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To cite this article: Simon Garbellini, Dave Parsons & Christine Imms (05 Feb 2025): Use of the Neurological Hand Deformity Classification in clinical practice for children with cerebral palsy: a case study approach, *Disability and Rehabilitation*, DOI: [10.1080/09638288.2025.2458752](https://doi.org/10.1080/09638288.2025.2458752)

To link to this article: <https://doi.org/10.1080/09638288.2025.2458752>



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Published online: 05 Feb 2025.



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Use of the Neurological Hand Deformity Classification in clinical practice for children with cerebral palsy: a case study approach

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ABSTRACT

Introduction: The management of hand deformities of people with neurological impairment is complex and challenging. The use of orthoses to manage hand deformity in clinical practice continues despite low level evidence. Understanding the purpose of an orthosis supported by a biomechanical framework, the Neurological Hand Deformity Classification (NHDC), to identify deforming forces and how to resolve them with appropriate orthotic intervention may reduce controversy surrounding orthosis use.

Methods: Detailed case descriptions were used to demonstrate how the NHDC can be clinically applied to aid orthotic decision making. In the description of the participants presented, the use of the NHDC provided structure to: observe and classify the dynamic movement of the wrist and hand musculature; identify the dynamic forces causing deformity; and guide decision making for intervention strategies.

Results: The identification of the structures involved in the deforming forces on the hand and how orthotic intervention to resolve the deforming forces was guided by the NHDC is discussed. Context is provided regarding the reason, purpose and description of the orthoses used, and timing and dosage of wear is outlined.

Conclusion: The NHDC can form part of a comprehensive upper limb assessment to inform intervention decisions including upper limb orthotic intervention.

> IMPLICATIONS FOR REHABILITATION

- Managing neurologically-based hand deformity can challenge even the most experienced clinician
- The Neurological Hand Deformity Classification was developed to guide clinicians to classify hand deformity and to identify deforming forces
- Descriptive case study methods are used to demonstrate how the Neurological Hand Deformity Classification can be applied clinically to aid upper limb orthotic decision making in managing deforming forces

ARTICLE HISTORY

Received 6 May 2024

Revised 1 December 2024

Accepted 17 January 2025

KEYWORDS

Hand deformity; classification; cerebral palsy; upper limb; orthosis; case report

Introduction

Hand deformities of people with neurological impairment vary according to the lesion in the brain, severity of the classified motor type (such as spasticity or dystonia), sensory impairment, severity of imbalance between hypertonic and paretic muscles, voluntary ability to grasp and release objects, secondary musculoskeletal change and age [1–6]. As secondary musculoskeletal changes progress [2,7–10], the degree of hand deformity, contracture, pain and functional deficits of the hand increase [1,11]. The management of hand deformities of people with neurological impairment is multi-faceted and can challenge even the most experienced clinician [12].

Upper limb orthotic intervention continues to be used in clinical practice to manage neurologically-based hand deformity despite low level evidence supporting this intervention [13]. Factors related to sample size, participants for whom the intervention might be appropriate/effective, duration of intervention, variation in terminology, reasons for orthoses, and orthosis design, have limited

studies aimed at establishing the effectiveness of orthotic intervention [14,15]. Understanding the purpose and limitations of each orthosis and clearly identifying the reason for orthotic intervention provides a basis for clinical decision making and has the potential to reduce controversy surrounding orthosis use [16]. In addition, identification of deforming forces on the individual's wrist and hand and how to resolve these forces, if indicated, with the appropriate orthotic intervention is essential [12,17].

Clinicians must select appropriate tools to attain the information they require to guide intervention in clinical practice [18]. A biomechanical approach, focusing on anatomy, kinetics and kinematics, provides a way to analyse impairment and consider corrective options, one of which might be the use of upper limb orthoses [5,19,20]. However, there is an absence of studies that describe the reason for orthosis prescription relative to the dynamic movement observed or the forces created by the anatomical structures of the wrist and hand [14]. The Neurological Hand Deformity Classification (NHDC) is an impairment-based

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classification system that provides a biomechanical approach to classify hand deformity [21]. It is a discriminative classification [22] used to distinguish the differing levels of hand deformity among individuals with neurologically-based upper limb impairment. Once hand deformity is classified and the structures causing the deformity are identified, individual intervention options can be considered to correct or minimise further deformity.

In the absence of robust evidence, accurate and clear descriptions of management of individuals within their authentic contexts, that draw on the clinician-researcher's knowledge, can provide information to guide clinical research and inform clinical practice [23–25]. The purpose of this paper is to use a case study approach to illustrate how classifying hand deformity using the NHDC can guide clinical decision making for choosing and tailoring orthotic intervention and address the question: How can the NHDC be used to apply orthoses for people with hand deformity secondary to neurological impairment in clinical practice?

Methods

Design

Detailed case descriptions, based on case study methods [25], were used to demonstrate how the NHDC can be clinically applied to aid decision making. The CAsE REport (CARE) guidelines [23] were adapted to provide a framework for these case studies. Adaptation of the guidelines was necessary to describe how to apply the NHDC in clinical practice, rather than describe the effect of a specific intervention. The body functions and structure domain of the International Classification of Functioning, Disability and Health (ICF) [26] was used as a framework to present clinical information about the participants presented. The Outcome Measures Rating Form [27,28] was used to structure the information about the clinical utility of the NHDC.

