EXPLORING THE MEASUREMENT OF DEXTERITY IN REHABILITATION

EXPLORING THE PERCEPTIONS, PRACTICES AND CONSTRUCTS SURROUNDING THE MEASUREMENT OF DEXTERITY IN THE REHABILITATION OF PERSONS WITH HAND AND WRIST INJURIES

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Lay Abstract

Dexterity is the ability to do tasks, successfully, quickly and accurately. Loss of dexterity is common and affects our ability to do our tasks of daily life and work. Unfortunately, there is a lack of agreement on the best way to measure dexterity. Our study aims to explore what dexterity means to health professionals. We focused on occupational therapists seeing persons with hand and arm injuries. In the first study, we interviewed therapists to understand how they measured dexterity. In the second study, we searched for dexterity tests used with persons with hand injuries. Then, we compared the tests we found to dexterity theories. We found that dexterity is measured in different ways. Therapists faced many barriers to using dexterity tests. Current dexterity tests are an incomplete reflection of a person's dexterity. The information gained from these studies could be used to inform future research on the measurement of dexterity.

Abstract

Introduction: Dexterity impairments are common and disabling. Measuring the extent of these impairments is important for care and service provision. Despite this, dexterity is poorly operationalized in the management of persons with hand and wrist conditions (HWC).

Thesis purpose: To understand: 1) how dexterity is defined in the management of persons with HWC and 2) how therapists working with persons with HWC perceive/understand the concept and measurement of dexterity and use of performance-based outcome measures of dexterity (PBOMD).

Methods: In study one, Interpretive Description was used to understand the perceptions and measurement practices of occupational therapists working with persons with HWC in Singapore. Study two involved a content analysis of the literature outlining the constructs measured by PBOMD that were validated for use in persons with HWC.

Results: Both studies highlighted the lack of conceptual clarity around ‘dexterity’ that is reflected in therapists’ and tool developers’ discourse. Many of the therapists we interviewed, perceive PBOMD to lack clinical value. Studies from this thesis suggest that identified PBOMD do not adequately cover dexterity.

Conclusion: Findings highlight the challenges surrounding the construct of dexterity and provide clinical practice recommendations.

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Declaration of Academic Achievement

This thesis comprises of an introduction, conclusion chapter, as well as two independent research studies. I, Joshua Yong, am the main contributor, author and investigator on all the chapters. However, this thesis was only possible with the valued mentorship and contribution of my supervisor: Dr. Joy Macdermid; my Master's thesis committee: Dr. Julie Richardson and Dr. Sandra Moll. The contributions are outlined as follows:

Chapter 2: Measuring the 'elusive'-A qualitative exploration of therapists' perceptions on the measurement of dexterity in hands and upper limb rehabilitation. Dr. Macdermid, Dr. Richardson and Dr. Moll contributed conceptually to the research design, analysis, implementation of the study as well as the revision and editing drafts of the manuscript. Dr. Moll was instrumental in guiding and supporting me through the iterative inductive analysis process to generate the research findings. The Singapore Association of Occupational Therapists and my employer: Sengkang General Hospital funded and provided the resources for the execution of this study. Finally, my study team from Singapore: Ms. Yap Jia En and Ms. Calise Tan assisted with the logistics of the study.

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List of Abbreviations and Symbols

400-point Hand Function Test	400T
Arthritis Hand Function Test	AHFT
Box and Block Test	BBT
Button Test	BT
Crawford Hand Function Test	CHFT
Complete Minnesota Dexterity Test	CMDT
Consensus-based Standards for selection of health Measurement Instruments	COSMIN
Functional Dexterity Test	FDT
Grip Ability Test	GAT
Hand and wrist conditions	HWC
International Classification of Functioning, Disability and Health	ICF
Interpretive Description	ID
Jebsen-Taylor Hand Function Test	JTHFT
MacHand Performance Assessment	MPA
Minnesota Manual Dexterity Test	MMDT
Moberg Pick-up Test	MPUT
Nine-hole Peg Test	NHPT
NK Dexterity Test	NKDT
Patient-rated outcome measure	PRO
Performance-based outcome measures of dexterity and hand function	PBOMD
Preferred Reporting Items for Systematic Reviews and Meta-analyses	PRISMA
Prospective Registration of Systematic Reviews	PROSPERO
Purdue Pegboard Test	PPT
Quality of movement	QOM
Sequential Occupational Dexterity Assessment	SODA
Short version of the Sequential Occupational Dexterity Assessment	SODA-S
Smith Hand Function Test	SHFT
Sollerman Grip Function Test	SGFT
Valpar Work Component Set 4	VWCS4

1 Chapter 1: Introduction-Measurement of Dexterity in Persons with Hand and Wrist Injuries

1.1 Importance and Uniqueness of Dexterity, and the Many Dimensions Where the Hand Contributes to Human Life

1.1.1 The Development and Role of the Hand in Being Human

The hand is considered to be intimately linked to human evolution and culture (Alpenfels, 1955). More than an extension of the mind, McGinn (2015, p. 74) suggests that the hand coevolved with the mind, and has "important constitutive links to the kind of mind we have evolved." He cites how society associates prehensile terms like "grasping (an idea)" or " to comprehend" to the functions of the mind(McGinn, 2015).

The human hand (which is free from the burden of locomotion, possesses many degrees of freedom, and an independent, opposable thumb) is a unique, differentiating aspect of being human(Alpenfels, 1955; McGinn, 2015). It is suggested that the characteristics listed above make it "free to do the bidding of his (man's) expanded brain"(Alpenfels, 1955, p. 8) as an instrument of perception, expression and performance(Alpenfels, 1955; McGinn, 2015). These functions are integral to all domains of human existence and serve as a platform for engagement in productivity, social engagement and leisure(Duruoz, 2014; McGinn, 2015).

In the end, it is the responsiveness, and presence of the multiple degrees of freedom of the hand that also make the control of purposeful movement complex, and the role of the mind crucial. The successful control of purposive movement requires the coordination of multiple body systems, including the musculoskeletal, neurological, sensory systems while accounting for adaptive and anticipatory responses to environmental variables (Cano-de-la-Cuerda et al., 2015;

M. Latash, 2008; Shumway-Cook & Woollacott, 2012). While current theories of motor control like the equilibrium-point hypothesis, principle of abundance, and dynamic system theory try to explain different aspects of the control of purposeful movement, there is currently no universal theory that completely explains how the mind controls the hand (Cano-de-la-Cuerda et al., 2015; M. Latash, 2008; Shumway-Cook & Woollacott, 2012).

Dexterity represents the embodiment of the complex interaction between the human mind and body in purposive engagement with the world. Unfortunately, dexterity has often been reduced to the skill with the fingers, which limits our understanding of this concept. We will explore throughout the rest of this chapter the nature of dexterity and value of this expanded understanding.

1.1.2 Origins of Dexterity-the Representation of Skill

Dexterity has been considered an integral part of the functional capacity of the hand (Duruoz, 2014; Jones, 1998). Historically, the word ‘dexterity’ can be traced to the Latin origin ‘dexter’ meaning on “right-hand side” and thus by extension, skillful. It later gained the connotations of favourable, fortunate, clever, acceptable and good from its association with the cultural perceptions of the right hand (Klein, 1966). Dexterity, thus became a noun representing skillfulness; cleverness; readiness and prosperity (Klein, 1966). While dexterity can be used to refer to mental or general skill at performing tasks, it has gained a greater association with the sense of manual skill (Cambridge University Press, 2019; Patridge, 1959).

1.1.3 Theoretical Exploration of Dexterity

As we can see from its history, dexterity can be defined as the innate quality of skillfulness. This quality was examined systematically by Nicholai Bernstein, a physician, neurophysiologist and leader in the field of motor control, in his work ‘on dexterity and its development’ (Bernstein, 1996). This work, written in 1941 for a wide audience, was unpublished due to the political movements in Russia (Feigenberg & Latash, 1996). Subsequently, the manuscript was found by Bernstein’s student- Feigenberg who had it published in 1991, years after the death of its author (Feigenberg & Latash, 1996). While this publication comes after the advent of many popular dexterity outcome measures and empirical examination of the construct, Bernstein’s work remains one of the most reflective and thorough explorations of dexterity. His ideas are summarized here and inform the core concept of dexterity adopted in this thesis.

Bernstein, through his thoughtful examination of anthropology, neurophysiology and observation of skilled movement in daily life, posits that dexterity is the “ability to find a motor solution for an external situation, that is to adequately solve an emerging motor problem accurately, rationally and resourcefully”(Bernstein, 1996, p.228). Bernstein suggests that dexterity does not exist as a skill or a combination of skills, but as an ability built on the relationship between the mind and skills over multiple levels, including the coordination of 1) postural control, 2) movement of the extremities, 3) control of movement in space and 4) cognitively driven, task-focus execution of motor activities in interaction with the demands of the environment (where the task is taking place) (Bernstein, 1996). The measurement of dexterity, Bernstein(1996) postulates, is highly specific to the type of tasks in question and has to be done with respect to dimensions such as speed and accuracy, as well as rationality and resourcefulness (achieving the desired results in a suitable manner, regardless of the circumstance). Measurement, in his opinion, has to be done both quantitively and qualitatively (Bernstein, 1996).

The purposeful task lies at the centre of dexterity. The ***nature of the task in question and the environment*** in which it is being done becomes an important variable to consider. Unfortunately, there is no consensus about the most important characteristics of these tasks. The topic of manual dexterity and the classifications of characteristics of different dexterous tasks was examined by Jones (1998), who attempted to reconcile the skill involved in slow, controlled tasks like microsurgery; with speed-driven activities like typing. She suggested that there are three distinguishing task dimensions of dexterity: displacement, force control and movement speed (Jones, 1998).

Another way to categorize tasks is by ***task-specific demands***. Kimmerle, Mainwaring & Borenstein (2003), in their model of the Functional Repertoire of the Hand, suggested that characteristics influencing the complexity and difficulty of the task include: 1) object-related characteristics (size, texture, number, spatial position); 2) movement pattern complexity (single movement compared to sequences of different actions); and 3) performance demands (specific characteristics including the force, endurance required, spatiotemporal demands (direction, speed/rhythm required) and environmental demands).

A third way to classify tasks is by their ***intrinsic purpose and goal***. The possibilities here are limitless, given that there are countless possible tasks. Furthermore, each task could have more than one purpose. For example, cooking could be considered a domestic task completed for the purpose of sustenance, but it could also be completed as a required task of employment. Differences in purpose could influence both the demands of the task and the environment in which the performance occurs.

The assertion that dexterity is a multidimensional construct that is task-specific is supported by studies using factor analysis of different dexterity outcome measures (Fleishman & Hempel, 1954; Jarus & Poremba, 1993; Lawrence E.L. et al., 2015). These factor analysis studies point to dexterity as a product of a) task factors like anatomical and biomechanical variables-finger, manual(arm), pinch or grasp; b) task characteristics such as daily activities, target accuracy/aiming (Fleishman & Hempel, 1954; Jarus & Poremba, 1993) and c) body-capacity factors like strength and sensorimotor processing (Lawrence E.L. et al., 2015). None of the tests included in these factor analysis studies fully addressed the additional characteristics described by Bernstein, such as resourcefulness and rationality which involve concepts such as the economy of movement and effort, as well as effective resolution of the motor tasks (Bernstein, 1996; Canning, Ada, & O'Dwyer, 2000; Wang et al., 2018).

In addition, one of the gaps in the theoretical literature is the lack of studies that empirically validate the different dimensions of tasks and their associated performance demands. Our understanding of dexterity is still in the developmental stages; more studies are needed, including studies that encompass wider ranges of tasks and dimensions of dexterity. Empirical studies might inform our understanding of conceptual and technical issues in measuring dexterity.

1.1.4 Challenges in Operationalizing Dexterity- Capturing the Complexity of the Performance of the Hand

The measurement of dexterity requires a judgement about the accuracy, economy of movement, and whether the results were achieved in a suitable way (Bernstein, 1996).

Examining these qualities of dexterity in a reproducible and objective way requires an understanding of what constitutes a suitable or accurate execution of a task. As identified above in our discussion about task-specific demands, there are numerous environmental and task variables that occur even within a simple task like eating, and these variables can vary substantially according to culture and circumstance.

Even if we navigate the diversity of the tasks associated with dexterity and focus on the most common patterns, another issue is how to reliably record and measure the human movement that occurs during the tasks, so that one can comment on the deviance from expected patterns deemed to be biomechanically and ergonomically suitable. Winter (2009) asserts that the traditional method of direct observation can result in "tremendous overload" of information for even the experienced observer, who still needs to contend with the task of documenting observations with enough accuracy and detail to allow comparison with future observations. This highlights the challenge in achieving a balance between feasibility and comprehensiveness during the evaluation of dexterity.

The need to document movement patterns of the hand in a functional and anatomically meaningful way led to the emergence of grasp classification systems (Napier, 1956). Napier(1956, p. 902) created a prehension classification system, classifying movement of the hand into "*prehensile movement*-movements where an object is seized or held partly or wholly within the compass of the hand; and *non-prehensile movement*-or movement in which no grasping or seizing is involved but by which objects can be manipulated by pushing or lifting motions of the hand as a whole, or of the digits individually." Napier(1956, p. 903) then divides *prehensile movements* into; 1) *power grip* where the "object is held in a clamp formed by partly flexed fingers and the palm, counter pressure being applied by the thumb lying more or less in the plane of the palm”, and 2) *precision grip* where the object is “pinched between the flexor aspects of the finger and the opposing thumb”.

Napier’s system was then adapted and refined by Landsmeer (1962) who suggested the term *precision handling* instead of grip, to reflect its purpose, which is to allow the manipulation of the objects freely between the tips of the fingers, thus only exerting minimal force. Grasp pattern systems have since evolved through the work of researchers like Kapandji (1982), and Cutkosky(1989) including a higher number of grasp patterns, each with more precise anatomical configurations. In 2015, Feix, Romero, Schmiedmayer, M. Dollar, & Kragic (2015), aiming to create a comprehensive common language for research in hand dexterity, compared different grasp taxonomies and synthesized them to form the GRASP Taxonomy, consisting of 33 different grasp patterns. Similar work was done by Bullock, Ma, & Dollar (2013), to develop a hand-centric manipulation taxonomy which attempts to describe “non-prehensile” and “in-hand” manipulation patterns.

Movement pattern taxonomies have been used to explore the variety and frequency of occurrence grasp patterns in daily life (Vergara, Sancho-Bru, Gracia-Ibáñez, & Pérez-González, 2014). These studies can be used as a basis to examine whether a movement during a task is accurate and effective. However, the PBOMD are simulations of daily activities and are not the exact task themselves, thus whether these patterns can be generalized beyond the PBOMD is not known. There has been little focus on describing the grasp patterns used to handle objects in PBOMD (many of which do not restrict the test taker to a specific pattern of movement). Finally, the hand does not function in isolation; it has been recognized that abnormal movement patterns can occur at other joints in the body, thus ideally, patterns of movement exhibited by the whole body need to be considered during the assessment (Bisset, Russell, Bradley, Ha, & Vicenzino, 2006).

The use of technology such as three-dimensional motion-capture, electromyography signal processing, and the generation of sophisticated biomechanics models of the hand that allow the mapping of complex hand movements (Metcalf et al., 2014) may be the answer to measuring the accuracy, efficiency and effectiveness of task execution, however to my knowledge, these methods are not commonly used in daily clinical practice and thus, are beyond the scope of this thesis.

1.1.5 Value of Dexterity as a Construct

As dexterity is the expression of the skill at performing tasks,motor control and its association with the hand, it has been used as an indicator of cognitive function (Kobayashi-Cuya et al., 2018; Vasylenko, Gorecka, & Rodríguez-Aranda, 2018). It is used by engineers as a benchmark for the development of sophisticated mechanical hands (Salvietti, 2018). In addition, dexterity has been associated with quality of life in different clinical populations (McEwen, Mayo, & Wood-Dauphinee, 2000; Verma, Parikh, Nadkar, & Mehta, 2017).

1.1.6 Epidemiology of Hand Conditions and Impact of Dexterity Impairments

Unlike medical interventions which focus on direct management of the biological processes driving various medical conditions, rehabilitation is concerned with the consequences of these conditions (Stucki & Kroeling, 2000). Studies examining the loss of the ability to manage tasks with the hand suggest that this may be a common and potentially disabling issue (Bizier & Statistics Canada, 2016; Public Health England, 2017; Taylor, 2018).

Direct injuries to the hand are one of the major potential reasons for loss of dexterity (de Putter et al., 2012; Trybus, Lorkowski, Brongel, & Hl'adki, 2006). A study on the consequence of hand injuries found that 58.5% of persons treated for hand injuries had a hand impairment of variable severity (Trybus et al., 2006). A study done in the Netherlands and Denmark reported that hand and wrist injuries accounted for 29% of emergency department visits (Larsen, Mulder, Johansen, & Larsen, 2004). Examining the incidence rates of upper limb injuries from 1986 to 2008, Polinder, et al., (2013) demonstrated that the incidence of hand and wrist injuries had been steadily increasing over time, with the highest incidence occurring in young persons and elderly women. These injuries tend to be prominent in young and otherwise healthy adults, with the majority of the economic burden of these hand and wrist injuries relating to the loss of productivity rather than direct-health care expenditure (de Putter et al., 2012; Siotos et al., 2018). De Putter et al. (2012) estimates that hand and wrist injuries cost society $740 million annually, making it the most expensive type of injury.

