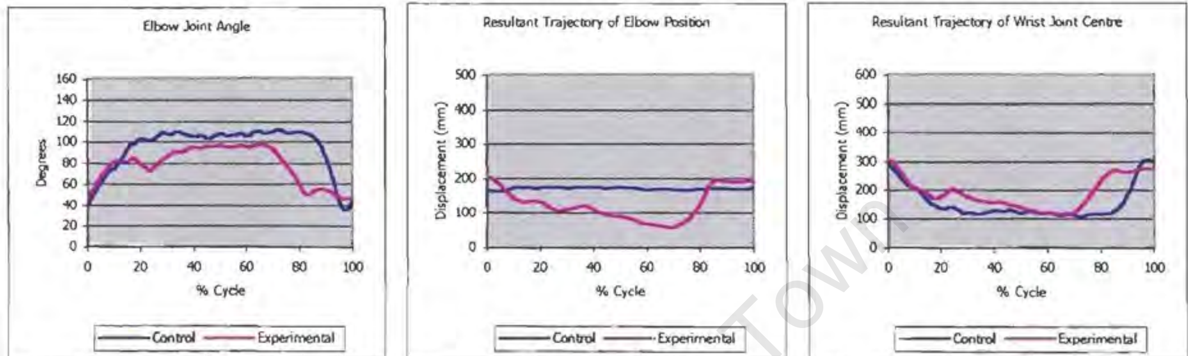

Figure 71 Graphs illustrating the movement trajectory of the gesture "key" for ES4 and CS4.

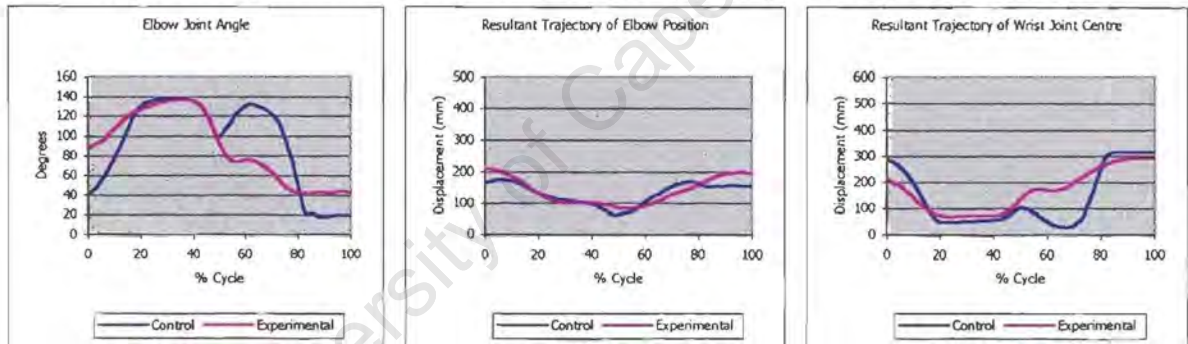

Figure 72 Graphs illustrating the movement trajectory of the sign "snake" for ES4 and CS4.

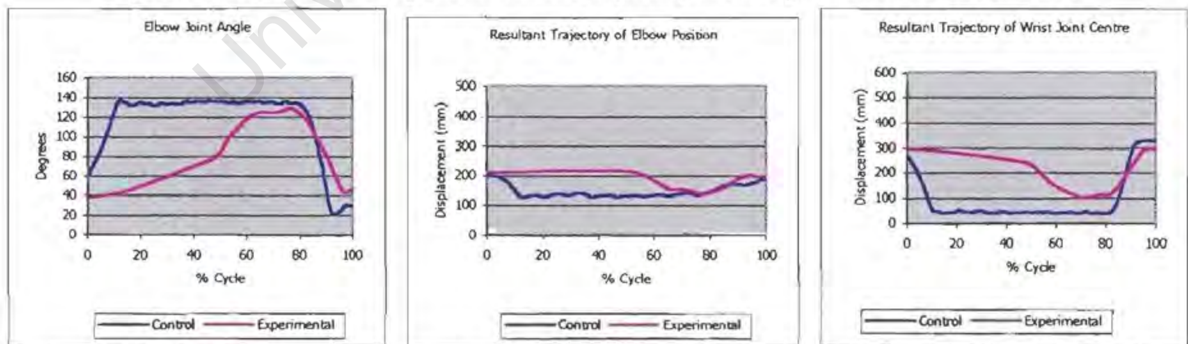

Figure 73 Graphs illustrating the movement trajectory of the sign "like" for ES4 and CS4.