Participants

Two participants were purposively selected from one of two Australian multi-centre, assessor-blinded, randomised controlled trials investigating the use of rigid wrist hand orthoses for children with cerebral palsy (CP): (i) the Infant Wrist Hand Orthosis Trial (iWHOT) [29]; and (ii) the Minimising Impairment Trial (MIT) [30]. The participants were selected from the wrist hand orthosis intervention group as part of the trials, as: detailed information on upper limb orthotic intervention was collected; they represented the two different trials (participant 1 was in the iWHOT and participant 2 in the MIT); and had different severity of hand deformity. A total of three limbs were classified in the two individuals. The participants' characteristics are presented in Table 1.

Table 1. Participant's characteristics.

Characteristic	Participant 1	Participant 2
Gender	Male	Female
Age at baseline assessment	2Years 11 months	10Years 11 months
Topographical distribution	Unilateral	Bilateral
(mini) MACS	Level II	Level V
GMFCS	Level I	Level V
NHDC at baseline	Left: F2	Right: F5; left E2

Note: MACS: Manual Ability Classification System [31]; GMFCS: Gross Motor Function Classification System [32]; NHDC: Neurological Hand Deformity Classification [21].

Classification tool

The NHDC was used to classify each participant's hand deformity according to their observed wrist and hand movement. The NHDC has a freely available website www.neurohanddeformity.com and manual online [21], which describes the standard procedure for administration and classification. Construct validity, test-retest and inter-rater reliability of the NHDC has been established [33]. The NHDC can be used to discriminate between levels of hand deformity in an individual and can be reliably reproduced [33].

The purpose of the NHDC [21] is to: (1) facilitate observation and analysis of the anatomical and biomechanical components of wrist and hand deformity in people with neurologically-based impairment; (2) identify the primary factors causing the dynamic presentation of the deformity during active wrist and hand movement; and (3) provide a framework for therapists to consider intervention options based upon the dynamic pattern of movement observed.

The clinical use of any classification or measurement tool must consider: format; clarity of instruction; qualification required to use the tool; time taken to complete measurement; and cost [27,28]. These considerations, as they apply to the NHDC, are described as follows:

- Format – Observational classification requiring the participation of the client.
- Clarity of instructions – Comprehensive written and diagrammatic instructions are outlined in the NHDC manual [21].
- Qualifications – For use by clinicians (e.g., Occupational and Physical Therapists) working with clients with neurologically-based upper limb impairment, no formal training or certification required.
- Completion time – Administration 5–10 minutes, classification 5–10 minutes.
- Cost – Nil, freely available.

Administration and set up of the NHDC

The standard procedure to administer and set up the NHDC was followed, as outlined in the NHDC manual and website [21]. The procedure included observation of three attempts of wrist and hand movement during attempted grasp and release of an object, with the most consistent movement used to classify the level of hand deformity for each included limb. The maximum degree of wrist flexion observed at any stage of the movement determined the classification level [21]. Video recording is recommended when classifying hand deformity with the NHDC. The video camera was placed one metre from the non-classified side of the participant to include observation of the thumb position [21]. Review of the video recorded footage was used to classify the participant's hand deformity.

Participant 1

The participant sat on his parent's lap at an adjustable table set to the recommended height as described in the NHDC manual [21]. As the participant had active reach and hand placement with his affected left upper limb, a soft toy, approximately the size of the participant's fist, was placed on the table in front of him. The participant's parent restrained his unaffected right upper limb, and the participant was encouraged to approach, grasp and

release the toy with his left hand. The NHDC was used to classify the participant's dynamic left wrist and hand movement from a video recording.

Participant 2

The participant was seated in a supported seating system on a manual wheelchair. Both hands of the participant were classified, so the video camera position was moved according to the side being classified. Due to the participant's inability to reach towards the object, a ball, approximately the size of the participant's fist, was presented to the hand being classified. The ball was used to stimulate the dorsal and volar surfaces of the fingers to elicit any active movement. The NHDC was used to classify the participant's wrist position and amount of finger movement from video recordings.



Figure 1. NHDC level for the left hand of participant 1 is F2.

Clinical findings

The clinical findings for each participant, presented below, include the level of hand deformity classified using the NHDC, and the identification of the primary factors causing hand deformity.

Participant 1

Classification type

Participant 1 had a NHDC level of **F2** for his left hand (Figure 1). The participant had wrist flexion of greater than 20° during active finger extension; active wrist extension and finger flexion were present during the observed movement.