Loss of dexterity can manifest due to non-traumatic health issues. These can include ageing, repetitive stress injuries (Tjepkema, 2003); common chronic conditions like osteoarthritis, rheumatoid arthritis, diabetes mellitus and systematic sclerosis (Poole, 2011). Loss dexterity is also common sequela of neurological insult (Keng-He, S.G, & Jeanette, 2011; Pohar & Allyson Jones, 2009).In addition, studies suggest that repetitive strain injuries of the hand are common in a variety of vocations like homemaker physicians, musicians and athletes (Austin et al., 2019; Kok et al., 2018; Kox et al., 2018; Yang & Cheung, 2016). The measurement and management of dexterity loss should, therefore, be relevant and responsive to the different needs of persons with diverse conditions, age groups and vocations.

1.2 Measurement of Dexterity of the Hand in Healthcare

1.2.1 Measurement of Outcomes in Healthcare

Measuring outcomes is part of the quality control process that helps determine the value in health care created for the patients, payers and other stakeholders (Nichol, 2006). This quality improvement process eliminates unwanted ‘variance’ in treatment results and works towards the improvement of delivered care(Daum, Brinker, & Nash, 2000). Porter (2016), suggested that outcome measures should include functional outcomes in order to reflect the ‘value’ to patients accurately. Outcome measures can help support clinical decision making by describing a person’s attribute at the current moment in time, evaluate changes in a person’s attribute across time, distinguish different groups of persons or to predict prognosis or results of another test (Kirshner & Guyatt, 1985). The value of outcome assessment is supported by research associating the routine use of standardized functional outcome measures to improved clinical decision making (Colquhoun et al., 2017), patient outcomes and patient satisfaction(Kotronoulas et al., 2014).

1.2.2 The Measurement of the Patient’s Ability to Perform Activities and Participate in Daily Life.

Dexterity is defined as the ability to solve motor problems successfully (Bernstein, 1996). We consider dexterity to be an unseen complex theoretical construct. Constructs, as defined by Slaney (2017), are a class of theoretical concepts used to denote phenomenon and/or relations between phenomena. These constructs are “created, specified, defined and used by humans, and thus are human-dependent” (Slaney, 2017, p. 223). In this thesis, I subscribe to Messick’s (1981, p.583) constructivist-realist view that “while some constructs may have a counterpart reality in the person, the situation, or the interaction, other constructs may be applied as “heuristic devices for organizing observed relationships with no necessary presumption of real entities underlying them." These unseen constructs cannot be directly measured the same way we measure length or weight.

Feigl (1950), suggests that while constructs like dexterity have ascribed meaning that cannot be expressed through observable properties, we can study them as a "network"; mapping the relationships amongst directly observable properties and indirectly testable properties. These theoretical constructs can then be confirmed by examining the relationships and magnitudes of directly observed properties to assigned indirectly testable properties (Feigl, 1950). It is through these observable properties that we measure dexterity, and the construct validity of the measure is evaluated (Cronbach & Meehl, 1955).

According to the COnsensus-based Standards for the selection of health Measurement Instruments initiative (COSMIN), the most important measurement property in a health-status measure is content validity (Terwee et al., 2018). COSMIN defines *content validity* as "the degree that the content of a measurement instrument is an adequate reflection of the construct to be measured" (Mokkink et al., 2010, p. 748). This was explicitly separated from *construct validity* (psychologists on the panel considered content and construct validity the same thing) which they defined as "the degree to which a score of a measurement instrument is consistent with hypotheses (for instance with regard to internal relationships, relationships to scores of other instruments, or differences between relevant groups) based on the assumption that (outcome measure) validly measures the construct to be measured"(Mokkink et al., 2010, p. 748).

COSMIN recommends that the aspects of content validity that needs to be considered include *comprehensiveness* (whether the instrument covers all aspects of the construct), *relevance* (whether the items on the instrument are relevant to the construct and targeted population, and finally *comprehensibility* (whether the items can be understood by the target population) (Terwee et al., 2018). This is congruent with the process of content validation proposed by COSMIN, which is to clearly elaborate the theoretical background and conceptual model, target population as well as the purpose of the measurement instrument (Mokkink et al., 2010). This means that an outcome measure seeking to measure dexterity should ideally cover all attributes of dexterity listed by Bernstein and address a range of tasks relevant to the population in question. This can be a challenging endeavour given the breadth of the tasks available and the heterogeneity of acceptable human performance.

There are two commonly used approaches to operationalize dexterity: *performance-based outcome measures* administered by a rater or *patient-rated outcome measures* where the patient gives their opinion about their current status (de Vet, Terwee, Mokkink, & Knol, 2011). The result of both approaches reflects different constructs. Patient-rated outcome measures reflect the patient's perception of their current status, while performance-based outcome measures reflect the patient's demonstrated ability judged against an external criterion (de Vet, Terwee, Mokkink, & Knol, 2011). Research studies comparing both approaches in musculoskeletal injuries confirm that these two approaches measure different constructs, and suggest that both have different roles to play in patient management(Bean, Ölveczky, Kiely, LaRose, & Jette, 2011; Michener, 2011; Mizner et al., 2011; Nazari, Shah, MacDermid, & Woodhouse, 2017). These studies found that performance-based outcome measures are more responsive than patient-rated outcome measures in the acute phase of an injury, are less subject to a ceiling effect and have stronger relationships with impairments other than pain (Bean et al., 2011; Bolink, Grimm, & Heyligers, 2015; Michener, 2011; Mizner et al., 2011).

1.3 Operationalizing Dexterity of the Hand in the Rehabilitation of Persons with Hand and Wrist Injuries.

1.3.1 Current Measurement Trends in Clinical Practice

Despite the increasing number of campaigns to encourage the use of standardized outcome measures, and positive sentiments around the use of standardized outcome measures (Jette, Halbert, Iverson, Miceli, & Shah, 2009), clinicians have been slow to adopt performance-based outcome measures of dexterity and hand function (PBOMD). Surveys of assessment practices of therapists working in hands and upper limb rehabilitation show that most clinicians do not routinely use PBOMD (de Klerk, Buchanan, & Pretorius, 2015; Grice, 2015).

Grice (2015) through a series of closed and open-ended questions about the use of occupational-based outcome measures by hand therapists, identified that participants who did administer occupational-based outcome measures found them useful for developing treatment goals, determining interventions to use, and measuring change to justify services. However, the vast majority of therapists did not use these measures, citing environmental barriers like “time constraints,” “lack of familiarity with assessments” and lack of access to assessments (de Klerk et al., 2015; Grice, 2015, p. 302). Despite the reported limitations to using standardized tests, therapists did assess the ability to perform tasks. Grice (2015) identified that most participants reported evaluating the patient’s ability to perform daily activities primarily through informal interviews with their patients; few therapists assessed performance by observing their patients executing the activities. The limited use of observation of task performance is surprising, as this represents a disconnect between the value reported in the literature about the use of standardized performance-based assessment (listed earlier) and is contrary to the popular belief that observation of task performance and/or movement is a core aspect of rehabilitation focused assessments (Bernhardt, Bate, & Matyas, 1998; Law, 1993).

This shift in practice patterns could be due to issues with the instruments themselves, the congruence of the instruments with clinicians and their working environment, or could be an indication that these observations are not considered a standalone assessment. These observations could be implemented informally, for instance, in the same way, that therapists working in geriatrics, unofficially supplement their standardized assessments with their clinical observations of their patient's performance (Krohne, Torres, Slettebø, & Bergland, 2014).

Understanding what influences a clinician's decision to use a performance-based outcome measure or choose to observe a patient's performance is very complex. The theory of planned behaviour by Fishbein & Ajzen is one of the theories explaining the factors influencing rational behaviour choice (Fishbein & Ajzen, 2010). The theory of planned behaviour suggests that the primary determinant of the behaviour actually occurring is the intention to perform the behaviour, which in turn is a product of 1) the person's *attitudes towards the behavior;* 2) *subjective norms* of the person's referent group towards the behaviour; and 3) *Perceived behavioural control* that the person has over actually performing behaviour (Fishbein & Ajzen, 2010). While this is a useful structure to consider the low use of PBOMD, the theoretical sufficiency of the theory of planned behaviour has been called into question, with the theory failing to explain a large percent of the variance in targeted behaviour (Gold, 2011). In addition, the decision to use a PBOMD may be influenced at a system level by the clinicians' health care system, organization or professional organization; thus I decided that solely focusing on elements of the theory of planned behaviour may result in overlooking and misrepresenting the true reasons for the low use of PBOMD.

The possible reasons for low use of PBOMD in the clinical setting may lie within 1) the interactions between the tools, users and practice environment; 2) the lack of in-depth understanding about how dexterity is being assessed in practice, and 3) the significance PBOMD plays in patient care. As such, I feel that a qualitative approach is the most appropriate approach to this question. A qualitative approach prevents the loss of complexity and context, allowing for the exploration of possible reasons for the low use of PBOMD (Atieno, 2009).

1.3.2 Overview of Performance-based Measurement Instruments Addressing Dexterity

Another question that needs to be addressed is how the conceptually complex construct-dexterity is measured in health care measurement instruments. Reviews on the PBOMD, try to separate the concepts of ‘dexterity’ from ‘hand function,’ however, there appears to be overlap in what is considered a measure of ‘dexterity’ or ‘hand function’ (Schoneveld, Wittink, & Takken, 2009; Van de Ven-Stevens, Munneke, Terwee, Spauwen, & van der Linde, 2009; Wang et al., 2018; Yancosek & Howell, 2009). Overall, there appears to be lack of studies supporting the psychometric properties of the PBOMD, and a large variety in the way dexterity is operationalized (Schoneveld et al., 2009; Van de Ven-Stevens et al., 2009; Wang et al., 2018; Yancosek & Howell, 2009).

Van de Ven-Stevens, et al.(2009, p. 151) adopting the ICF, broadly classified the PBOMD into three categories: “1) pegboard tests measuring fine hand use only; 2) instruments measuring fine hand use only by picking up, manipulating, and placing different objects; and 3) instruments measuring single tasks (and fine hand use) by scoring task performance". The content validity and construct validity of the identified tools were judged to be lacking, and the anticipated relationships between the associated constructs were not clearly verbalized by studies evaluating the construct validity of the PBOMD (van de Ven-Stevens et al., 2009). Echoing these assertions are Wang, et al.(2018) who classified the PBOMD that could be potentially used by persons who have undergone an amputation, by three different characteristics: 1) movement planes assessed, 2) types of grasp patterns used, and 3) whether results were quantified by time or quality of movement. They concluded that validated PBOMD might not "adequately address all necessary aspects of functional restoration" (Wang et al., 2018, p. 959).

Recently, there have been efforts to develop a core outcome set for assessment tools for impairments and activity limitations for patients with hand conditions (Ven-Stevens et al., 2015). However, the invited experts were unable to reach consensus on observational instruments for categories 'fine hand use' and 'hand and arm use' due to differences in personal preferences (L. Ven-Stevens et al., 2015).

The difficulty in evaluating the validity of these measures may suggest that there is a lack of clarity about dexterity. If so, there may be value in comparing the constructs measured by dexterity outcome measures with theoretical concepts put forth by Bernstein and other researchers. Finally, acknowledging that the theoretical constructs are socially constructed, there is a need to reflect on what dexterity means today and examine which constructs are useful in facilitating patient care.

1.4 A Qualitative Approach to Exploring the Measurement of Dexterity in Hand and Upper Limb Rehabilitation

1.4.1 Qualitative Inquiry in Health Care and Rehabilitation

Qualitative inquiry had its roots in ancient Greece in the descriptive reports of nature and medicine by Aristotle and Galen of Pergamon, it declined during the age of enlightenment with the emergence and popularity of quantitative inquiry, only to gain a resurgence in the fields of anthropology in the late 1900s (Frederick, 2011). A similar resurgence is happening in rehabilitation, with an increase in the number of qualitative studies being published in the recent 20 years (VanderKaay et al., 2018). This increase comes with the recognition within the health care community that qualitative inquiry can answer complex questions about clinical reasoning and human behaviour, as well as the experience of living with a disability (VanderKaay et al., 2018). This analysis is not intended to set up a dichotomy between quantitative and qualitative research, but a statement that the choice between the research paradigm depends on the question being asked by the researcher (Atieno, 2009).

As we are seeking to gain a rich understanding of how therapists measure dexterity in hand and upper limb rehabilitation; including their perceptions of the nature of dexterity and value of PBOMD, the choice of qualitative methodology makes the most sense. Similarly understanding how dexterity is defined by outcome measures acknowledges that dexterity is socially constructed and thus is subject to interpretation. The question then would be which interpretation provides the most useful predictions in clinical practice.

1.4.2 Epistemology- Setting the Stage for Study Design and Methods

Schwandt (2001, p. 201) defines epistemology as “the study of knowledge and justification,” representing how knowledge is created and how we acquire this knowledge. Carter & Little (2007) assert that your epistemology guides the choice of methodology and methods, and the internal consistency between the methodology, methods and epistemology serves as a judge of the rigour of qualitative research. For the purpose of this thesis, I have adopted a constructivist epistemology. Constructivism is a view that “Knowledge and truth are created, not discovered by the mind”(Schwandt, 1998, p. 238).

Adopting a constructivist perspective, I believe that:

1) What we label as dexterity is a socially constructed concept used to identify and explain phenomena that we see in the real world. Hence, there may be varying ideas about what constitutes dexterity, and these ideas may change over time depending on the social, temporal and institutional context. The usefulness of these different constructs is, in part, what we are trying to explore in this research.

2) Each clinician measuring dexterity has a unique circumstance and experience that has led to their perception of the construct and PBOMD.

These assumptions will frame the way I understand and draw useful insights into the measurement of dexterity. The methodologies and methods I have chosen to use in my thesis were designed to be congruent with these beliefs. As a result, the practices designed to verify the “truth” and “accuracy” of interpreted meaning (such as member checking and inter-rater reliability scores like kappa) were not used. Where disagreement arose between the team members/participants, I sought to understand and examine their reasons and perspective. Thus, achieving consensus was not about choosing the perspective of the majority, but about clarifying different perspectives and negotiating the best way to represent our shared understanding.

1.4.3 Interpretive Description

In the first study, Interpretive Description (ID) was chosen to explore the perception of occupational therapists on the measurement of dexterity. ID was created by Sally Thorne (a nurse and researcher) to understand clinical phenomena, with the end goal of yielding findings that have implications for clinical practice (Thorne, Kirkham, & MacDonald-Emes, 1997). Thorne recognized that clinicians do not exist in a theoretical vacuum, and the knowledge and expertise that they have could be used as a starting point for qualitative inquiry (Thorne et al., 1997). An inductive approach to qualitative inquiry, ID accounts for these characteristics while lending credibility and legitimacy to applied health qualitative research (Thorne et al., 1997).

Borrowing from the traditions of phenomenology, grounded theory, ethnography and naturalistic inquiry, ID emphasizes:

1) purposive sampling to achieve diversity of opinion

2) concurrent data analysis and collection

3) triangulation of data sources (Thorne, Kirkham, & O'Flynn-Magee, 2004).

The product of the method is a co-constructed 'tentative truth claim' about a phenomenon (Thorne et al., 2004). Constant comparison analysis originating from grounded theory methodology was used to inform the analysis process. Constant comparison analysis aims to generate theoretical abstraction of social phenomena by iteratively comparing data to other pieces of data, and inductively reduce raw data into increasingly abstract, meaningful, categories/themes (Glaser & Strauss, 1967).

1.4.4 Content Analysis

Drisko & Maschi (2015, p. 7) define content analysis as "a family of research techniques for making systematic, credible, or valid and replicable inferences from texts and other forms of communication." Content analysis began in political advocacy, sociology and journalism as the analysis of the literal meaning of the written word (Drisko & Maschi, 2015). Starting with methods like counting the frequency of words present in the text, it has since evolved to include the use of statistical analysis and inductive interpretation of the text, to account for contextual and latent meaning (Drisko & Maschi, 2015).

While there are many ways to classify content analysis we have chosen to adopt the Hsieh & Shannon's three-category classification of content analysis: 1) conventional content analysis where categories are developed inductively from examination of the text 2) directed content analysis where prior theory is used to determine the initial coding structure and relationship between codes and 3) summative content analysis which focuses on inferring the underlying meaning of a word from its context (Hsieh & Shannon, 2005). All three approaches explore data using a primarily naturalistic inquiry paradigm, the primary difference being the way the initial coding scheme is derived (Hsieh & Shannon, 2005).

1.4.5 Rigour/trustworthiness in Qualitative Inquiry

In qualitative inquiry, the researcher is the instrument of analysis, collection and generation of insights. Criteria and their accompanying strategies were introduced by Guber and

Lincoln in the 1950s, to ensure the methodological strength of qualitative studies and to foster confidence in qualitative research (Lincoln & Guba, 1985).