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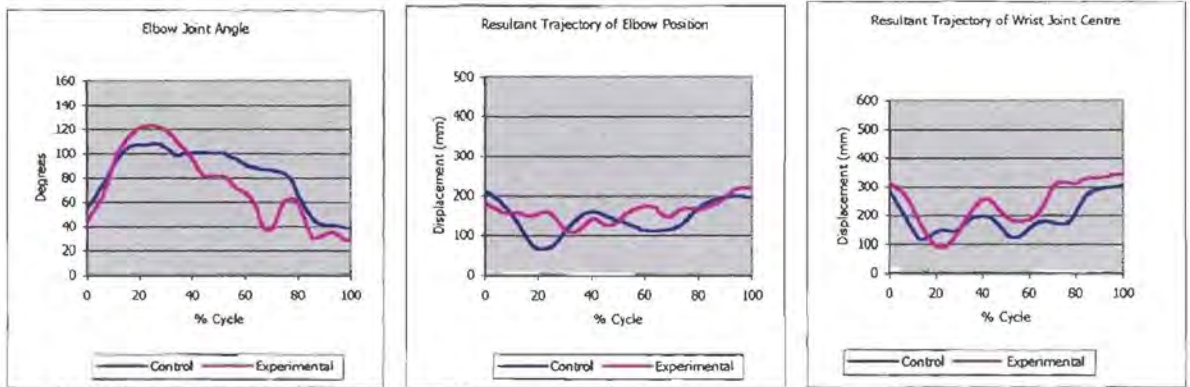

Figure 74 Graphs illustrating the movement trajectory of the sign "z" for ES4 and CS4.

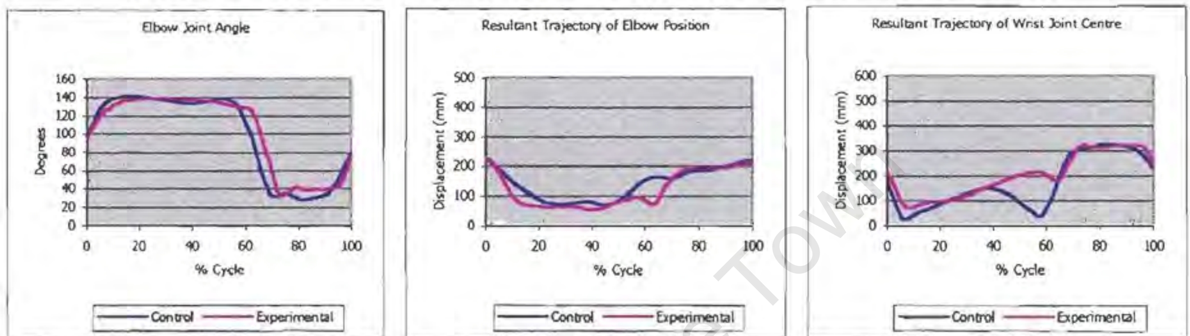

Figure 75 Graphs illustrating the movement trajectory of the sign "weird" for ES4 and CS4.

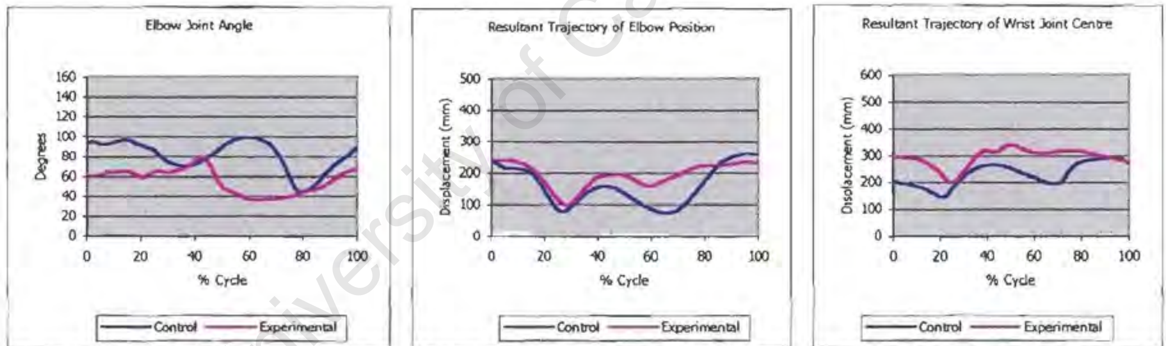

Figure 76 Graphs illustrating the movement trajectory of the sign "aeroplane taking off" for ES4 and CS4.