Participant 2

Classification type

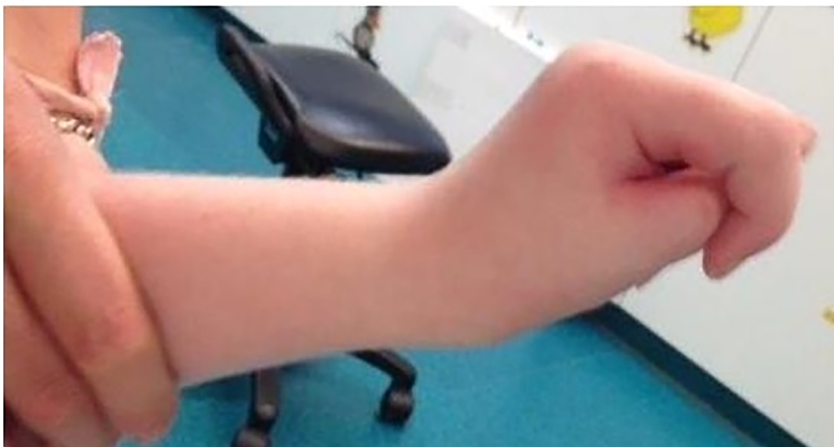
Participant 2 had NHDC levels of **E2** for her left hand (Figure 2(a)) and **F5** for her right hand (Figure 2(b)). On the left, the participant's wrist remained in wrist extension with no active wrist or finger movement. On the right, the participant's wrist remained in wrist flexion with no active wrist or finger movement.

Diagnostic assessment

Classification of hand deformity, using the NHDC, through observation of the dynamic interplay of the participants' wrist and finger movement identified the primary structures requiring further assessment. For participant 1, active left wrist flexion of greater than 20°, wrist ulnar deviation, metacarpophalangeal (MCP) hyperextension and interphalangeal (IP) joint flexion during observed movement indicated that the left wrist, finger and thumb flexors required further assessment. For participant 2, on the left, the persistently extended wrist and flexed MCP posture with no observed active wrist and finger movement indicated that the left wrist extensors and intrinsic muscles of the left hand required further assessment. On the right, the persistently flexed wrist posture of greater than 20° with flexed fingers with no observed active wrist and finger movement indicated that the wrist and finger flexors required further assessment.

Outcome measures used to further assess the structures contributing to hand deformity were:

a)



b)

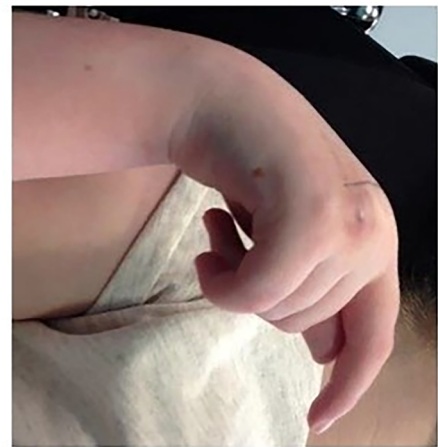


Figure 2. NHDC levels for left and right hand of participant 2. (a) level E2 for the left hand, (b) level F5 for the right hand.

- Passive range of motion (PROM) using a goniometer
 - Assessment of end PROM of the wrist flexors was assessed with the fingers flexed
 - Assessment of end PROM of the finger flexors was assessed with the fingers extended
 - Assessment of end PROM of the wrist extensors was assessed with the fingers flexed
- Spasticity using the Modified Tardieu Scale (MTS), the initial resistance on rapid passive motion (R1) [34]
- Hypertonicity using the Modified Ashworth Scale (MAS) [34]

The PROM, MTS and MAS outcome measures were part of the orthosis trials' protocols. The range of wrist movement was referenced from -90° (full flexion) to $+90^\circ$ (full wrist extension), where 0° indicated a neutral wrist position.

Participant 1

Participant 1's assessment details are presented in Table 2.

Primary structures causing deformity

Increased muscle tone in the wrist flexors, predominantly Flexor Carpi Ulnaris (FCU), caused dynamic wrist flexion. Active wrist extension was observed during movement, however the wrist flexion force was greater than the extensor force required from Extensor Carpi Radialis Longus (ECRL) and Extensor Carpi Radialis Brevis (ECRB) to maintain a less flexed wrist posture. A loss of passive motion of the finger flexors was indicated by the difference between the end of passive motion for wrist extension with fingers flexed and with fingers extended (Table 2). Increased muscle tension was observed in the finger flexors with the MTS. A combination of the loss of passive motion and increased muscle tone of the finger flexors caused greater than 20° of wrist flexion, hyperextension of the MCP joints and flexion of the IP joints during active movement. This supported the NHDC classification of **F2**.

Associated thumb deformity

Left carpometacarpal (CMC) joint adduction and MCP and IP joint hyperextension were present during the observed movement. A lack of observed thumb abduction and extension or opposition at the thumb CMC and MCP joints during movement, in combination with the resistance felt during passive thumb extension and abduction, indicated increased muscle tone in the thumb adductor, Adductor Pollicis (AP). The flexed wrist position increased tension through the long thumb extensor, Extensor Pollicis Longus (EPL), pulling the IP joint into hyperextension.

Table 2. Assessment of the left hand body structures for participant 1.

Primary body structure causing deformity	Diagnostic assessment		
	PROM ($^\circ$)	MTS ($^\circ$)	MAS
Wrist flexors – FCU	80	-2	1+
Finger flexors – FDS/FDP	67	-60	3
Thumb adductor – AP	70	Not assessed	Not assessed

Note: PROM: end of passive wrist extension was measured with fingers flexed for wrist flexors and with fingers extended for finger flexors; MTS: Modified Tardieu Scale reports joint angle at initial resistance on rapid passive motion (R1); MAS: Modified Ashworth Scale; FCU: Flexor Carpi Ulnaris; FDS: Flexor Digitorum Superficialis; FDP: Flexor Digitorum Profundus; AP: Adductor Pollicis.