These criteria include the use of reflective memos, negative case analysis, audit trails, triangulation and peer debriefing (Morse, 2015). Given that ID is a co-constructed 'truth claim' and that participant observation and unstructured intervention were not used, the qualitative study featured in this thesis excludes the use of member-checking, prolonged engagement as these strategies do not add to the rigour of the study.

Dependability strategies such as sending summaries of findings to the participants and getting their opinions about the interpretation were done to create data overlap and allow for verification of the data set internally (Morse, 2015). Triangulation of data sources, peer debriefing and negative case analysis were used as primary strategies to establish credibility in the study(Morse, 2015). Reflexive memos and field notes were used extensively, and audit trails were created to maintain objectivity.

1.5 Current Gaps in the Literature

1.5.1 Lack of Consensus on How to Measure Dexterity

Currently, there is a lack of conceptual clarity about dexterity. The terms 'dexterity' and 'hand function' appear to be used interchangeably and inconsistently in reviews of performance-based outcome measures (Schoneveld et al., 2009; Van de Ven-Stevens et al., 2009; Yancosek & Howell, 2009). The lack of semantic clarity may result in miscommunication among clinicians and misinterpretation of research on dexterity.

There is also a lack of consensus about the best way to measure dexterity potentially due to the difficulty establishing content validity because of 1) the wide scope of tasks needed to represent the diverse roles of the hand adequately; 2) the lack of a uniformed and objective benchmark of what constitutes a successful performance of a task. There is also a lack of studies supporting the psychometric properties of these PBOMD (Schoneveld et al., 2009; L. A. van de Ven-Stevens et al., 2009; Yancosek & Howell, 2009).

1.5.2 Incomplete Understanding of Why Clinicians do not Use PBOM

Current practice surveys highlight the poor usage of PBOMD (de Klerk et al., 2015; Grice, 2015). Clinicians report having factors like the lack of time, awareness and familiarity with measures as a reason for non-use (Grice, 2015). However, it is observed that most clinicians measure the ability to perform a task through informal interviews, with very few clinicians observing the performance tasks (Grice, 2015). The reported lack of use of direct observation to assess the task performance of a patient is not congruent with the perceived importance of task/movement observation in clinical judgement, and the understanding that self-report task performance is a different construct from observed task performance(Law, 1993; Mizner et al., 2011).

1.6 Thesis Goals and Objectives

My thesis aims to study the measurement of dexterity in the rehabilitation of persons with hand and wrist conditions (HWC), in order to contribute to the measurement practices that support patient care and service delivery for persons with musculoskeletal hand and wrist injuries. The specific objectives are:

1) To explore the perceptions of occupational therapists working with persons with HWC in Singapore regarding the measurement of PBOMD and the measurement of dexterity, to generate recommendations for clinical practice.

2) To explore the purpose and constructs measured by PBOMD (validated for use in persons with HWC) to understand how the concept and measurement of dexterity and hand function have changed over time.

3) To explore and examine how dexterity and hand function is operationalized by PBOMD (validated for use in persons with HWC) in comparison to theoretical concepts of dexterity and function, to serve as a foundation to evaluate content validity.

1.7 Composition of Thesis

This thesis is composed of four chapters. Chapter 1, *Introduction*, provided an overview of literature; introduced the qualitative inquiry methods and methodologies used; addressed how my position influences the execution and choice of methods; and explained the overall aims and objectives of this thesis.

Chapter 2 is titled *Measuring the elusive: A qualitative exploration of therapists' perceptions on the measurement of dexterity in hands and upper limb rehabilitation.* This chapter uses interpretive description to explore the practices and perceptions of occupational therapists in Singapore around the measurement of dexterity in order to generate recommendations to facilitate measurement of dexterity in clinical practice.

Chapter 3 is titled *Performance-based outcome measures of dexterity and hand function in persons with hand and wrist injuries: A structured review of measured constructs*. Systematic search strategies and processes were used to identify PBOMD validated for use with persons with HWC. Content analysis was used to inductively explore the purpose of each PBOMD and how dexterity and hand function was defined. The items and scoring criteria of the PBOMD were compared to theoretical concepts of function and dexterity. Study findings provide an overview of current PBOMD and can serve as a basis to judge content validity and raise awareness regarding the shifting concept of dexterity.

Finally, Chapter 4, *Discussion and Conclusion* presents an overview of the thesis; lay summaries of Chapter 2 and 3; discusses the main themes emerging from the synthesis of research done in this thesis; overall limitations of the thesis; and suggests practice implications and knowledge translation recommendations.

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2 Chapter 2-Measuring the elusive': A qualitative exploration of therapists' perceptions on the measurement of dexterity in hands and upper limb rehabilitation

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Abstract

Background: There is low usage of standardized performance-based outcome measures of dexterity and hand function (PBOMD) by therapists working in hands and upper limb rehabilitation despite evidence supporting the use of standardized outcome measures.

Purpose: This study aims to explore what influences the use of PBOMD by occupational therapists practicing in hand and upper limb rehabilitation in Singapore.

Methods: A qualitative, interpretive description approach was used to explore therapists' perceptions of and experiences with PBOMD. Semi-structured interviews were conducted with a purposive sample of 12 therapists from Singapore. Interview transcripts were analyzed in an inductive process of identifying key themes.

Findings: The study identified three themes. The first was dexterity as an 'elusive construct' associated with conceptual ambiguity and the lack of visibility of dexterity in practice. The second theme was "operationalizing dexterity is contentious' reflecting the diverse opinions around measurement approaches. Finally, 'standardized measures as a low-yield investment' reflecting a reluctance to spend time on the situation-dependent benefits of PBOMD.

Implications: Conscious reflection by therapists on operationalizing dexterity and awareness of efficient test procedures may improve measurement practices around dexterity and increase the utility of PBOMD in daily clinical practice.

2.1 Introduction

Dexterity is defined by Bernstein (1996, p.228) as the "ability to find a motor solution for an external situation, that is to adequately solve an emerging motor problem accurately, quickly, rationally and resourcefully." The authors recently suggested an adaptation of Bernstein's definition for use in rehabilitation given the focus on functional movement, defining dexterity, "the coordination of voluntary movement to accomplish an actual or simulated functional goal/task accurately, quickly, resourcefully and adapting to environment or change" (Yong, MacDermid, & Packham, 2019, p. 4).

A census conducted in 2016 in Canada, revealed that dexterity impairment was the fifth most common type of impairment (Bizier & Statistics Canada, 2016). The loss of dexterity is associated with common musculoskeletal conditions (Nazari, Shah, MacDermid, & Woodhouse, 2017; World Health Organization, 2018), and has been known to reduce accumulated wealth and participation in life roles (World Health Organization, 2018). The high prevalence and impact of dexterity is not limited to Canada and has been found in other developed countries (Public Health England, 2017; Taylor, 2018), making it a global healthcare issue.

In order to address dexterity in clinical decision making and program development, an accurate assessment is needed (Michener, 2011). Standardized outcome measures, in conjunction with subjective clinical judgement, have been suggested to provide more precise and valid information on clinical progress than clinical judgement alone (Colquhoun et al., 2017). This increased precision may aid clinical decision making and improve client outcomes (Colquhoun et al., 2017). Outcome measures can be broadly divided into patient-rated and clinician-rated (performance) outcome measures. Research suggests that they evaluate different aspects of the effect of treatment and thus have different and complementary functions (Michener, 2011).

Much research has been done in the field of knowledge translation to encourage the use of outcome measures and increased usage of patient-rated outcome measures (PRO) of disability and participation (Valdes et al., 2016). However, there has been very little increase in the use of performance-based outcome measures of dexterity and hand function (PBOMD) compared to PRO of disability and participation, in clinical practice by therapists working in hands and upper limb rehabilitation (de Klerk, Buchanan, & Pretorius, 2015; Grice, 2015).

We need to uncover the reasons for the low usage of dexterity outcome measures. It is possible that PBOMD are antiquated tests with limited value, are only useful in a very restricted set of circumstances, or not used because of barriers to implementation in practice. Currently, studies exploring the phenomena of low use of outcome measures in hand and upper limb rehabilitation are not specific to PBOMD and are mainly descriptive surveys (de Klerk et al., 2015; Grice, 2015). These studies focused on environmental factors such as lack of time and availability of the tool as reasons for poor use of outcome measures. However, studies looking at outcome measures used in other patient groups have suggested a myriad of other reasons including lack of cultural relevance, lack of knowledge and organizational barriers (Demers et al., 2019; Odole, Odunaiya, Ojo, & Akinpelu, 2018). Given the diversity and complexity of clinical practice, a qualitative, exploratory approach has the potential to provide valuable insights into the forces that shape therapists' clinical decisions. These insights can, in turn, inform integrated knowledge translation designed to improve assessment practices in hand and upper limb rehabilitation.

2.2 Study Purpose

This study aims to explore the perceptions of occupational therapists working in hand and upper limb rehabilitation in Singapore regarding the measurement of dexterity and the use of PBOMD.

2.3 Methods

An interpretive description (ID) approach was used to guide the data collection and analysis process. ID is an inductive analytic approach developed by Thorne, Kirkham, & MacDonald-Emes (1997) for use in applied clinical fields. ID applies key principles and strategies from traditions of phenomenology, ethnography, naturalistic inquiry and grounded theory to understand clinical phenomena and generate application implications (Thorne et al., 1997). This approach emphasizes explicit acknowledgement of the researcher's theoretical framework at the outset of the project so that it can be consciously challenged and examined throughout the iterative process. (Thorne et al., 1997).

2.3.1 Researcher's Perspective and Context

The primary investigator has an 'insider perspective' since he worked for three years as an occupational therapist providing hand and upper limb rehabilitation services at an outpatient rehabilitation centre at a general hospital in Singapore. He subscribes to a constructivist epistemology-believing that truth is created and relative to each individual (Schwandt, 1998), and a perspective on clinical practice informed by the Theory of Planned Behaviour (Fishbein & Ajzen, 2010).

The practice context for the research focused on both private and public hand therapy clinics based in Singapore. Hand therapy focuses on the rehabilitation of injuries and conditions of the upper extremity and is traditionally a role performed by Occupational therapists and Physiotherapists after advanced certification (American Society of Hand Therapists, 2018). In Singapore, this role is primarily performed by Occupational therapists, who receive on-the-job training after completing their basic professional qualifications. Most of these therapists work in hospitals as well as private practice. Public health care may be partially funded by the government while private practices require payment from the patient or a third party (e.g. insurer)

The private centres typically deliver hand therapy using one-to-one sessions. The public hospital has overlapping consultation meaning therapists provide dedicated consultation time of about 15 to 20 minutes with each patient, following which patients complete prescribed exercises independently and/or are provided with a therapeutic modality like a hot pack or electrical stimulation. The therapist then attends to other patients, while patients complete their independent program.

2.3.2 Participants

Occupational therapists were eligible for participation if they had a valid practising license and were working primarily with patients with orthopedic and musculoskeletal hands and upper limb injuries in Singapore for at least one year during the study recruitment period of August 2018 to January 2019. Clinicians were recruited through managers of rehabilitation centres who disseminated electronic invitations, as well as through snowball sampling where clinicians recruited their acquaintances that met the inclusion criteria. This approach also facilitated purposive sampling, maximizing diversity with respect to years of experience and practice setting.

Ethical approval was obtained from Singhealth Centralised Institutional Review Board (CIRB 2018/2568) and the Hamilton Integrated Research Ethics Board (2018-5145-GRA). Informed consent was obtained from clinicians prior to commencing data collection, and data was de-identified for analysis.

Twelve occupational therapists were recruited (see table 1 for an overview of participant characteristics). Clinicians came from private centres and public hospitals, with most therapy sessions lasting 30 to 60 minutes.

Table 1: Overview of participant characteristics

Characteristics	Number of participants
Practice setting	
Private centre	2
Hospital	10
Years of experience in hand and upper limb rehabilitation	
1-3 years	1
3-5 years	3
5-8 years	2
>8 years	6
Frequency of PBOMD use	
Less than once a year	6
Several times a year	5
Several times a month	1

2.3.3 Data Collection and Analysis

Semi-structured interviews lasting 75-120 minutes were the primary mode of data collection. The principal investigator conducted interviews based on a semi-structured interview guide (refer to Appendix A for interview guide) and allowed clinicians the flexibility to discuss topics that arose spontaneously. Following the interviews, clinicians were shown video clips of three different dexterity outcome measures and asked to give their opinions on the tests. Interviews were audio-recorded with a digital audio recorder and transcribed verbatim. Field notes were written by the principal investigator to capture salient points during the interviews.

Clinicians were also asked to complete a reflective diary to explore whether discussing the topic had changed their perceptions. Diaries were to be submitted by clinicians if they had additional insights on the topic.

Data collection and analysis were done concurrently, and data was coded and analyzed through an iterative process of constant comparison which involves comparing pieces of data within and across interviews to identify patterns and connections (Charmaz, 2015). NVivo version 12 plus (QSR International, 2019) was used to facilitate data management and analysis.

Recruitment was concluded when data sufficiency was reached; identification of rich, consistent themes which sufficiently addressed the study aims.

2.3.4 Rigour

Throughout the study, reflexivity was practiced by the primary researcher, using strategies such as reflective logs, and iterative review of the data (Berger, 2015). Triangulation of data methods (interview, video-elicitation, and diaries) was used to enhance trustworthiness by forming a fuller understanding of the perceptions on measuring dexterity (Farmer, Robinson, Elliott, & Eyles, 2006) and increase familiarity and knowledge on PBOMD among therapists. In addition, iterative reviews of de-identified data and emergent themes were conducted by the research team.

Summarized findings were sent to clinicians immediately after interviews were coded, and at the end of the study, after the final analysis to create opportunities for clinicians to contribute additional ideas and to strengthen the credibility of interpretation of the data (Birt, Scott, Cavers, Campbell, & Walter, 2016). Feedback and thoughts from clinicians were used as a form of peer debriefing to re-examine the interpretation of data critically.

2.4 Findings

Three overarching themes were identified. The first focuses on dexterity as an 'elusive construct.' This theme was evident in comments about the ambiguous and complex nature of dexterity when therapists were asked to define the term. The second theme, 'operationalizing dexterity is contentious' reflects the diverse approaches that clinicians adopt when measuring dexterity in a clinically meaningful way. Finally, 'low-yield investment' relates to clinicians' comments about the challenges of making time for PBOMD, and how PBOMD was viewed useful only under specific circumstances. (See fig. 1 for a visual representation of findings)

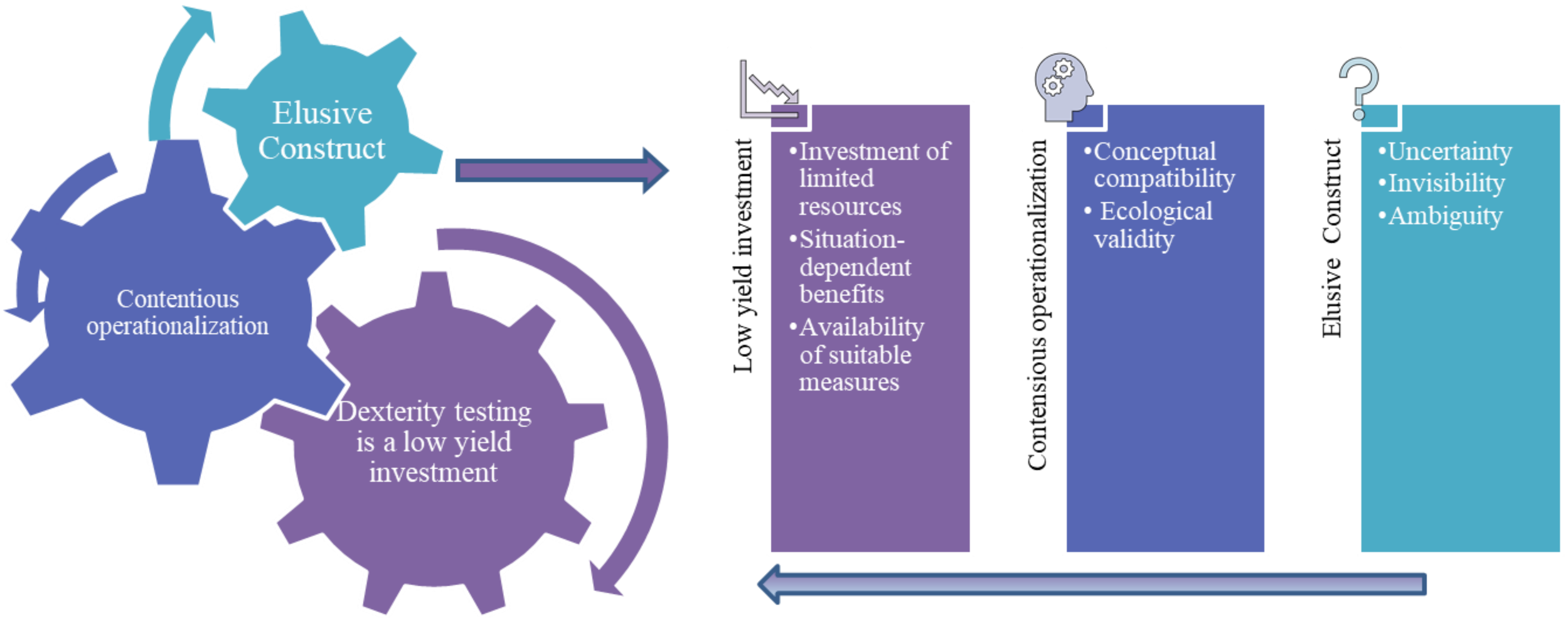

Fig 1: Identified themes surround the measurement of dexterity in hands and upper limb rehabilitation

2.4.1 Dexterity as an Elusive Construct

When asked to provide a definition of dexterity and explain how they assess dexterity in their practice, many of the clinicians' comments reflected the lack of clarity and 'elusive' nature of the construct. Uncertainty, invisibility and lack of consensus regarding the core elements of dexterity were evident.