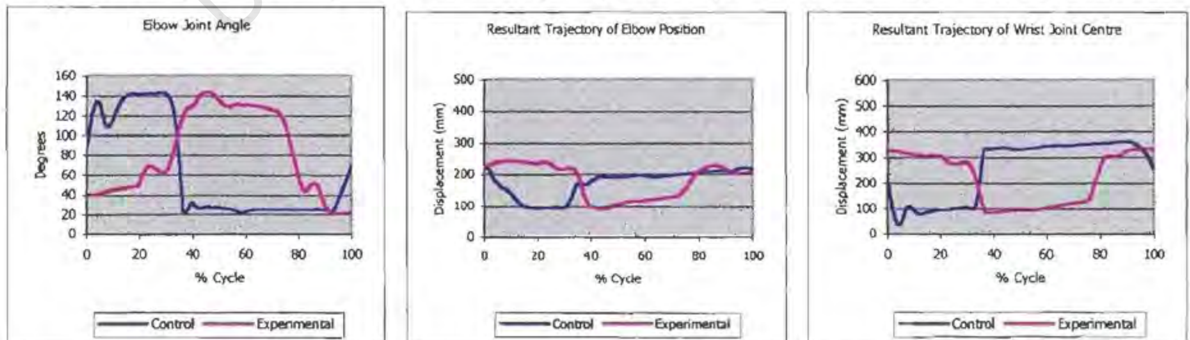

Figure 77 Graphs illustrating the movement trajectory of the sign "good morning" for ES4 and CS4.

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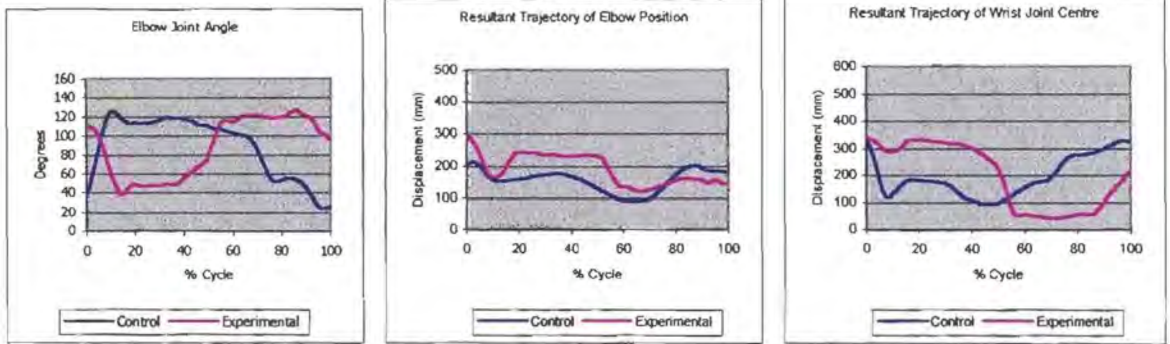

Figure 78 Graphs illustrating the movement trajectory of the sign "starfish" for ES4 and CS4.