Participant 2

Participant 2's assessment details for the left hand are presented in Table 3.

Primary structures causing deformity

On the left, increased muscle tone and shortening of the extrinsic wrist extensors, ECRL, ECRB and Extensor Carpi Ulnaris (ECU) caused the extended wrist position. The participant's left forearm remained in pronation. Consideration of the observed forearm posture eliminated the reinforcing effect gravity would have added to the wrist extension deformity if the forearm was in supination. The MCP joints were at 60° of flexion, with the proximal interphalangeal (PIP) joints flexed to 70° , and the distal interphalangeal (DIP) at 40° of flexion. This observed posture was caused by increased muscle tone and shortening of the intrinsic muscles of the hand (causing MCP flexion) and shortening of the extrinsic finger flexors, FDS and FDP.

Associated thumb deformity

On the left, CMC joint adduction and MCP joint flexion with the interphalangeal joint positioned between the index and middle fingers were observed. Assessment suggested that increased muscle tone and shortening of the Flexor Pollicis Brevis (FPB) and AP intrinsic muscles caused the thumb posture.

Loss of passive wrist flexion supported the NHDC classification of **E2**, as the participant's left wrist remained in extension with minimal passive motion into wrist flexion available. There was no limitation in passive extension of the MCP joints of the fingers and thumb.

Participant 2's assessment details for the right hand are presented in Table 4.

Primary structures causing deformity

On the right, increased muscle tone and shortening of the wrist and finger flexors Flexor Carpi Radialis (FCR), Palmaris Longus (PL), FCU, FDS and FDP was assumed to cause the flexed wrist posture. Observation of the forearm position indicated the potential effect of gravity in reinforcing the wrist flexed posture, at rest, of 50° of flexion. An absence of active wrist extension was observed.

Associated thumb deformity

On the right, CMC joint adduction with IP joint hyperextension was observed. Increased tone in the thumb adductor, AP, and shortening of Flexor Pollicis Longus (FPL) was assumed to cause adduction of the right thumb. The flexed wrist position increased

Table 3. Assessment of the left hand body structures for participant 2.

Primary body structure causing deformity	Diagnostic assessment		
	PROM ($^\circ$)	MTS ($^\circ$)	MAS
Wrist extensors – ECRL/ECRB/ECU	-10	No R1	2
Finger flexors – FDS/FDP	59	28	2
Intrinsic muscles – Lumbricals	0	Not assessed	Not assessed
Intrinsic muscles – FPB	0	Not assessed	Not assessed

Note: PROM: End of passive wrist flexion was measured with fingers flexed for wrist extensors and with fingers extended for finger flexors; MTS: Modified Tardieu Scale reports joint angle at initial resistance on rapid passive motion (R1); MAS: Modified Ashworth Scale; ECRL: Extensor Carpi Radialis Longus; ECRB: Extensor Carpi Radialis Brevis; ECU: Extensor Carpi Ulnaris; FDS: Flexor Digitorum Superficialis; FDP: Flexor Digitorum Profundus; FPB: Flexor Pollicis Brevis.

tension through the long thumb extensor, EPL, causing hyperextension of the IP joint.

Contracture in the finger flexors of the right hand was observed. There was a difference of 94° between the end of passive wrist extension with fingers flexed and with fingers extended, indicating shortening of the finger flexors FDS and/or FDP. The persistent flexed wrist position and shortening of the finger flexors supported the NHDC **F5** classification.

Additional diagnostic assessment

The NHDC was used to classify hand deformity and identify the body structures causing the deformity for both individuals. Subsequently, those body structures were assessed which provided information about the severity of the impairment. This information forms one part of a more comprehensive upper limb assessment that quantifies the client's upper limb function and can be used to guide intervention. An example of the complexity of information required to assess hand movement and function is represented within the ICF framework [26] in Figure 3.

Table 4. Assessment of the right hand body structures for participant 2.

Primary body structure causing deformity	Diagnostic assessment		
	PROM (°)	MTS (°)	MAS
Wrist flexors – FCR/FCU/PL	66	34	1+
Finger flexors – FDS/FDP	–28	–40	2

Note: PROM: End of passive wrist extension was recorded with fingers flexed for wrist flexors and with fingers extended for finger flexors; MTS: Modified Tardieu Scale reports joint angle at initial resistance on rapid passive motion (R1); MAS: Modified Ashworth Scale; FCR: Flexor Carpi Radialis; FCU: Flexor Carpi Ulnaris; PL: Palmaris Longus; FDS: Flexor Digitorum Superficialis; FDP: Flexor Digitorum Profundus.

In addition to the participants' body structure and function information, an assessment of their activity capacity and performance is also required to quantify upper extremity function and guide the selection of intervention options [35]. In the context of upper extremity function, capacity describes the person's ability to reach, grasp, manipulate and release objects. How a person uses their upper limb in everyday activity in their environment describes their performance. Once the assessment of a child's upper limb biomechanical presentation, upper limb function capacity and performance has been completed, clinicians, clients, and their family can decide how to intervene best.