2.4.1.1 Uncertainty

Dexterity was not an easily defined concept to clinicians. When asked to define dexterity, many had to think for some time before replying. Some clinicians were reluctant to claim that their definition of dexterity was definitive, using phrases like "when I think of dexterity, I think of…" (OT4) or "that's my own definition" (OT9). One clinician even expressed the lack of belief that there was even a conclusive definition. "Yup… There must be thousands of definitions" (OT3). A couple of clinicians had a vague impression of what dexterity was and had to find their personal definition of the concept during the interview. "When you talk about what dexterity is, it suddenly kind of makes me realize I don't really know what dexterity is" (OT5).

2.4.1.2 Invisibility

Many clinicians reported that dexterity was seldom discussed directly in clinical practice. Clinicians reported that official procedures for treatment protocols, clinical guidelines, and documentation forms did not include the measurement of dexterity. Clinicians who were assisting in research reported similar trends with ongoing research protocols. This absence of focus on dexterity appeared to reduce the awareness of clinicians. As one clinician confessed when asked about the documentation forms used at the workplace:

> "So, we need to write…reduced range of motion, reduced weakness, and then the next part of the documentation is treatment. Then that's all. There is no column for dexterity (laughs), so if it's not stated, we just…we will not look at it". (OT05)

Given the broad range of tasks and dimension covered by dexterity, some clinicians choose alternative terms to discuss skill at executing the task. As one clinician commented:

> "We have not been using this word (dexterity)…I don't really talk about dexterity; even the surgeons don't talk about dexterity, we really talk about functional things like patients are able to do this, the patient is not able to do that." (OT5)

Since the term was not part of the shared lexicon in the organization, there was limited visibility and awareness of dexterity as a key part of the assessment process.

2.4.1.3 Ambiguity

Another challenge seemed to be the lack of consensus regarding the core elements of dexterity. Most clinicians referred to dexterity as the "ability" (OT1) or "skill at executing tasks" (OT8), which encompasses the way the task is performed or "how (patient) use their hands" (OT4). Clinicians felt that dexterity is built on a "combination of these factors (body functions like strength, coordination)" (OT10), but the interaction between the factors was not well understood. One clinician commented:

> "Dexterity is a component that is an overlap of a little bit of everything but is not entirely it (sum of dexterity's parts)" (OT02)

There were, however, differences in opinion regarding what qualified as dexterity. Three clinicians, for example, distinguished 'fine' dexterity involving fine motor movements, such as prehensile actions of the thumb, index and middle fingers or 'manipulating things in hand'

(OT07), from ‘gross’ dexterity involving movements which used the entire hand to synergistically ‘grasp’ an object. Another clinician limited dexterity to tasks that involved precision control of the hand. In contrast, two clinicians subscribed to a broader definition of dexterity, encompassing many functional movements.

> “Usually, dexterity involves all tasks, even gross tasks like just holding a bag. You need to place your arms in space to reach for the bag handle, at the exact speed and strength that you require and then lift (the bag), that is a lot of coordination. So, yeah. Dexterity is everywhere when we perform a task.” (OT10)

Considerable overlap was noticed in the use of the terms ‘dexterity’ and ‘hand function’ in the clinicians’ discourse. Clinicians had varying interpretations of the relationship between the two terms. Most clinicians described ‘dexterity’ as “part of hand function” (OT08). Clinicians considered ‘hand function’ as an overarching term, a “bigger umbrella of all things your hand needs to do” (OT06). For some clinician ‘hand function’ extended to constructs like strength. One clinician, however, felt that ‘dexterity’ was an archaic term that waned to make way for ‘hand function.’

> “You can see (the things I say) relates more to hand function, dexterity means the same thing to me” (OT05)

It is not surprising that most of the clinicians who limited the scope of dexterity to movements relating to the hand and fingers perceived that dexterity was a less common complaint amongst their patients than those with a broader definition of dexterity.

2.4.2 Operationalization of Dexterity is Contentious

While clinicians reported that formal measurement of dexterity did not happen frequently, they appeared to informally evaluate different aspects of dexterity as part of their clinical decision-making. These evaluations tended to happen spontaneously throughout the course of a therapy session and can include unstructured task observation during the use of PBOMD. As one clinician shared:

> "Like whenever we ask patients to wash their hands before commencing heat modalities, we would really observe the engagement of their affected hand, how they actually move their proximal shoulder joint, how guarded they are, et cetera. These are more subjective observations." (OT2)

Ambiguity and uncertainty regarding the construct of dexterity were also reflected in comments about how it should be measured in clinical practice. The primary tensions revolved around 1) competing conceptual models of dexterity, and 2) ensuring ecological validity by selecting measures that best respect the 'individual's context' and approximate their valued tasks.

2.4.2.1 Conceptual compatibility

Measurement of dexterity was conceptualized by clinicians in two primary models: 1) as a product of body functions like strength, sensation, etc. (formative model), or as a distinct latent construct to be measured through multiple task-performance indicators like the ability to complete a task or the speed of task completion (reflective model). While both models served important clinical purposes, some clinicians placed more emphasis on one over the other.

In the first model, (used by all clinicians) considered dexterity as a product of physical body capacities and evaluated dexterity to identify deficits in physical and neurological functions responsible for the limitations in task performance. This was an informal process where clinicians observed restrictions in the patient's performance to generate hypotheses about reasons for performance limitations.

> "I will ask (patients) to bring their own things and then ask them to do the task. I would do a task analysis to identify problems that (person) is having. From that, I will give some recommendations. Is it a postural thing? Maybe a lack of grip strength?" (OT11)

Tensions arose when clinicians measured dexterity to determine if patients can successfully execute a task. Clinicians reported considering this primarily towards the end of the patient's rehabilitation before they returned to work and other life roles. Clinicians with an emphasis on dexterity as a product of physical capacities often obtained this information indirectly. These clinicians estimated their patients' actual ability to handle daily task by measuring body functions like strength or through accounts of patients' perceived ability. A clinician share:

> "You won't assess how the patient is playing tennis, but from the range of motion that the patient has, probably you can actually postulate how the patient might play" (OT02)

However, some clinicians felt that these indirect measures were not adequate indicators of the ability to perform daily activities: "patients can get better (in their body functions), but their (functional performance) does not improve" (OT09). These clinicians applied the second model, judging a patient's dexterity or actual ability to handle daily tasks separately from physical capacities by evaluating task-performance indicators. While clinicians used different phrases to describe the indicators, most focused on three primary indicators: the ease of successfully completing the task, task efficiency, and 'quality of movement.' One clinician described quality of movement as "adopting awkward movement patterns in performing the task" (OT12). This model is more consistent with current PBOMD.

Clinicians approach the measurement of dexterity differently, navigating two different, ambiguous, models and with little theoretical guidance, making each measurement attempt an unverbalized and highly variable process.

2.4.2.2 Ecological validity

Another source of tension relates to the extent to which dexterity is tied to the performance of specific tasks. Clinicians spoke of dexterity as a construct that must be measured in the context of the task. They questioned the validity of measures that lack similarity to the tasks of interests to their patients. They felt that PBOMD that were too dissimilar to the 'actual real-world task' might not provide useful predictions. This judgement on the adequacy of a 'match' between 'test task' and 'actual task' was highly individualized and subjective. For some clinicians, it was observing the general similarity between the general context of the tasks:

> "For example, Bennett's hand tool (featuring common tools like the screwdriver) will be for technicians. (Bennett's hand tool) is something good, (patients) can see what the link is. For the Purdue pegboard (featuring the manipulation and assembling of pins and washers) sometimes I use it for certain groups of patients who are technicians, as well as to simulate things like picking up screws, given the relevance of the assessment to their daily activities." (OT09)

However, other clinicians paid greater attention to the similarity between the movement patterns featured within tasks, allowing for generalization of results to tasks that did not precisely resemble the actual task in question but had featured similar grasp patterns and movements. As one clinician describes:

> "If you (patient) want to cut a steak with fork and knife because you're going fine-dining and you're meeting all those delegates from overseas, I (therapist) need to work on that. If I use the Purdue pegboard, maybe the results can only translate to using salt and pepper?" (OT06)

. Clinicians also commented on the lack of PBOMD that could translate to a task involving modern technology like typing, or culturally relevant tasks like the use of chopsticks. They felt that most PBOMD were a better match with patients who performed skilled technical labour.

The benchmark that these reflective construct indicators were compared against was dependent on the individual patient, and the clinician's interpretation of what was a 'normal' and 'acceptable' task efficiency and movement pattern for the patient. This decision was usually a judgement made in collaboration with the patient; "(patients) would be able to do tasks as per normal, or what they think is normal." (OT01) Deciding which dimension to focused on and measure was a highly subjective process, as some dimensions did not have practical value to patients. As another clinician verbalizes:

> "When you're talking about housewives being able to cut the vegetables. Sometimes when (housewives) feel like they can cut better, then that is good enough for them… (Housewives) don't need a perfect quality of movement as compared to the athletes who really need to go for a competition." (OT11)

The complexity and lack of clarity around dexterity made it difficult for clinicians to measure it comprehensively in clinical practice. As a clinician describes, “That’s the problem. When you talk about dexterity, the thing is what does dexterity encompass? And if you want a test to test each aspect of dexterity, that is not easy.” (OT05)

2.4.3 Standardized Measures as a Low-yield Investment

The final theme relates to the perceived ‘return on investment’ in using formal, standardized measures for evaluating dexterity. The workplace context, resources available and perceived benefits of obtaining an ‘objective’ result shaped the extent to which therapists perceived that it was worth the time and effort to use a PBOMD in clinical practice.

2.4.3.1 Investment of limited resources

Only one clinician used standardized PBOMD more than several times a year. The reason given by all the clinicians for low usage was insufficient time. It was interesting to note, however, that it did not seem to make any difference as to whether the clinicians had 15 minutes of consultation time or 1-hour consultation time with their patients. When clinicians were asked to share how they conducted their sessions and their approaches to choosing assessment, clinicians viewed time with their patient as a currency that had to be invested for the greatest benefit. One clinician, for example, explains:

> “We only have 15 minutes to 45 minutes or an hour for therapy sessions. We have to really carefully choose what we want to do in order for patients to gain the most.” (OT01)

Clinicians generally invested time on actions they perceived to have the most benefit to the patients and the organization for whom they were working. Clinicians would prioritize administering treatment, adhering to organization policies and using outcome measures that provided information that helped resolve issues prioritized by patients. If there were considerable benefits to using a PBOMD, one clinician shared that therapy assistants could assist, or pre-set markers could be used to reduce the time to set up PBOMD.

2.4.3.2 Situation-dependent benefits

The perceived value of PBOMD varied with the clinician's definition of dexterity; most clinicians found PBOMD more relevant when patients had conditions relating to the finger or could affect sensation.

> "(I) mainly use (dexterity assessment), especially with those patients with like skin grafts, or pathologies at the fingertips, or nerve injuries." (OT05)

This perception was built on a combination of information from the literature associating dexterity with the condition and experience.

Clinicians verbalized that standardized PBOMD provided specific benefits. PBOMD were perceived by clinicians to provide more objective and reliable results. This objectivity allowed for consistency and less potential bias in results; this was seen as invaluable for formal reports. The clinician who used the standardized PBOMD several times a month did so due to the high volume of legal reports that needed to be handled at the workplace. PBOMD were also seen as a good way to produce numerical data that was "easy to analyze" (OT07). Clinicians who used PBOMD for these reasons expressed a preference (when shown videos of PBOMD) for measures which had very standardized procedures and grading criteria, with results that were easily measured, such as time.

This ability to generate objective and repeatable results was perceived by clinicians as an asset when a comparison of functional ability needed to be done. Clinicians saw standardized

PBOMD as a useful way to track the functional progress of a patient across different visits as this could provide an objective benchmark to motivate patients by providing them with a goal to work towards, to calibrate a patient's perception of their abilities.

> "I think it is more realistic to observe the patient, rather than (rely on) self-report, because (patients) may sometimes over-estimate or under-estimate their ability to do so. "(OT09)

Some clinicians found this comparison especially useful in cases where the patient was not able to understand how improvement in physical capacities contributed to their functional goals.

Clinicians felt that the use of PBOMD would potentially allow for comparison between a patient and a larger population (such as with normative data, or with other research studies) to give an idea of the patient current recovery trajectory. However, most clinicians were unable to find relevant and current normative data fitting the cultural and vocational profile of their patients, and many were not comfortable or familiar with concepts like the minimally clinically important difference. Unfortunately, almost all the clinicians found that they were unable to discern any clinical value in comparing their patients to norms.

> "I don't know what kind of value it would bring to my therapy other than telling me that the patient is a certain percentile of the norm which again may not be very useful because the population is different" (OT12)

One clinician considered how the use of standardized PBOMD could potentially allow for more accurate documentation of task performance. The clinician felt that currently, documenting informal measures of dexterity requires precise descriptions of the task being observed and the movement pattern, which was time-consuming and subject to error. Another clinician echoed that sentiment, feeling that PBOMD would be useful as a comparison between therapists working in the setting, but only if the entire workplace was using it:

> “if all your therapists are doing the same assessment with (patients), for example – then it gives very good information across different diagnostic groups, and how each patient is performing” (OT09)

In summary, clinicians perceived that PBOMD with highly standardized procedures were more worth spending time on when they had to engage in formal legal communication or required the increased engagement of specific groups of patients in rehabilitation

2.4.3.3 Availability of suitable PBOMD

Finally, clinicians reported that if they were unable to locate a PBOMD that suited their needs within their setting, they would choose not to use any measure. Many clinicians reported that acquiring the literature on PBOMD and the actual tool was a logistically challenging process, due to restricted access to articles, long organization processes and limited funds. One clinician explained: “We have to prioritize our needs; our needs would be mainly for treatment, not outcome measures” (OT05).

There was also a lack of awareness of the range of PBOMD currently available on the market and their associated research, including studies on normative data. Some therapists were not aware of the measures within their practice setting. One clinician reflects:

> “The awareness is not there, I feel. The more you don’t use it, the more you don’t see it. You are not reminded that it could be a useful thing. So, the awareness of using all these tools are actually not common” (OT09)

The measurement of dexterity was rarely a focus during staff training at work. Clinicians shared that senior therapists did not role-model the use of PBOMD in their practice. A few clinicians recounted their cursory introduction to the PBOMD available in the centre and how they were left to their own devices about how to use and interpret the PBOMD. This low emphasis on PBOMD contributed to lack of awareness and knowledge of the PBOMD and their potential usefulness. As observed by a clinician:

> "You don't see the senior therapists using them (PBOMD). (PBOMD) are not the first tools that you will be thinking of using because you follow what they do and it doesn't take time, and you forget about these tools and about which one is which. You don't remember which tools are there." (OT03)

The only exception was the sensory retraining protocol at one of the centres, where the Moberg pick-up test was part of the centre's assessment procedures. Consequently, all members of the centre that were interviewed during this study used this PBOMD.

> "It is actually guided by, the sensory re-education protocol in Sweden. So, we do follow it fairly strictly, including the assessments involved. The only exception is the use of Sollerman hand function test as the sensory assessment; we have changed it to Moberg pick up to suit the local context." (OT09)

2.5 Discussion

The study findings highlight the lack of conceptual clarity surrounding the concept of dexterity, lack of agreement about how to evaluate it, and lack of commitment to incorporating standardized measures of dexterity in day-to-day practice. The findings, based on practices of Occupational Therapists in Singapore, highlight important conceptual, personal and organizational barriers to consistent and optimal use of PBOMD. Although dexterity, or 'the ability to execute tasks' is a core concern in rehabilitation (World Confederation for Physical Therapists, 2019; World Federation of Occupational Therapists, 2019), there appear to be gaps in how it is understood and operationalized in practice. This study sheds light on and provides possible reasons for the trend noted in surveys regarding the low use of PBOMD in practice.