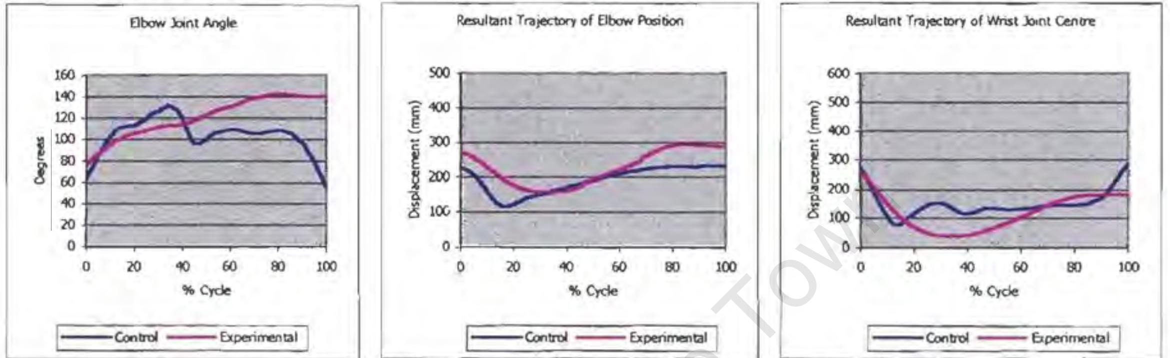

Figure 79 Graphs illustrating the movement trajectory of the sign "bridge" for ES4 and CS4.

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APPENDIX IV

GRAPHS ILLUSTRATING THE VICON MOTION ANALYSIS SYSTEM'S RESULTS OF THE "GESTURED PICTURES" TASK

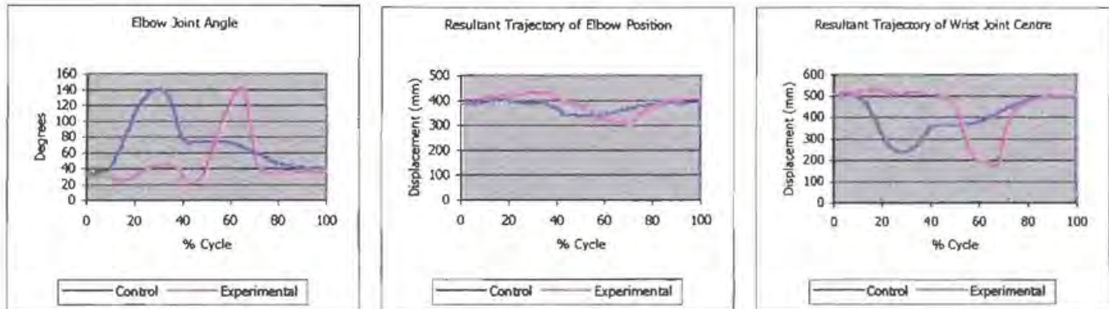

Figure 80 Graphs illustrating the movement trajectory "axe" for ES2 and CS2.

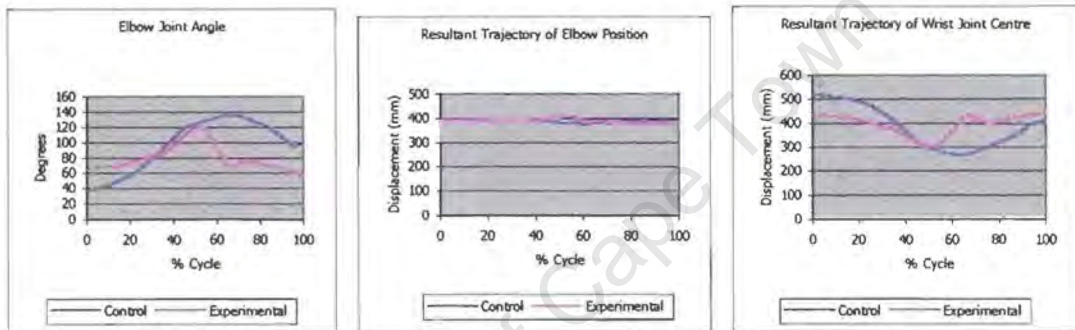

Figure 81 Graphs illustrating the movement trajectory "axe" for ES3 and CS3.

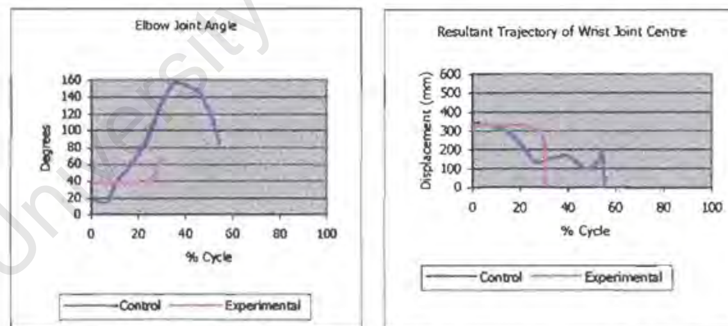

Figure 82 Graphs illustrating the movement trajectory "axe" for ES 4 and CS 4

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