Therapeutic intervention

Intervention decision making is informed by the best available evidence [13], practice based knowledge [36] and the goals and priorities of the child and family. Current upper limb intervention focuses on maximising the efficiency of the individual's response to the environment and demands of the task, leading to changes in upper limb movement capabilities and task performance [37]. Because biomechanical presentation, upper limb capacity and performance, and goals differ between individuals, so too does the choice of appropriate therapeutic intervention.

The level of hand deformity, classified with the NHDC, may guide the choice of upper limb intervention. For children with an unilateral presentation, the level of hand deformity and impairment could inform the selection of constraint-induced movement therapy versus bimanual occupational therapy [37]. The level of hand deformity and the child's performance of daily tasks could inform the selection of goal-oriented training [38]. The level of hand deformity and identified structures causing the deformity could inform the muscle selection for using Botulinum Toxin Type

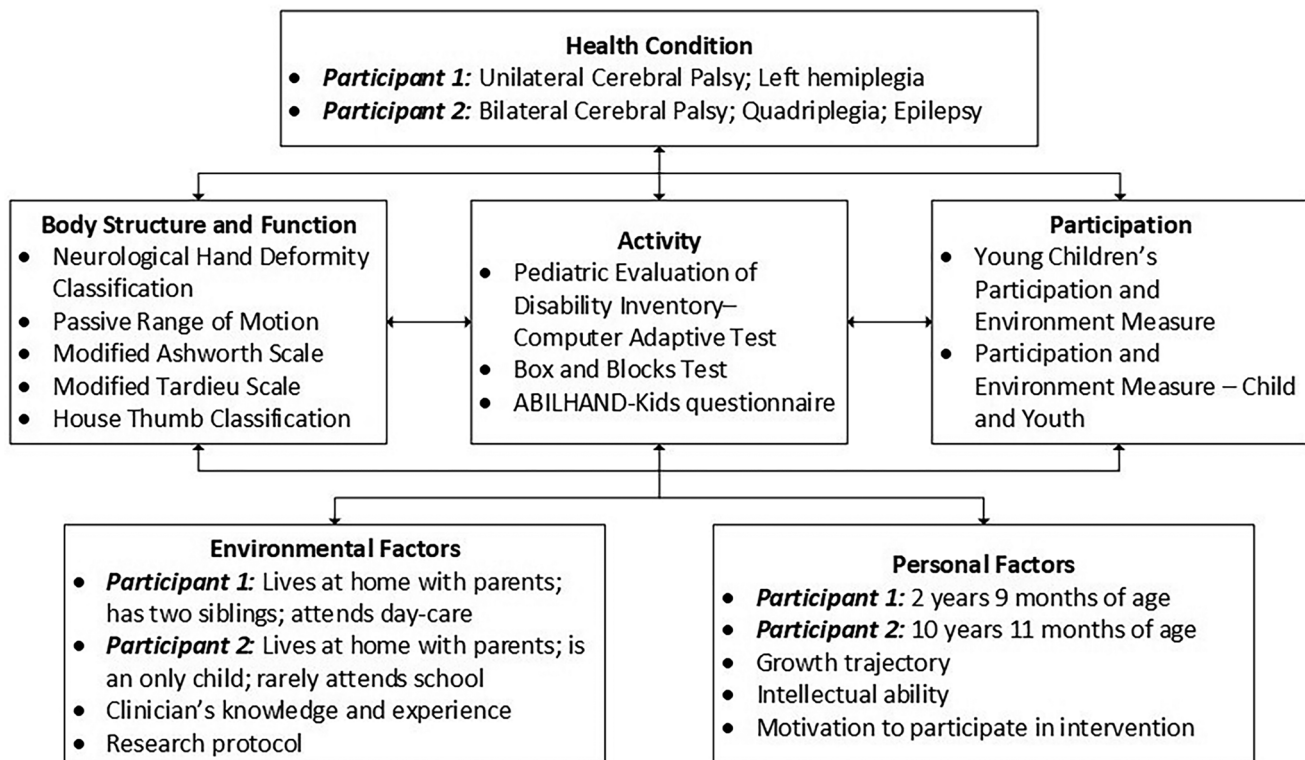


Figure 3. ICF representation of factors and example assessments that could guide intervention decisions.

A [39] and/or inform the biomechanical application of an upper limb orthosis or cast [5,17].

Biomechanical influences of hand deformity are not well reported in the literature as part of the rationale for upper limb orthosis prescription [14]. The literature lacks sufficient description of the dynamic interplay of the wrist and fingers in action and how this information can guide orthosis prescription. Prior to prescribing an upper limb orthosis, it is essential to analyse the deforming forces generated by the wrist and finger musculature [14]. This analysis provides information on the direction, location and intensity of forces that are needed to minimise or resolve the deformity with an orthosis.

Reported recommendations for the continued use of upper limb orthotic intervention include: observation and analysis of hand deformity; clear documentation of the reason for orthosis prescription; and using consistent terminology to describe the purpose of the orthosis [14]. Based on the information obtained from the NHDC, the reason for orthosis prescription, the purpose and description of the orthosis will now be presented in further detail for each participant.