The clinicians' diverse definitions of dexterity and the overlap in discourse with the associated term 'hand function' are reflective of the diversity of constructs and outcome measures that are currently present in rehabilitation focused literature on PBOMD (Ven-Stevens et al., 2015; Yancosek & Howell, 2009). This lack of a unified definition can be found in other complex latent constructs like 'balance' (Ragnarsdóttir, 1996), 'frailty' (Pel-Littel, Schuurmans, Emmelot-Vonk, & Verhaar, 2009), and 'health-related quality of life' (Karimi & Brazier, 2016). Consequently, the ambiguity in conceptualization leads to difficulty measuring and aggregating knowledge on the construct (Pel-Littel et al., 2009; Ragnarsdóttir, 1996).

A common language and understanding around these related concepts is a crucial step not only to facilitate communication but to allow meaningful aggregation and comparison of knowledge across persons, professions, countries and studies. The International Classification of Functioning, Disability and Health (ICF) created through the synthesis of opposing models of function and disability, systematic field trials and international consultation shows how a unified understanding of complex concepts can accomplish these goals (Maribo et al., 2016; World Health Organization, 2001). Dexterity might be more consistently defined using a framework like the ICF, by integrating and testing promising theories of motor control like the system theory and dynamic action theory (Cano-de-la-Cuerda et al., 2015), while seeking agreement from stakeholders on an operational definition of dexterity. In the meantime, clinicians and researchers should clearly define ‘dexterity’ and ‘hand function’ when using these terms. The authors have suggested a definition of dexterity, which they consider to be robust yet operationalizable, (Yong et al., 2019) however this and other models of dexterity need to be validated to show its usefulness in clinical practice.

All participants conceptualized dexterity as a product of specific physical components (formative model), assessing dexterity to identify reasons for problems in task performance; however, this is not the primary purpose of current PBOMD. (Wang et al., 2018; Yancosek & Howell, 2009). A PBOMD based on a formative model of dexterity may better support current practice needs. An example of such a performance-based measure is the Balance Evaluation System Test (BESTest), which evaluates balance across six postural control systems (Horak, Wrisley, & Frank, 2009). The BESTest was identified by Mancini & Horak (2011) in their review of balance assessment to be better suited for identifying underlying causes of deficits then measures (similar in concept to current PBOMD) like Berg Functional Balance Test.

Clinicians perceived the PBOMD to provide objective, reproducible assessments of dexterity, which facilitates comparison and communication; however, they prioritized the ecological validity of their clinical assessment. As such, they supplemented assessment results with unstructured observations of the patient and chose to forgo PBOMD that would not reflect ‘real-world’ performance. Krohne, Torres, Slettebø & Bergland (2014) observed a similar trend in therapists working in geriatric rehabilitation, where they identified the overlap of objective test data and subjective ‘clinician’s gaze’ in the administration and use of standardized measures.

This study found that clinicians tend to make judgements of the validity of a PBOMD intuitively by judging its face validity. Lack of reference to research regarding psychometric properties may be due to the limited understanding about the validity of PBOMD, as it has been identified that there are few high-quality studies establishing the ecological and content validity of these measures. (Schoneveld, Wittink, & Takken, 2009; Yancosek & Howell, 2009) In addition, this judgement is contingent on having a robust concept of dexterity (Terwee et al., 2018). Thus, in addition to the development of conceptual clarity, more studies need to be done on promising measures to assure clinicians about the validity of these PBOMD.

Consistent with the previous survey with members of the American Society of Hand Therapists, standardized outcome measures of dexterity and hand function were used infrequently (Grice, 2015). Reasons for lack of use of these measures were similar to the top three reasons identified by the survey-namely perceived lack of time, lack of familiarity with outcome measures and limited availability of appropriate outcome measures. This trend was consistent across other studies exploring the use of standardized outcome measures in allied health professions working in different practice settings (Asaba, Nakamura, Asaba, & Kottorp, 2017; Duncan & Murray, 2012; Piernik-Yoder & Beck, 2012)

The participating clinicians reported that they used other outcome measures regularly, so it is important to understand why there was such low use of PBOMD. Despite clinicians reporting lack of time to be an issue, the length of patient consultation time did not appear to influence the use of PBOMD by the clinicians. Instead, the primary barriers to using PBOMD were: lack of awareness of the available tools, skepticism about the utility of PBOMD for patient care, and low priority at an organizational level regarding the measurement of dexterity. Duncan

& Murray (2012) reported similar interactions between time and clinicians' assessments of whether measures guided patient care and could be practically applied in the setting in their systematic review of barriers and facilitators to routine outcome measure use.

While improving access to resources so that clinicians have the time, equipment and expertise to use PBOMD are important; there is a pressing need to increase the actual and perceived clinical value of PBOMD. Studies indicate that in common injuries like distal radius fractures, dexterity impairments can persist up to two years after the injury, suggesting that greater attention to restoration of dexterity is warranted(Bobos, Lalone, Grewal, & MacDermid, 2018; Bobos, Nazari, Lalone, Grewal, & MacDermid, 2018). Research that documents dexterity deficits, updated normative data in populations stratified by age, gender and occupational profile and anticipated recovery trajectories could make existing PBOMD more meaningful in clinical practice. Training aimed at increasing the confidence at interpreting PBOMD results and applying these insights to clinical practice would also improve perceived value. Therapists would make time for administering measures if doing so provides information of greater clinical value then what can be obtained from informal assessments.

2.5.1 Implications for Practice and Future Research

Our study suggests that measuring dexterity can be an important but unrecognized, or underutilized aspect of clinical practice. Therapists typically measure dexterity in an unstructured manner, and often the insights gained from these measurements are poorly recorded, making progress hard to track. Therapists may gain greater precision and objectivity in their clinical assessments of their patient's task performance and consequently, patient outcomes, if they consciously assess, reflect upon and document the dimensions of dexterity they are evaluating.

PBOMD can provide therapists with a platform for clearer comparison and communication in clinical practice and with existing literature. From the perspective of the Theory of Planned Behaviour, low use of PBOMD is influenced by therapists' attitudes and the subjective normative belief around the lack of visibility of the concept of dexterity and the perception that PBOMD seldom yields useful information. Work needs to be done to develop a unified conceptualization of dexterity as a basis for measures, by developing, validating and adopting promising models and operational definitions. There is also the need to increase familiarity and knowledge of PBOMD among therapists. Organizations can support clear communication and increase the use of PBOMD by formulating a common understanding and discourse around 'dexterity' and 'hand function,' and integrating these concepts into their procedures and protocols while supporting access to resources on PBOMD and interpretation of standardized measures.

More research should be done in improving the interpretability and clinical utility of outcome measures, through relevant updated normative data as well as studies on expected recovery trajectories. The development of PBOMD that facilitate identification of reasons for impaired task performance could support an unmet clinical practice need. Further content validation of PBOMD with current tasks using kinematic analysis and studies correlating actual task performance to abstract tasks would improve confidence in the ecological validity of PBOMD. Currently, PBOMD like the 400-point Hand Function Test (Gable, Xenard, Makiela, & Chau, 1997) mimic the current model of practice and can be useful in operationalizing dexterity and hand function with less change to current patterns of practice.

2.5.2 Strengths and Limitations

This is a qualitative study conducted with occupational therapists in Singapore. The findings are congruent with research conducted with therapists in other settings but are not necessarily transferable to a broader group of professionals in other clinical settings. The confusion around terminology and lack of perceived relevance are important themes that explain the trends in current practice. The identified factors suggest a general lack of understanding of how dexterity assessment might be used to enhanced practice and remediate the persistent deficits in dexterity that occur after upper extremity injury.

Furthermore, because of logistical and ethical constraints, participant observation was not done. Triangulation with participant observation could have yielded an alternative perspective about the way dexterity is measured and communicated in clinical practice. There was a low-rate response from participant diaries; most clinicians reported having nothing further to add. However, the summarised individual and group findings yielded rich responses, with clinicians elaborating on themes emerging from their interviews or describing their opinions and theories regarding the themes arising from consolidated interviews. The active feedback allowed for a richer understanding of identified themes.

2.5.3 Reflexivity

Reflexivity in research allows for rich insight on data and transparency through the researchers' introspective examination on the ways in which their unique position and interpersonal dynamics influence their interpretations of the data (Finlay, 2002).The primary investigator is a therapist who has worked in the setting but also as a researcher currently engaged in a systematic review of outcome measures of dexterity. The investigator's experience and knowledge enhanced understanding of the phenomena; however, also placed the researcher at risk of ‘going native’ and losing objectivity. The risk to objectivity necessitated not only the regular use of reflexive memos, field journals but also deliberate use of peer debriefing by discussing of insights with study team members, (two members did not practice in this area) and study participants by sending them summaries of findings.

2.6 Conclusion

This study provides new information about the perspectives of occupational therapists on the meaning and implementation of dexterity in upper limb rehabilitation. The study identifies the lack of conceptual clarity around dexterity, which complicates meaningful operationalization in practice, and highlights the perception held by some therapists that PBOMD are of limited value. It gives context to the low use of PBOMD found in previous studies and indicates that work needs to be done to explore and validate clinically useful models of dexterity in order to achieve a unified understanding of the phenomenon. The increased conceptual clarity and visibility of dexterity may increase the clinical utility of PBOMD available to therapists and improve clinical measurement practice.

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3 Chapter 3: Performance-based outcome measure of dexterity in person with hands and wrist injuries: A structured review of measured constructs

Target Journal: Journal of Hand Therapy

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Abstract

Background: Dexterity impairments are common and disabling. Currently, there is no consensus on an operational definition to measure dexterity.

Purpose: This review aims to provide an overview of constructs measured by performance-based outcome measures of dexterity and hand function (PBOMD) validated for use in persons with hand and wrist conditions.

Study Design: Structured review, with qualitative content analysis

Methods: Medline, Embase, CINAHL, PsycINFO were search from inception until August 2018. Two reviewers identified studies investigating the psychometric properties of PBOMD in persons with hand and wrist conditions. Original articles and manuals of validated PBOMD were obtained. Reviewers independently extracted and performed a content analysis of constructs comparing the theoretical concepts of dexterity and function.

Results: Twenty PBOMD were identified. Description of the construct measured indicated overlap between dexterity and hand function. There was an increase in the number of daily activities represented, from a focus on mobility to include domains like self-care and domestic life; and measurement of qualitative aspects of performance in newer tools. However, the majority of identified tools (70%) solely measured speed as a criterion for performance. None of the PBOMD evaluated dexterity associated with leisure activities or modern technologies like smartphones, nor measured the ability to adapt to environmental changes when completing tasks.

Conclusions: Hand function and dexterity are imprecisely defined and operationalized in PBOMD. Dexterity is a complex construct which is incompletely captured by current PBOMD, and often quantified as the speed of movement ignoring other important aspects like accommodating environmental changes during task performance. Clinicians should consider tasks included in PBOMD, quantification method, and each PBOMD’s limitations when choosing PBOMD.

3.1 Introduction:

Loss of dexterity is a sequala of many common musculoskeletal conditions of the hand and upper limb.[1,2] A recent census in Canada found that approximately 1 in 28 adults have a disability relating to dexterity.[3] This trend extends internationally, with many studies from other countries reporting a high prevalence of dexterity impairment and an associated loss of ability to retain paid employment and engage in daily activities.[4–6]

Despite the frequency of dexterity impairments and its significant impact on daily function, experts and systematic reviews of measurement tools remain divided on how best to measure the construct.[7–9] This tension is important to address as standard outcome measures form an integral part of healthcare, serving not only as a clinical decision-making aid[10] but also as a way to ensure the delivery of effective and economically efficient patient care.[11]

This lack of consensus on how to measure dexterity is partly due to debate over content validity, and how to best select from a diverse range of performance-based measures (ranging from timed pegboard tests to criterion-rated simulation of daily activities).[7,8,12] An important part of establishing content validity is documenting the relevance and comprehensiveness of the tool in capturing the theoretical scope of the measured construct; this is difficult without a clear, consistent and operationalizable construct.[13]

We proposed to use three different conceptual models to catalogue and compare the different aspects of the constructs of PBOMD. 1) The International Classification of Functioning, Disability and Health (ICF)[14] was selected to explore the scope of body function and activities covered by the tools.2) The classification system created by Vergara et al.,[15] to characterize the grasp patterns used in activities of daily living, provided a system to explore the scope of the tools from a biomechanical perspective. 3) A theoretical conceptualization of dexterity was used to explore the dimensions of dexterity. Bernstein (p. 228)[16] describes dexterity as the "ability to find a motor solution for an external situation." In a foundational work in dexterity and motor control, he asserts that a task done with dexterity is completed with four complementary characteristics: accuracy, quickness, economy and resourcefulness.[16] This study aims to explore the constructs and content of performance-based outcome measures of dexterity and hand function (PBOMD), using these three schemas. The resultant evidence synthesis can provide clinicians with an overview of how current dexterity and hand function are operationalized: this information will aid in the selection of tools for practice settings and individual clients. The study also aims to develop a common understanding of dexterity and hand function in the context of clinical measurement, to serve as a foundation to evaluate the content validity of tools claiming to evaluate these constructs.

3.1.1 Objectives

1. Describe how the constructs 'dexterity' and 'hand function' are defined by tool developers
2. Examine the extent to which that PBOMD measure the key theoretical dimensions of dexterity and function
3. Describe the purpose of the identified PBOMD as intended by the tool developers

3.2 Methods

The purpose of this review was to describe and compare the constructs of the tools. These constructs are generally expressed in written words and inferred from the subtests and scoring criteria of the PBOMD. Thus, qualitative content analysis, a technique used to make systematic inferences from text and other forms of communication, was used to explore the constructs measured by the PBOMD.[17]. As the methodological quality of retrieved articles and mapping the breadth of the literature was not relevant to our purpose, we did not adhere to the procedures of the systematic review, or scoping review. This review was done in tandem with a systematic review of the psychometric properties of PBOMD in hand and wrist conditions. Both reviews shared the same search strategy and study selection process. The protocol to this systematic review was registered on PROSPERO (CRD42018106940) and can be accessed at https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=106940

3.2.1 Eligibility Criteria:

3.2.1.1 Studies were Included if They Met the Following Inclusion Criteria:

1. The outcome measure of interest included one of the following:
    a. Dexterity, defined as "the ability to find a motor solution for any external situation, that is to adequately solve an emerging problem accurately, quickly, rationally and resourcefully."(p.228)[16] This is commonly quantified by, but not limited to the measurement of parameters of tasks involving fine manipulation of small objects.
    b. Hand function, defined as an individual's ability to use their hands to execute 'activities' as defined by the 'activities' domain in the International Classification of Functioning, Disability, and Health (ICF).[18]

2. The study population included human adults (≥18) years with hand or wrist injuries making up at least 80% of the total study sample. Hand and wrist injuries were defined as conditions resulting in dysfunction to the hand and wrist due to the following reasons:
    a. Conditions and injuries involving the peripheral nervous system
    b. Traumatic and/or over-used conditions involving the musculoskeletal system.
    c. Burns and vascular conditions
    d. Autoimmune diseases and conditions
3. The instrument in question was a PBOMD, defined as an observer-rated evaluation/measurement of a person's ability to perform an action or activity.[19]
4. The aim of the study was the development of an outcome measure or the evaluation of one or more of its measurement properties.
5. Publication was a full-text original article in a peer-reviewed journal.

3.2.1.2 Studies were Excluded if:

1. The focus was on patients with conditions involving the central nervous system (e.g., Stroke or traumatic brain injury).
2. The study did not report data on a measurement property (e.g., reliability, validity).
3. The focus was on patient-rated outcome measures (PRO), including studies where a PBOMD of dexterity or hand function was correlated to the PRO, and no other measurement properties of the PBOMD was reported or evaluated.
4. The instrument was developed specifically to evaluate constructs relevant to only specific diagnostic groups (e.g., prosthesis use in persons with amputees).

5. The outcome measure required complex research technologies such as 3D motion capture analysis that are not commonly used in most clinical settings.
6. The outcome measure had no available studies to evaluate its psychometric properties
7. The article was based on conference proceedings or dissertations.

3.2.2 Search Method for Identification of Studies

A search of the following search terms and their synonyms was completed in August 2018 on the following electronic databases: MEDLINE, Embase, CINAHL, PsycINFO. Key search terms and synonyms included four main categories below were combined for the search strategies.

Construct of Interest: Dexterity, fine motor skill, motor performance, motor skill, finger coordination

Target population: Hand, wrist forearm, finger, thumb, upper extremity, upper limb

Measurement Properties: Psychometrics, clinimetrics, reliability, validity, responsiveness.

Measurement Instrument: Performance-based outcome measures, outcome measure, test, index, observational test, task performance and analysis

The search terms were modified for use in different databases. An information specialist and a committee comprising of experts in the systematic review methodology (two persons), hand therapy (one person) and work role function (two persons) reviewed search terms and strategy (please refer to Appendix B-E for full search strategy).

We used adapted search terms based on a validated PubMed filter[20] shown to retrieve more than 97% of articles on measurement properties. Titles and abstracts of retrieved articles were screened for names of PBOMDs by one reviewer (JY). An additional search was then performed in each database, using the names of the tools found in title/abstract and full-text articles meeting the inclusion criteria (criteria involving population was not applied) during the initial search. Systematic reviews on the topic of performance-based outcome measures of the upper limb were then screened for PBOMD names.

The names of the PBOMD were extracted and the tools evaluated to see if they measured dexterity or hand function as defined above. The tools meeting the criteria were combined with the keywords for the target population and measurement properties to evaluate if they should be included in the final strategy. The search results for each PBOMD was compared with the results of the initial strategy to see if they yielded unique citations that met the inclusion criteria. The names of these PBOM, together with keywords for the target population and measurement properties, were combined with the initial search strategy to form a second search strategy. The two searches strategies were then combined for the final search. Exclusion filters were applied to all searches (see Appendix G for the screening process). Reference list and bibliographies of articles that met the study criteria were then screened to identify additional relevant studies.

3.2.3 Data Management

Citations were managed using RefWorks and duplicates were screened and consolidated by Principal Investigator (JY) with the assistance of the tool-‘Deduplicator’ developed by the Centre for Research in Evidence-Based Practice (CREBP).[21] After duplicates were removed, the citations, the duplicate removal process was repeated, and the screening process was done using Covidence.[22]

3.2.4 Selection of Abstracts and Full-text Articles

Two reviewers, a hand therapist and a physiotherapist (JY and PB) independently reviewed 100 titles, to pilot the screening process. When consensus was reached, one reviewer (JY) screened the remainder of titles. Titles and abstract as well as full-text article screening was completed by two reviewers (JY and PB), and subsequently, the reference lists of the studies were retrieved. A third reviewer (JM) assisted in resolving differences. Original development articles or manuals of included PBOMD were located where possible. When the original document could not be located, secondary references were used.

3.2.5 Data Extraction and Content Analysis

The two coders (JY and TP) with clinical and research experience in the rehabilitation of persons with hand and wrist conditions independently extracted the general characteristics of the PBOMD from original development articles or manuals. Characteristics included the specific constructs measured, characteristics of the study population, the intended purpose of the tool, date of publication, and subscales within each PBOMD.

Conventional content analysis was then adopted to inductively categorize the purpose of each PBOMD and their definitions of dexterity and hand function. All the articles were read prior to analysis, and the purpose and definitions of dexterity and hand function were extracted and coded in Microsoft Excel[23], and identified codes were compared to formulate categories. JY and TP triangulated their interpretations through regular meetings and discussion about identified categories. Rigour and trustworthiness were established using reflexive memos.

Data was extracted on the scope of the evaluation, subtests, and constructs measured to examine the extent the tools reflected the following concepts:

1. The involved joints, anatomical movement and type of grasp patterns.
2. The construct measured including the key dimensions of dexterity: the accuracy of performance, quickness, the economy of effort and movement (quality of movement), resourcefulness.[16]
3. The domains and codes in the International Classification of Functioning, Disability and Health (ICF).[24]

The content of the tools was examined in reference to the date that the articles were published to explore how the measurement of dexterity/hand function had changed over time. Any disagreements during the deductive extraction phase, comparison and synthesis phase were resolved by a third reviewer (JM).

3.3 Results

The first search yielded 4680 records, with 128 articles and 73 potential PBOMD that met the criteria (see fig.1: flowchart showing study selection process; see Appendix F for a list of outcome measures). Reference lists of six reviews on PBOMD[9,12,25–28] were evaluated for possible names of tools, yielding 20 unique tools, none of which met the inclusion criteria (see Appendix G for details on the list of outcome measures and the number of citations by the database). The final search, which included the names from the first search, yielded 5682 records, 60 articles and 20 unique PBOMD that met the full inclusion criteria (see fig.1 for study flow).

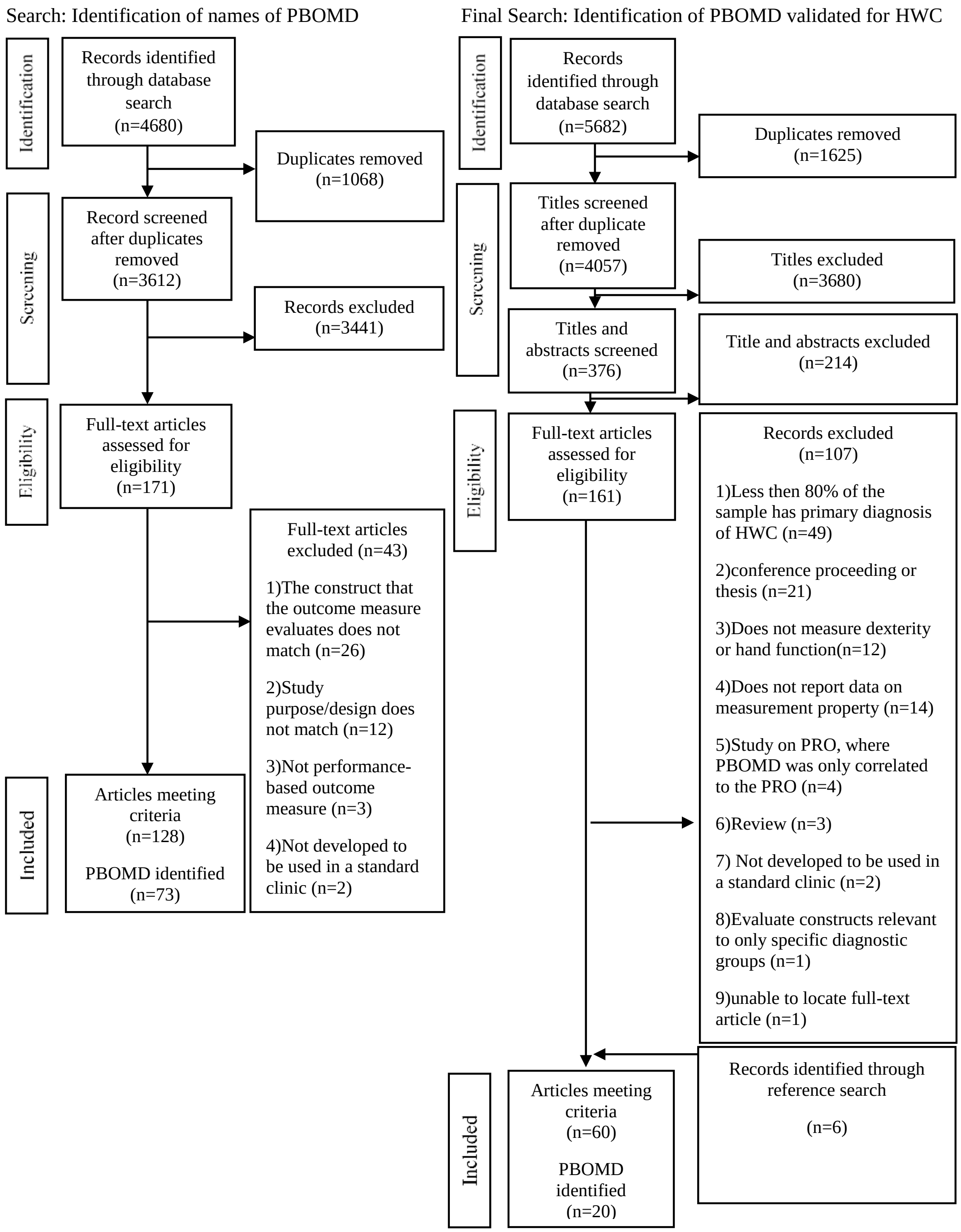


Fig 1: Flowchart showing study selection process

Several tools were excluded because no studies evaluating their psychometric properties in a sample composed primarily of persons with hand and wrist conditions were located (See Appendix H for a list of excluded tools and the reasons for exclusion). Thirty-two published development articles and user manuals were analyzed inductively and iteratively with reference to the origin of the authors, date of publication, publication source as well as the content of the tools (see table 1 for a description of documents).

Table 1: Characteristics of documents on Performance-based Outcome measures of dexterity and Hand function that were examined

No.	Year	Tool name	Type of document	
			Academic journal	User Manual
1	1931	Minnesota Manual Dexterity Test	(Surrey, et al., 2003)[29]	(Lafayette instrument,2017)[30]
2	1946	Complete Minnesota Dexterity Test	(Surrey, et al., 2003)[29]	(Lafayette instrument, 2015)[31]
3	1948	Purdue Pegboard		(Tiffin, 1968)[32]
4	1956	Crawford Small Part Dexterity Test	(Berger,1985; Osborne & Sanders,1956)[33,34]	
5	1958	Moberg pickup Test	(Moberg,1958; Dellon,2015; Ng, et al.,1999)[35–37]	
6	1969	Jebsen Taylor Hand function Test	(Jebsen, et al., 1969)[38]	
7	1971	Nine-Hole Peg Test	(Kellor, et al., 1971; Mathiowetz, et al., 1985)[39,40]	
8	1973	Smith Hand Function Test	(Smith, 1973)[41]	
9	1975	Valpar Component Work Sample 4	(Botterbusch,1982; Christopherson & Hayes, 2006)[42,43]	
10	1976	Box and Block Test	(Cromwell, 1976; Mathiowetz, et al., 1985)[44,45]	
11	1991	Arthritis Hand Function Test	(Backman, et al., 1991; Backman & Mackie, 1995; Backman & Mackie, 1997; MacBain, 1970)[46–49]	
12	1991	Button Test	(Pincus, et al., 1991)[50]	
13	1995	Sollerman Hand function Test	(Sollerman & Ejeskar, 1995)[51]	
14	1995	Grip Ability Test	(Dellhag & Bjelle, 1995)[52]	
15	1996	Sequential Occupational Dexterity Assessment (SODA)	(Van Lankveld, 1996)[53]	
16	1997	400 Bilan Test	(Gable, et al., 1997; Gable et al, 2012)[54,55]	
17	1999	NK dexterity Test	(Turgeon, et al., 1999)[56]	
18	1999	SODA-S (shorten version)	(Van Lankveld, 1999)[57]	
19	2003	Functional Dexterity Test	(Aaron, et al., 2003)[58]	
20	2012	MacHand Performance Assessment	(Packham, et al., 2012)[59]	(Packham et al., 2012)[60]

3.3.1 Exploring the Definitions of 'Dexterity' and 'Hand Function.

Nine tools were identified as measuring dexterity.[29–34,39,40,44,45,53,56,58] Eight tools were identified as measuring hand function [38,41,46–52,54,55,59,60]; some of these tools also included dexterity as part of the measured construct (e.g., the Arthritis Hand Function Test).[46–49,54,55,59,60] Despite being profiled as PBOMD, 2 of the 20 tools did not explicitly identify as measuring dexterity or hand function.[35,42,43] The Moberg pick up test, and the Valpar Component Work Samples 4 did not claim to measure either construct, the former being a "functional test for examining sensibility"(p.454)[35], and the latter "used to appraise an individual's physical, mental abilities, interest and other characteristics…" according to Wright as cited by Christopherson & Hayes(p.1).[43] The article on the short version of the Sequential Occupational Dexterity Assessment (SODA-S) used the terms 'hand function' and 'dexterity' interchangeably when describing what it measured[57] (see table 2 for an overview of the classification of tools by construct they reportedly measured).

Many of the identified articles did not clearly define dexterity and hand function. Six of 15 (40%) tools which claimed to include dexterity as part of their measured construct, and 6 of 9(67%) tools which claimed to measure hand function did not explicitly define the terms, referring to terminology like 'manual dexterity' or 'hand function' without further explanation. The definitions of 'dexterity' and 'hand function' varied across studies and both constructs appeared to overlap

Table 2: Content analysis of performance-based outcome measures of dexterity and hand function, classified by intended purpose, construct they report to measure and example of quotes representing the reported purposes of the tools.

Intended purpose	**Name of PBOMD**	**Construct they reported to measure**	**Example of a quote representing the intended purpose**
Identify and evaluate worker suitability	Complete Minnesota Dexterity Test	Dexterity	"The Purdue pegboard is a test of dexterity designed to aid in the selection of employees for industrial jobs such as assembly, packing, operation of certain machines and other manual jobs"(p. 2)[51]
	Minnesota Manual Dexterity Test	Dexterity	
	Crawford Small Part Dexterity Test	Dexterity	
	Purdue Pegboard Test	Dexterity	
	Valpar Component Work Sample 4	Mental, physical, interest and other characteristics	
Measuring specific types of grasp or prehensile patterns	Nine Hole Peg Test	Dexterity	"The purpose of the FDT is to provide the clinician with an assessment tool that requires a minimum amount of time to administer and that gives information regarding the patient's ability to use the hand for functional tasks requiring a dynamic 3-jaw chuck prehension pattern."(p.12)[31]
	Box and Block Test	Dexterity	
	Functional Dexterity Test (FDT)	Dexterity	
	NK Dexterity Test	Dexterity	
Evaluate the ability of the hand to manage daily function task	Jebsen Taylor Hand Function Test	Hand function	"Assess broad aspects of hand function commonly used in activities of daily living." (p. 311)[56] "This new test measures dexterity, which is defined as a complex of bimanual functional abilities in activities of daily living." (p.27)[32]
	Button Test	Hand function	
	Sequential Occupational Dexterity Assessment	Dexterity	
	Short version-Sequential Occupational Dexterity Assessment	Uses dexterity and hand function interchangeably	
	Sollerman Hand Function Test	Hand function	
	Grip Ability Test	Hand function	
	MacHAND Performance Assessment	Hand function	
Evaluating hand function at an activity and impairment level	Smith Hand Function Test	Hand function	"The AHFT differs from other tests of upper extremity function in that it examines the performance on pure and applied strength and dexterity task…" (p. 246)[54]
	Arthritis Hand Function Test (AFHT)	Hand function	
	400 bilan/ 400-point Hand Function Test (400T)	Hand function	
Functional test of sensation	Moberg Pickup Test	Functional sensibility	"I have worked out a new functional test for examining sensibility in an injured hand" (p.454)[29]

3.3.1.1 Exploring the Construct- 'Dexterity'

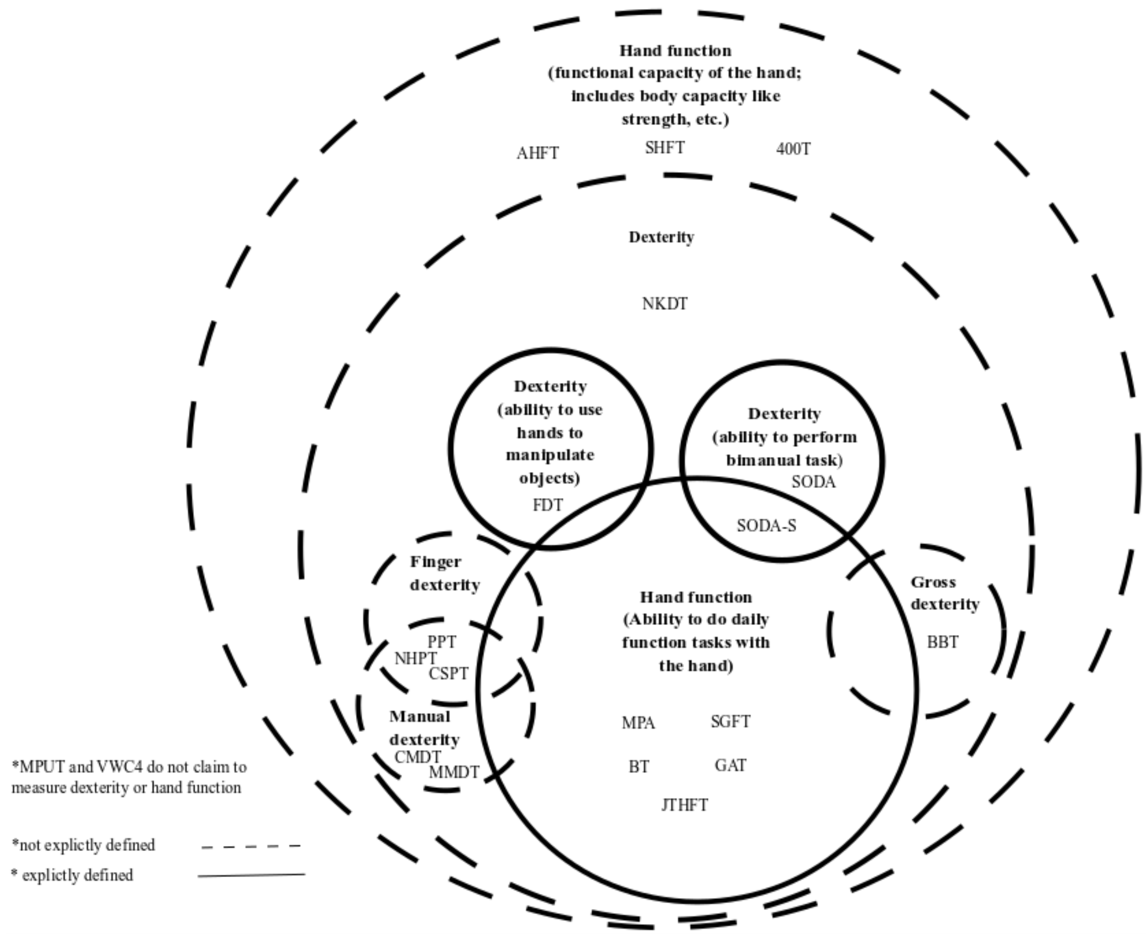
In general, most of the articles that provided a definition of dexterity referred to it as an ability to execute and complete some type of task. The type of task and what it involved varied between different definitions, from specific types of tasks like "manipulate objects with the hands." (p.12)[58], to broader categories of tasks like "bimanual functional abilities in activities of daily living" (p.27)[53] or as Desrosiers et al., states "the ability to use the hands" as cited by Gable et al. (p.96)[54] (the developers of the 400-point Hand Function Test).