Participant 1 – left upper limb orthotic intervention

Analysis of left hand deformity. Participant 1 – NHDC level **F2**. The participant's left wrist and finger flexors were the primary structures causing the deforming forces (see arrows, [Figure 4\(a\)](#)). As part of the iWHOT, the orthotic intervention implemented for Participant 1 was directed by the objective of the trial – to determine the effectiveness of a rigid wrist and hand orthosis worn at night to prevent loss of passive range of wrist extension over a three-year period [29]. A wrist orthosis to address the deforming wrist flexion forces during functional activity may have improved the efficiency of the finger flexors and extensors during grasp and release of objects, but was excluded as part of the study protocol. Although excluded within the trial protocol, the participant's mother indicated that he was not likely to accept wearing an orthosis during daily functional activities or play.

The positional deformity could be corrected with the application of reciprocal forces (see arrows, [Figure 4\(b\)](#)), around the axis of the left wrist joint, with the application of a volar wrist orthosis ([Figure 4\(b\)](#)). Notably, the wrist and finger positions in the orthosis are greater than the angle of the initial catch (refer to [Table 2](#)) assessed with the MTS [34], potentially providing stretch to the wrist and finger flexors.

Reason for orthosis prescription. To maintain optimal postural alignment of the left wrist and fingers to: (i) prevent complications associated with muscle shortening due to abnormal posturing, and (ii) maximise the potential for functional use of the hand.

Purpose of the orthosis. The primary purpose was to apply reciprocal forces to extend the wrist and fingers in a position that opposed the deforming forces identified using the NHDC.

Description of the orthosis. A mobilising wrist and hand orthosis, used to apply passive forces to gain motion [40,41], of a volar design. A 2.0 millimetre thick thermoplastic material was used (micro-perforated Orfit). The orthosis was held in place by VELCRO® straps (Velfoam).

Timing and dosage of wear. Night wear for six to eight hours during sleep. Night wear allowed Participant 1 to have his left hand free to be actively used as an assisting hand during the day. The participant wore the orthosis for the three-year period of the iWHOT study. The orthosis was serially adjusted or re-made to sustain mobilising forces on the deforming structures during this period. Since completing the iWHOT study, the participant's parents have chosen to continue orthotic intervention with a left mobilising wrist and hand orthosis worn at night.

Participant 2 – bilateral upper limb orthotic intervention

Analysis of left hand deformity. Participant 2 – NHDC level **E2**. The participant's left wrist extensors, extrinsic finger flexors and intrinsic hand muscles were the primary structures causing the deforming forces (see arrows, [Figure 5\(a\)](#)) of wrist extension, MCP flexion and finger flexion. The positional deformity could be corrected by applying reciprocal forces (see arrows, [Figure 5\(b\)](#)) with a wrist and hand orthosis. The wrist is positioned in a neutral position, only 10° less than the amount of available passive wrist flexion.

Analysis of right hand deformity. Participant 2 – NHDC level **F5**. The participant's right wrist and finger flexors were the primary structures causing the deforming forces (see arrows, [Figure 6\(a\)](#)) of wrist and finger flexion. The positional deformity could be corrected by applying reciprocal forces (see arrows, [Figure 6\(b\)](#)) with a wrist and hand orthosis.

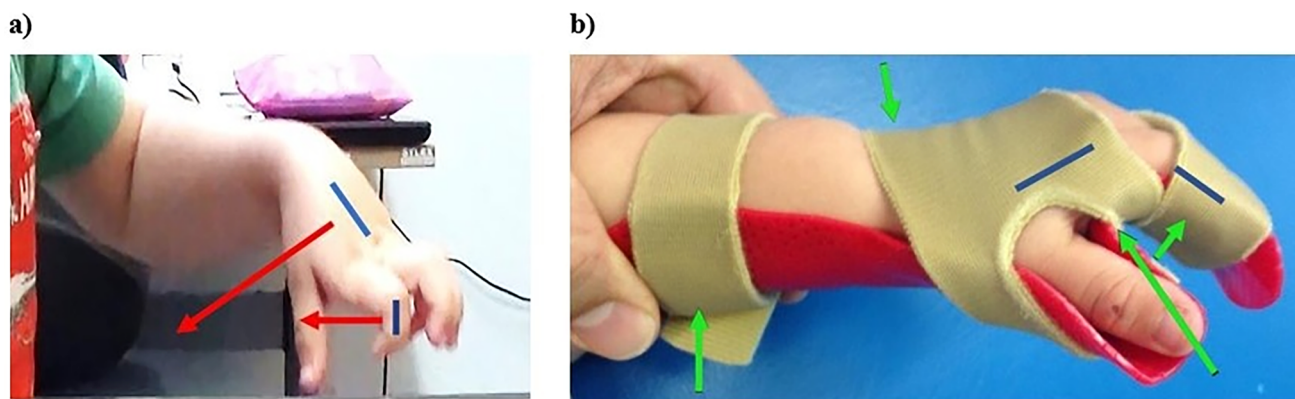


Figure 4. (a) Hand deforming forces without orthosis and (b) reciprocal resolving forces with orthosis for the left hand.
Note: Arrows figure (a) – deforming forces; arrows figure (b) – reciprocal forces.