The concept of dexterity was also broken into subsets by some articles. These articles referenced the concepts of 'finger dexterity' and 'manual dexterity'; terms first used by Fleishman & Hempel[61] to describe dimensions from their factor analysis of dexterity tests. This categorization implied that the ability to execute a task with the hand was divided anatomically into 1) finger-centric movement versus 2) skilled arm and hand movements.

3.3.1.2 Exploring the Construct-'Hand Function'

Like dexterity, hand function was a broad concept which had varied interpretations. Many articles indirectly referred to the concept of function or the idea of daily activities without directly explaining what 'hand function' meant. Most of the identified articles providing definitions generally referred to as 'hand function' as the "ability to use the hand to perform daily activities." (p.1560)[52] Another interpretation of 'hand function' was taken by the developers of MacHAND Performance Assessment, defining hand function as "task performance across grasp and pinch patterns." (p304)[59] Finally, while most PBOMD examined the ability to perform specific tasks, some tools like the Arthritis Hand Function Test included physical capacities like sensation and strength when operationalizing 'hand function.'

The varying scope of dexterity and hand function makes their relationship complicated. Tools like the Functional Dexterity Test view “dexterity as a component of function.” (p.12)[58] In contrast, tools like SODA, SODA-S and 400-point Hand Function test (400T) view dexterity and hand function as interchangeable concepts at the level of the hand.[54,57] Fundamentally, dexterity (ability to execute tasks successfully) and hand function (ability to perform daily activities) are similar constructs, that differ based on the scope of the tasks or anatomical region. If hand function is used to describe all the capacities of the hand, including capacities like strength, it is a broader concept than dexterity (refer to Fig.2 for visual depiction of relationships).



400T-400-point Hand Function Test *AHFT-Arthritis Hand Function Test *BBT-Box and Block Test *BT-Button Test *CMDT-Complete Minnesota Dexterity Test *CSPT-Crawford Small Part Test *FDT-Functional Dexterity Test *GAT-Grip Ability Test *JTHFT-Jebsen Taylor Hand Function Test *MPA-MacHand Performance Assessment* MMDT-Minnesota Manual Dexterity Test *MPUT-Moberg Pickup Test *NHPT-Nine-hole Peg Test *NKDT-NK dexterity Test *PPT-Purdue Pegboard Test *SODA-Sequential Occupational Dexterity Assessment *SODA-S-Short version of Sequential Occupational Dexterity Assessment *SHFT-Smith Hand Function Test *SGFT-Sollerman Grip Function Test *VWCS4-Valpar Work Component Set 4

Fig. 2: Visual representation of the relationships between the constructs measured by Performance-based outcome measures of dexterity and hand function

3.3.2 Examining the Extent that PBOMD Measure the Theoretical Dimensions of Dexterity and Function

Across PBOMD, dexterity and hand function were evaluated according to different criteria through contrived tasks. These standardized tasks were designed to simulate different daily activities, or elicit different movement, or grasp patterns. To determine how comprehensive each PBOMD was in covering the diverse roles of the hand, we classified the tasks/items featured in each PBOMD in two ways. 1) Biomechanically, according to potential grasp pattern featured, and whether the task was done with a single hand or both hands in tandem; 2) by the purpose of the items on the PBOMD, according to the domains of body function and activities featured in the ICF model.

3.3.2.1 Examining the Scope of the PBOMD-a Biomechanical Perspective

The majority of the tools did not explicitly specify the grasp pattern to be used during a task; the tools were therefore grouped broadly based on Landsmeers'[62] classification into 1) "power grip" where the fingers are static when handling the object, with movement coming from the arm; and 2) "precision handling" where the fingers can manipulate the object, independent from the arm. Ten of 20 tools focused on precision handling,[29–36,39,40,42–45,50,58] whereas the other 10 featured a mix of precision handling and power grasp.[38,41,46–49,51–57,59,60]

To examine the diversity of grasp patterns featured in the PBOMD, we mapped out the patterns that could be potentially used when executing tasks in the PBOMD, using the grasp pattern classification by Vergara et al.[15] (see fig. 3 pictorial depictions of grasp patterns).

Fig. 3: Grasp taxonomy by Vergara et al.[15]

The tools examining both precision handling and power grasp featured between four to eight of the nine possible grasp patterns.[38,41,46–49,51–57,59,60] The Sequential Occupational Dexterity Assessment[53] was the only tool that examined the non-prehensile pattern, and none of the identified tools included tasks utilizing the hook grasp pattern (a pattern commonly used during tasks like handling grocery bags). A summary of the number of grasp patterns incorporated in the tools is outlined in Table 3.

Table 3: Characteristics of performance-based outcome measures of dexterity and hand function.

Table 3a: Performance-based outcome measures of dexterity and hand function featuring primarily precision handling movements

No.	Tool name	No of tasks	Unimanual vs Bimanual	Tool description	No. of ICF codes	No. of grasp patterns	Results	Speed	QOM
1	Nine-Hole Peg Test (NHPT)	1	Unimanual	Picking up, inserting and then retrieving 9 pegs	1	3	Time (secs) for each trial done	√	×
2	Purdue Pegboard	4	Unimanual, Bilateral*, bimanual	3 subtest involving inserting pins into 25 holes, with the right, left then both hands simultaneously. The final subtest involves using both hands to assemble a sequence of pins and collars	1	3	Number of pins inserted within 30 secs; and for the assembly subtest: number of assembled parts	√	×
3	Functional Dexterity Test	1	Unimanual	Picking up, flipping and inserting 16 pegs without supinating the wrist	1	1	Time (secs) with penalties for supination and dropping	√	√
4	Box and Block Test (BBT)	1	Unimanual	Picking up and placing 2.5cm^2 blocks, transporting and releasing it across midline over a partition	1	3	Number of blocks transported within 60 secs	√	×
5	Complete Minnesota Dexterity Test (CMDT)/ Minnesota Rate of Manipulation Test (MRMT)	5	Unimanual, bilateral, bimanual	5 subtests involving: 1) picking up and inserting 60 discs;2) picking and turning the discs with 1 hand and replacing with the other; 3) retrieving and releasing the discs 4) turning discs with 1 hand 5) turning discs with both hands simultaneously	2	3	Time (secs) for each trial done	√	×

*Bilateral refers to both hands doing the same action simultaneously *Bimanual refers to both hands working together *QOM-Quality of movement refers to the presence of abnormal movement patterns *all test required standardized kit *ICF codes- each code represents a domain of human functioning or disability *grasp patterns by Vergara et al.[15] *Moberg pick up test also features purely precision handling tasks and is included under tools that include measurement of physical function.

Table 3a(continued): Performance-based outcome measures of dexterity and hand function featuring primarily precision handling movements

No.	Tool name	No of tasks	Unimanual vs Bimanual	Tool description	No. of ICF codes	No. of grasp patterns	Results	Speed	QOM
6	Minnesota Manual Dexterity Test (MMDT)	2	Unimanual, bimanual	2 subtests involving: 1) picking up and inserting 60 discs;2) picking and turning the discs with 1 hand and replacing with the other	2	3	Time (secs) for each trial done	√	×
7	Button test	1	Bimanual	Dressing task. Fastening and undoing 5 buttons on a frame while stabilizing frame with the other hand.	1	2	Time (secs) for each trial done	√	×
8	Crawford Small Part test (CSPT)	2	Unimanual, bimanual	Simulated manual work. 2 subtests involving:1) using Tweezers to pick up and place metal pins, then adding washer with the other hand 2) using a screwdriver to drive screws through a metal plate	2	2	Time (secs) for each trial; Time limit version-3 mins for pin/ 5 mins for screws	√	×
9	Valpar Component Work Sample 4 (VCWS4)	1	Unimanual	Simulated manual work. Reaching into a small hole, attaching and dissembling nuts and bolts	1	3	Time (secs) for each trial done	√	×

*Bilateral refers to both hands doing the same action simultaneously *Bimanual refers to both hands working together *QOM-Quality of movement refers to the presence of abnormal movement patterns *all test required standardized kit *ICF codes- each code represents a domain of human functioning or disability *grasp patterns by Vergara et al.[15] *Moberg pick up test also features purely precision handling tasks and is included under tools that include measurement of physical function.

Table 3b: Performance-based outcome measures of dexterity and hand function featuring both power grasp and precision handling movements

No.	Tool name	No of tasks	Unimanual vs Bimanual	Tool description	No. of ICF codes	No. of grasp patterns	Results	Speed	QOM
1	Grip Ability Test (GAT)	3	Unimanual, bimanual	3 functional tasks representing self-care: dressing, drinking and non-manual work.	3	6	Time (secs) for each task done (weighted)OR ceiling score: 60 secs	√	×
2	Jebsen Taylor Hand Function Test(JTHFT)	7	Unimanual	7 tasks with 4 daily activities and 3 tasks representing fine hand use. Uses a standardized kit	6	6	Time (secs) for each task done	√	×
3	NK Dexterity Test (NKDT)	3	Unimanual	Picking, manipulation and placing of 3 categories of objects: small, medium and large. Uses a standardized kit	2	6	Time (secs) for each task done	√	×
4	Sequential Occupational Dexterity Assessment (SODA)	12	Unimanual, bilateral bimanual	12 functional daily tasks	9	8	Performance rated scored according to criteria	×	√
5	Short version of SODA (SODA-S)	6	Unimanual, bimanual	6 functional daily tasks	5	7	Performance rated scored according to criteria	×	√
6	Sollerman Hand Function Test/ Sollerman Grip Function Test (SGFT)	20	Unimanual, bimanual	20 functional tasks representing 7 of 8 different hand grasp patterns.1 task representing fine hand use. Uses a standardized kit that can be constructed.	12	7	Performance rated according to criteria including established grasp patterns	√	√

*Bilateral refers to both hands doing the same action simultaneously *Bimanual refers to both hands working together *QOM-Quality of movement refers to the presence of abnormal movement patterns *all test required standardized kit *ICF codes- each code represents a domain of human functioning or disability *grasp patterns by Vergara et al.[15]

Table 3c: Performance-based outcome measures of dexterity and hand function, including measurement of physical function.

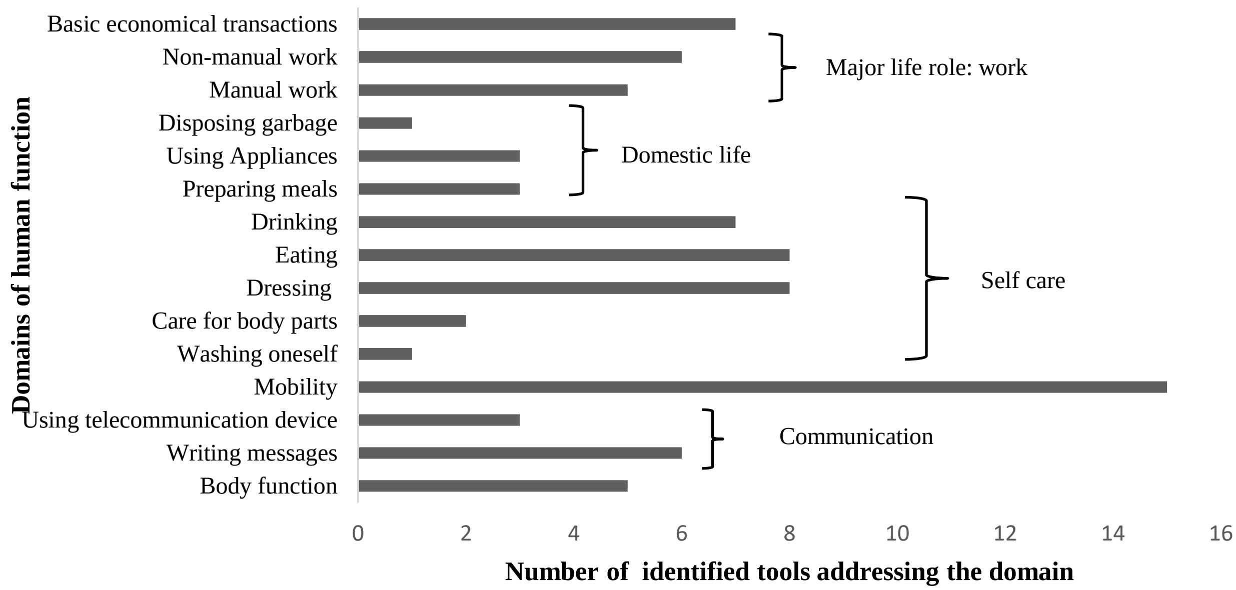
No.	Tool name	No of tasks	Unimanual vs Bimanual	Tool description	No. of ICF codes	No. of grasp patterns	Results	Speed	QOM
1	Moberg Pick up test (MPUT)	3	Unimanual	Picking up and placing 12 objects into a receptacle with and without vision followed by identifying the objects	2	3	Time (secs) for each trial done; objects identified	√	×
2	MacHANd Performance Assessment (MPA)	20	Unimanual, bimanual	20 functional tasks aiming to represent different grasp patterns, includes 6-peg pick up and insert task; as well as stereognosis test	13	6	Performance rated according to criteria to get a summative score	√	√
3	400 Bilan/ 400-point Hand Function test(400T)	57	Unimanual, bilateral bimanual	57 tasks, including 12 tasks representing joint function and mobility, 5 different strength measurements; 20 unimanual tasks representing picking and placing of daily objects; 20 bimanual functional tasks.	14	7	Performance rated according to criteria to get a summative score; only unimanual tasks are timed	√	√
4	Arthritis Hand Function Task (AHFT)	11	Unimanual, bimanual	11 tasks representing pure and applied dexterity as well as strength. Includes pinch and grip strength measurement; NHPT; unimanual and bimanual functional tasks.	7	7	Time (secs) for each task done	√	×
5	Smith Hand Function Task (SHFT)	16	Unimanual, bimanual	16 task including grip strength; assessor judged writing tasks and timed tasks representing daily activities and fine hand use	5	4	Primarily timed(secs)	√	×

*Bilateral refers to both hands doing the same action simultaneously *Bimanual refers to both hands working together *QOM-Quality of movement refers to the presence of abnormal movement patterns *all test required standardized kit *ICF codes- each code represents a domain of human functioning or disability *grasp patterns by Vergara et al.[15] *Moberg pick up test also features purely precision handling tasks and is included under tools that include measurement of physical function

3.3.2.2 Examining the Scope of PBOMD by the Purpose of Test Items

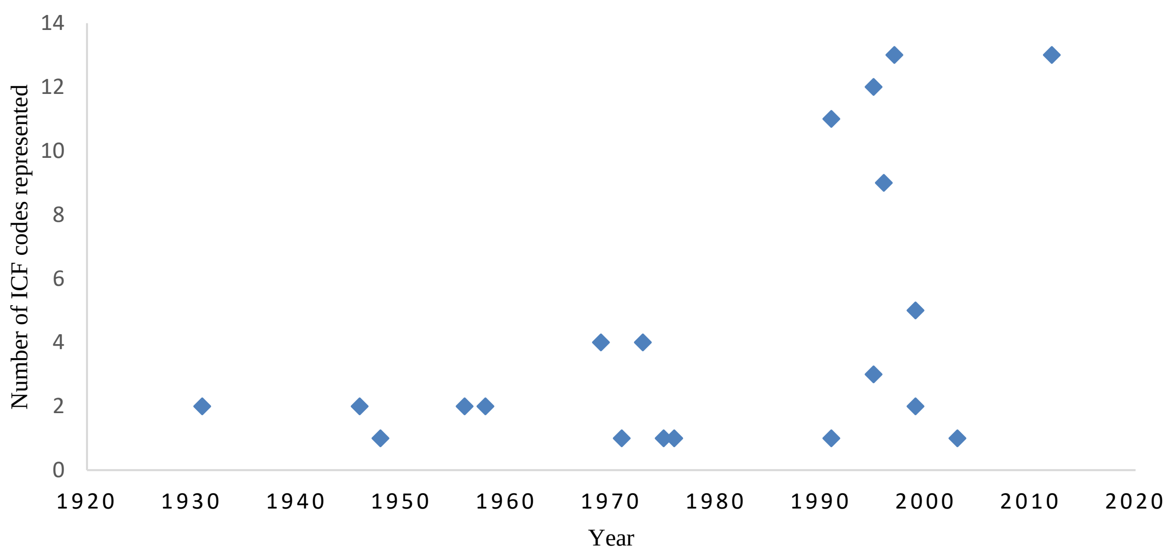
The tasks being evaluated in each tool were mapped to the ICF codes to compare the extent to which the tools assessed a range of human performance activities (see Table 4 for details).