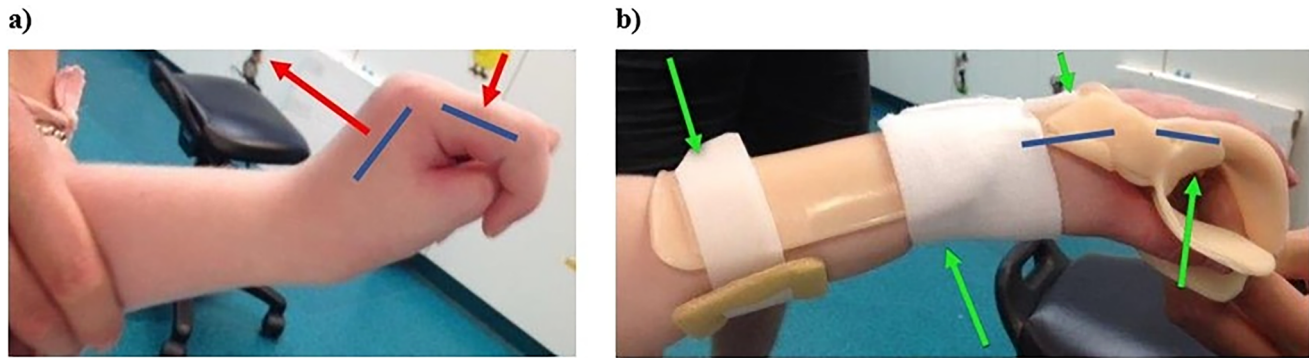


Figure 5. (a) Hand deforming forces without orthosis and (b) reciprocal resolving forces with orthosis for the left hand.
Note: Arrows figure (a) – deforming forces; arrows figure (b) – reciprocal forces.

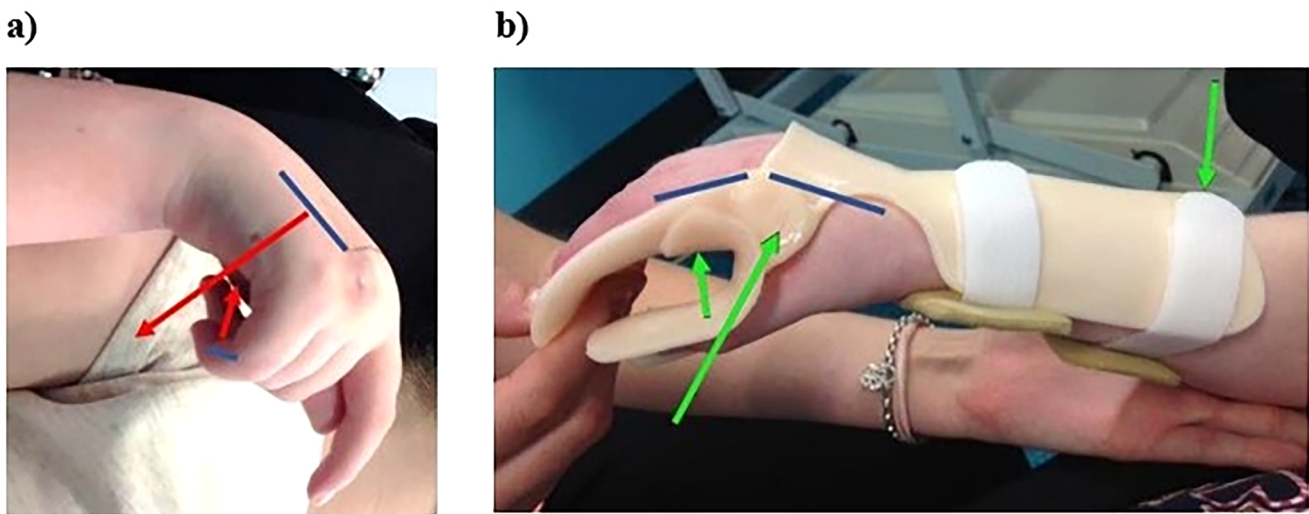


Figure 6. (a) Hand deforming forces without orthosis and (b) reciprocal resolving forces with orthosis for the right hand.
Note: Arrows figure (a) – deforming forces; arrows figure (b) – reciprocal forces.

Reason for orthosis prescription. (i) To prevent further loss of passive range of motion at the wrist and fingers; and (ii) prevent complications of pain and poor hygiene associated with muscle shortening.

Purpose of the orthoses for left and right hands. To apply forces to flex the left wrist and extend the MCP joints of the fingers in a position that opposed the deforming forces identified using the NHDC. The purpose of the orthosis for the right hand was to apply forces to extend the wrist and fingers in a position that opposed the deforming forces identified using the NHDC.

Description of the orthoses. A mobilising wrist and hand orthoses, used to apply passive forces to gain motion [40,41], of a dorsal/volar design. A 3.2 millimetre thick thermoplastic material was used (classic soft non-perforated Orfit). The orthosis was held in place by VELCRO® straps (Velcro and Velstretch).

Timing and dosage of wear. Night wear for six to eight hours during sleep for both the left and right hands. Given the participant had minimal active movement of her hands, sometimes her parents chose to don the orthoses for periods during the day. They did this if they felt her hands were particularly stiff or that her muscle tone had increased due to seizure activity. The

participant wore the orthoses for the 18 months they were enrolled in the MIT study. The orthosis was serially adjusted or re-made to sustain mobilising forces on the deforming structures during this period. The participant's parents chose continued left and right mobilising wrist and hand orthoses wear at night after the study ended.

Orthosis fabrication guidelines for the iWHOT [29] and MIT [30] were followed. The recommended positioning of the thumb, fingers and wrist in the orthoses were: (i) maximal abduction and extension of the thumb while avoiding hyperextension of the MCP joint; (ii) MCP and IP joints of the fingers in some flexion (i.e., 10°–30°); and (iii) wrist positioned in neutral wrist ulnar/radial deviation and 30°–55° extension (where 0°=neutral, 90°=full extension) or, maximal wrist extension while maintaining the position of the fingers outlined above. The guidelines accommodated the inability to approximate the recommended thumb, finger and wrist positions based on assessment of muscle tone and loss of passive range of motion, while respecting the typical biomechanics of the hand. For example, the thumb position achieved bilaterally for Participant 2 at the participant's maximal position of abduction and extension, noting the wrist position achieved in the orthosis and suggested contracture limited what appeared to be typical maximal abduction and extension of the thumb.

In both individuals, the orthoses were prescribed to mobilise tissues to maintain or gain passive range of motion. They were

not prescribed to rest the joints. There was no pathology to suggest the joints needed to be immobilised or rested. A static orthosis was prescribed to create mobilising forces to correct the dynamic deformity. The static orthoses were serially adjusted to sustain the mobilising forces over time. The orthoses were worn at night to allow the participants to free their hands during the day. Participant 1 could use his left hand to hold objects and stabilise objects with grip. Participant 2 could have her hands massaged and touched for interaction, care and cleaning.

Tolerance of the intervention

Both participants wore the orthoses for the time and duration prescribed. The parents of both participants understood the reasoning for, and were supportive of, the intervention. Neither participants' parents reported sleep disturbance from orthoses wear. Concerns related to orthosis fit or discomfort were addressed with orthosis modification or re-fabrication to accommodate growth. For example, modification either increasing or decreasing the amount of wrist or finger extension, was required to reduce pressure and shearing forces and maintain advantageous application of the reciprocal resolving forces (opposite to the deforming forces) of the orthoses.

Discussion

Assessment of neurologically-based upper limb impairment and choosing appropriate interventions is challenging. Understanding movement limitations of the wrist and finger musculature of people with neurologically-based upper limb impairment is critical to inform the reason for, and choice of, upper limb intervention [14]. In this paper, we describe the NHDC as providing structure to: observe and classify the dynamic movement of the wrist and hand musculature; identify the dynamic forces causing deformity; and guide decision making for intervention strategies. For clinicians new to working in the clinical area of managing neurologically-based upper limb conditions, the NHDC can be a guide to information-gathering and decision making. Further research is recommended to explore the clinical utility of the NHDC in diagnostic groups other than cerebral palsy.

Our aim was to describe how the NHDC can be used in clinical practice, not to present all possible upper limb assessments and interventions. The NHDC is an impairment-based classification tool that should not be used in isolation. A more complete clinical picture of the individual through assessment of their unimanual capacity and usual bimanual performance during activities, considering the impact of the individual's personal and environmental factors (refer to Figure 3), is critical to guiding the selection of upper limb interventions, including orthotic prescription. In busy clinical settings, time efficient measures with established validity, reliability and clinical utility are required. A clinician's experience and work setting also influence the choice of measurement tool. The NHDC can guide which body structures to assess in more detail based on the hand deformity classification, potentially saving time.

A strength of using a case description design is it allows a detailed and structured presentation of information using an exemplar to guide learning. The application of the NHDC followed a standard format and yielded pertinent information to guide decision making, even though the participants' ages and severity of impairment differed. Conversely, the selection of cases may be seen as a limitation. The two participants were purposively selected and it is unknown whether randomly selecting participants would have provided a different focus for the information presented in the case studies.

Conclusion

A description of how the NHDC can be used in clinical practice has been presented in the form of two case studies. For each individual, the NHDC was used to: (1) observe and analyse the anatomical and biomechanical components of the participants' hand deformity; (2) identify and further assess the primary structures causing the deformity with passive range of motion and muscle tone measures; and (3) provide a framework to direct the purpose, type of orthosis, and orthosis design needed to apply reciprocal resolving forces based upon the dynamic pattern of movement observed. When children present with upper limb hypertonicity, the NHDC can form part of a comprehensive upper limb assessment that includes body structure and function, activity and participation measures in the context of personal and environmental factors to inform intervention decisions.

Acknowledgements

We acknowledge Dr. Melinda Randall, Professor Catherine Elliott and Dr. Michael Steele for their initial supervision of this study, and Ms. Judith Wilton for her ongoing mentorship and clinical expertise. No funding was received for this study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

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