As noted in Figure 4a, the domain most frequently examined by the tools was the area of mobility, primarily represented by fine hand use measured through tasks involving picking up and placing of items.. The next most frequent domain was self-care; representing dressing, eating and drinking. Activities involving the domains of leisure and recreation, non-verbal communication, and modern technology use (e.g. computers, smartphones) were not represented in identified tasks. The majority of the tools measured one to four domains, but during the past 20 years, there has been an emergence of tools capturing nine or more domains.[51,53–55,59,60] (See Fig.4b for a graphical depiction of the number of ICF codes.)



*PBOMD-Performance-based Outcome Measures of dexterity and hand function*ICF codes- each code represents a domain of human functioning

Fig 4a: Frequency of ICF codes in performance-based outcome measures of dexterity and hand function validated for use in hand and wrist injuries



*Each point on the figure represent a unique performance-based outcome measure

Fig. 4b: Number of ICF codes in performance-based outcome measures of dexterity and hand function validated for use in hand and wrist injuries by date developed

Table 4: Overview of ICF codes identified in performance-based outcome measures of dexterity and hand function

		Tool names																				
		400T	AHFT	BBT	BT	CMDT	CSPT	FDT	GAT	JTHFT	MPA	MMDT	MPUT	NHPT	NKDT	PPT	SODA	SODA-S	SHFT	SGFT	VWCS4	Total
ICF code	**Description of items**	**Features representative item**																				
B (Body Function)																						
b298-Sensory function and pain, other specified	**Stereognosis**	×	×	×	×	×	×	×	×	×	√	×	√	×	×	×	×	×	×	×	×	**2**
b7101-mobility of several joints		√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	**1**
b7300-power of isolated muscles and muscle groups		√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	**3**
	Grip strength	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	3
	Pinch strength	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	2
Activity and Participation																						
D3(communication)																						
d345-writing messages		√	×	×	×	×	×	×	×	√	√	×	×	×	×	×	√	×	√	√	×	**6**
d360-using telecommunication device	**Picking up receiver**	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	×	√	×	**3**
D4(mobility)																						
d4300-lifting and carrying	**Lifting cans, etc.**	√	√	×	×	×	×	×	×	√	√	×	×	×	×	×	×	×	×	×	×	**4**
d4408-Fine hand use-other specified	**Pick and release**	√	×	√	×	×	×	×	×	√	√	×	√	×	×	×	×	×	√	√	×	**7**
d4408-Fine hand use-other specified	**Pick and insert**	×	√	×	×	√	√	×	×	×	√	√	×	√	√	√	×	×	×	×	×	**8**
d4408-Fine hand use-other specified	**Pick, manipulate and insert**	×	×	×	×	√	×	√	×	×	×	√	×	×	√	×	×	×	×	×	×	**4**
d4600-Moving around within the home		√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	√	×	**3**
	Opening door	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	√	×	2
	Using key	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	√	×	3

*ICF codes- each code represents a domain of human functioning or disability *item-test item included on a PBOMD *400T-400-point Hand Function Test *AHFT-Arthritis Hand Function Test *BBT-Box and Block Test *BT-Button Test *CMDT-Complete Minnesota Dexterity Test *CSPT-Crawford Small Part Test *FDT-Functional Dexterity Test *GAT-Grip Ability Test *JTHFT-Jebsen Taylor Hand Function Test *MPA-MacHand Performance Assessment* MMDT-Minnesota Manual Dexterity Test *MPUT-Moberg Pickup Test *NHPT-Nine-hole Peg Test *NKDT-NK dexterity Test *PPT-Purdue Pegboard Test *SODA-Sequential Occupational Dexterity Assessment *SODA-S-Short version of Sequential Occupational Dexterity Assessment *SHFT-Smith Hand Function Test *SGFT-Sollerman Grip Function Test *VWCS4-Valpar Work Component Set 4

Table 4(continued): Overview of ICF codes identified in performance-based outcome measures of dexterity and hand function

		Tool names																				
		400T	AHFT	BBT	BT	CMDT	CSPT	FDT	GAT	JTHFT	MPA	MMDT	MPUT	NHPT	NKDT	PPT	SODA	SODA-S	SHFT	SGFT	VWCS4	Total
ICF code	**Description of items**	**Features representative item**																				
D5(Self-care)																						
d510-washing oneself	**Washing/drying hands**	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	**1**
d520-caring for body parts	**Unscrew/squeeze toothpaste**	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	×	×	×	**2**
d540-dressing		√	√	×	√	×	×	×	√	×	√	×	×	×	×	×	√	×	√	√	×	**8**
	Tying a knot	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	1
	Buttoning	√	√	×	√	×	×	×	×	×	√	×	×	×	×	×	√	×	√	√	×	7
	lacing a shoe	√	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	3
	lacing a bow tie	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	2
	using zipper	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	×	2
	using belt	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	1
	using safety pins	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	2
	pulling on tubigrip onto arm	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	√	×	2
d550-eating	**handling utensils**	√	√	×	×	×	×	×	×	√	√	×	×	×	×	×	√	√	×	√	×	**7**
d560-drinking		√	√	×	×	×	×	×	√	√	√	×	×	×	×	×	√	×	×	√	×	**7**
	pouring water	×	√	×	×	×	×	×	×	√	√	×	×	×	×	×	√	×	×	√	×	5
	Simulated drinking	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	1
	opening bottle cap	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	2

*ICF codes- each code represents a domain of human functioning or disability *item-test item included on a PBOMD *400T-400-point Hand Function Test *AHFT-Arthritis Hand Function Test *BBT-Box and Block Test *BT-Button Test *CMDT-Complete Minnesota Dexterity Test *CSPT-Crawford Small Part Test *FDT-Functional Dexterity Test *GAT-Grip Ability Test *JTHFT-Jebsen Taylor Hand Function Test *MPA-MacHand Performance Assessment* MMDT-Minnesota Manual Dexterity Test *MPUT-Moberg Pickup Test *NHPT-Nine-hole Peg Test *NKDT-NK dexterity Test *PPT-Purdue Pegboard Test *SODA-Sequential Occupational Dexterity Assessment *SODA-S-Short version of Sequential Occupational Dexterity Assessment *SHFT-Smith Hand Function Test *SGFT-Sollerman Grip Function Test *VWCS4-Valpar Work Component Set 4

Table 4(continued): Overview of ICF codes identified in performance-based outcome measures of dexterity and hand function

		Tool names																				
		400T	AHFT	BBT	BT	CMDT	CSPT	FDT	GAT	JTHFT	MPA	MMDT	MPUT	NHPT	NKDT	PPT	SODA	SODA-S	SHFT	SGFT	VWCS4	Total
ICF code	**Description of items**	**Features representative item**																				
D6(Domestic Life)																						
(d630)- Preparing meals		√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	√	×	**3**
	Opening jar	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	√	×	3
	Pouring water from pan	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	1
	Using a match	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	1
	carrying weighted plate	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	1
d6403-Using household appliances		√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	√	×	**3**
	Lifting iron	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	2
	Plugging appliance	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	1
d6405-Disposing garbage	**Tearing newspaper**	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	**1**
D840(Major life areas-Work (manual))																						
d8451-maintaining employment		√	×	×	×	×	√	×	×	×	√	×	×	×	×	×	×	×	×	√	√	**5**
	using pliers	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	1
	threading needle	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	2
	using screwdriver	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	√	×	2
	using tweezer	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	1
	screwing/unscrewing nuts	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	√	√	4
	using hammer	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	1

*ICF codes- each code represents a domain of human functioning or disability *item-test item included on a PBOMD *400T-400-point Hand Function Test *AHFT-Arthritis Hand Function Test *BBT-Box and Block Test *BT-Button Test *CMDT-Complete Minnesota Dexterity Test *CSPT-Crawford Small Part Test *FDT-Functional Dexterity Test *GAT-Grip Ability Test *JTHFT-Jebsen Taylor Hand Function Test *MPA-MacHand Performance Assessment* MMDT-Minnesota Manual Dexterity Test *MPUT-Moberg Pickup Test *NHPT-Nine-hole Peg Test *NKDT-NK dexterity Test *PPT-Purdue Pegboard Test *SODA-Sequential Occupational Dexterity Assessment *SODA-S-Short version of Sequential Occupational Dexterity Assessment *SHFT-Smith Hand Function Test *SGFT-Sollerman Grip Function Test *VWCS4-Valpar Work Component Set 4

Table 4(continued): Overview of ICF codes identified in performance-based outcome measures of dexterity and hand function

		Tool names																				
		400T	AHFT	BBT	BT	CMDT	CSPT	FDT	GAT	JTHFT	MPA	MMDT	MPUT	NHPT	NKDT	PPT	SODA	SODA-S	SHFT	SGFT	VWCS4	Total
ICF code	**Description of items**	**Features representative item**																				
D840(Major life areas-Work (non-manual))																						
d8451-Maintaining employment (non-manual)		√	×	×	×	×	×	×	√	√	×	×	×	×	×	×	√	√	×	√	×	**6**
	Fastening paperclip on envelope	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	√	×	2
	Folding and manipulating paper	√	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	√	×	3
	Picking envelope	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	×	√	×	3
	Drawing a line with a ruler	√	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	2
	Using scissors	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	1
D860(Major life areas-Economic life)																						
d860- Basic economic transactions		√	√	×	×	×	×	×	×	×	√	×	×	×	×	×	√	√	√	√	×	**7**
	Open purse taking out paper	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	1
	Picking up coins	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	√	√	√	×	×	5
	Putting coins into slot	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	1
Total number of ICF codes		15	7	1	1	2	2	1	3	7	13	2	2	1	2	1	9	5	4	12	1	
Total number of discrete items		23	11	1	1	2	3	1	3	6	1	2	2	1	2	1	10	5	11	18	1	

*ICF codes- each code represents a domain of human functioning or disability *item-test item included on a PBOMD *discrete items-tests items representing a unique task *400T-400-point Hand Function Test *AHFT-Arthritis Hand Function Test *BBT-Box and Block Test *BT-Button Test *CMDT-Complete Minnesota Dexterity Test *CSPT-Crawford Small Part Test *FDT-Functional Dexterity Test *GAT-Grip Ability Test *JTHFT-Jebsen Taylor Hand Function Test *MPA-MacHand Performance Assessment* MMDT-Minnesota Manual Dexterity Test *MPUT-Moberg Pickup Test *NHPT-Nine-hole Peg Test *NKDT-NK dexterity Test *PPT-Purdue Pegboard Test *SODA-Sequential Occupational Dexterity Assessment *SODA-S-Short version of Sequential Occupational Dexterity Assessment *SHFT-Smith Hand Function Test *SGFT-Sollerman Grip Function Test *VWCS4-Valpar Work Component Set 4

3.3.2.3 Examining How Task Performance was Quantified by PBOMD

We examined how PBOMD evaluated task performance, by comparing the scoring criteria of each tool to the qualities of dexterous tasks described by Bernstein.[16] All the PBOMD implicitly measured whether the tasks were successfully completed. However, the majority (70%) focused primarily on quantifying speed, and none of the tools addressed the ability to respond to the changing environmental and situational demands dynamically. As outlined in Figure 5a, there was an increase over time (during the mid-1990s) in the number of tools addressing whether the task was performed in an accurate, appropriate manner, with the economy of effort/movement (quality of movement)[51,53–55,57–60] (Refer to fig. 5b for a cumulative number of tools grouped by operationalization method over time).

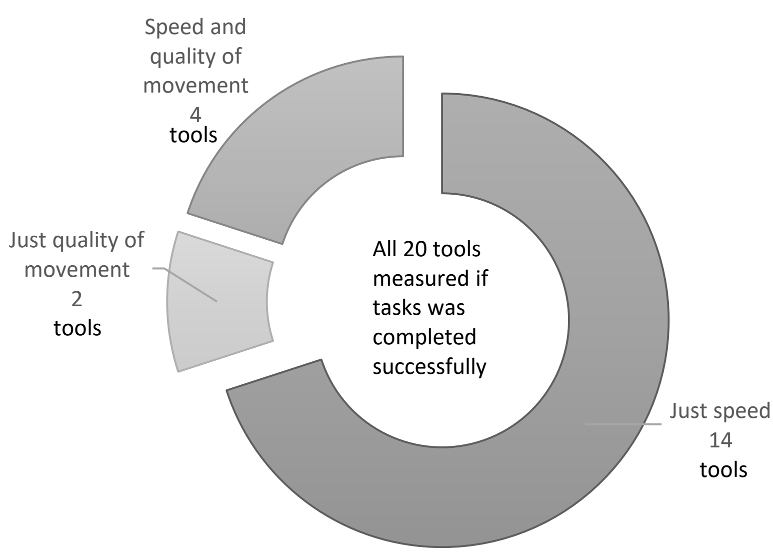


Fig. 5a: Overview of how dexterity and hand function is quantified by identified PBOMD

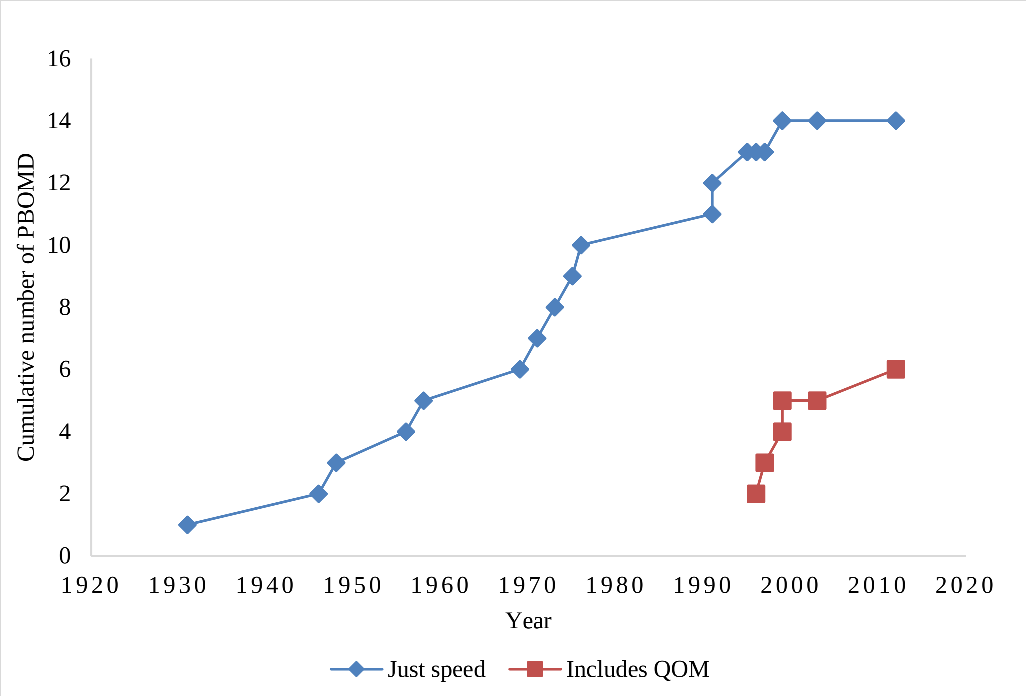


Fig. 5b: Cumulative number of performance-based outcome measures of dexterity and hand function validated for use in hand and wrist injuries grouped by operationalization method over time

3.3.3 Exploring the intended purpose of PBOMD

We examined the intended function of PBOMD and the way these tools operationalized their constructs, to explore how the function of PBOMD and the concept of dexterity and hand function had changed across time. Overall, there seemed to be two main functions driving the creation of the tools; a) to identify and evaluate worker suitability for manual work, or b) for use in healthcare to measure and document the capabilities of the hand (see table 2). Tools with a similar intended purpose tended to exhibit common traits designed to achieve the targeted goal.

3.3.3.1 PBOMD Designed to Evaluate Worker Suitability

Tools designed as a way to select workers for manual labour requiring skilled hand movement were developed between 1931 to 1975.[29–32,34,42,43] Originally intended for healthy individuals, these PBOMD featured precision handling tasks resembling manufacturing and technical work such as the operation of machinery and packing.[32] They quantified performance by measuring speed or task efficiency, and most tended to include normative data of healthy individuals doing manual work as a comparison.[29–32,34,42,43]

3.3.3.2 PBOMD Designed for Use in Healthcare

The PBOMD designed for use in healthcare emerged in 1958 and have continued to increase over time.[35,38,54,57,58,60] These tools, designed for evaluating persons with upper limb impairments, explore hand performance from three primary perspectives: 1) measuring the ability to perform specific prehensile patterns;[56,58] 2) measuring ability to complete functional activities;[38,50,51,57] and 3) measuring function at an activity and impairment level.[41,47,54] While the most common purpose of the tools was measuring the ability to complete functional activities; tools like the Functional Dexterity Test (FDT) and the 400-point Hand Function Test (400T)[55,58] developed in the past 20 years featured the other two approaches. Unique to other PBOMD, the Moberg pick up test was created specifically to measure body function (the impact of tactile/proprioceptive sensation) in a functional manner.[35] Refer to figure 6 for a graph representing the number of developed PBOMD by purpose. Since the mid-1990s, there has been a shift to include evaluation of other aspects of performance, with tools explicitly accounting for the quality of movement in their scoring criteria, for example, the MacHand Performance Assessment, and 400T.[54,60]

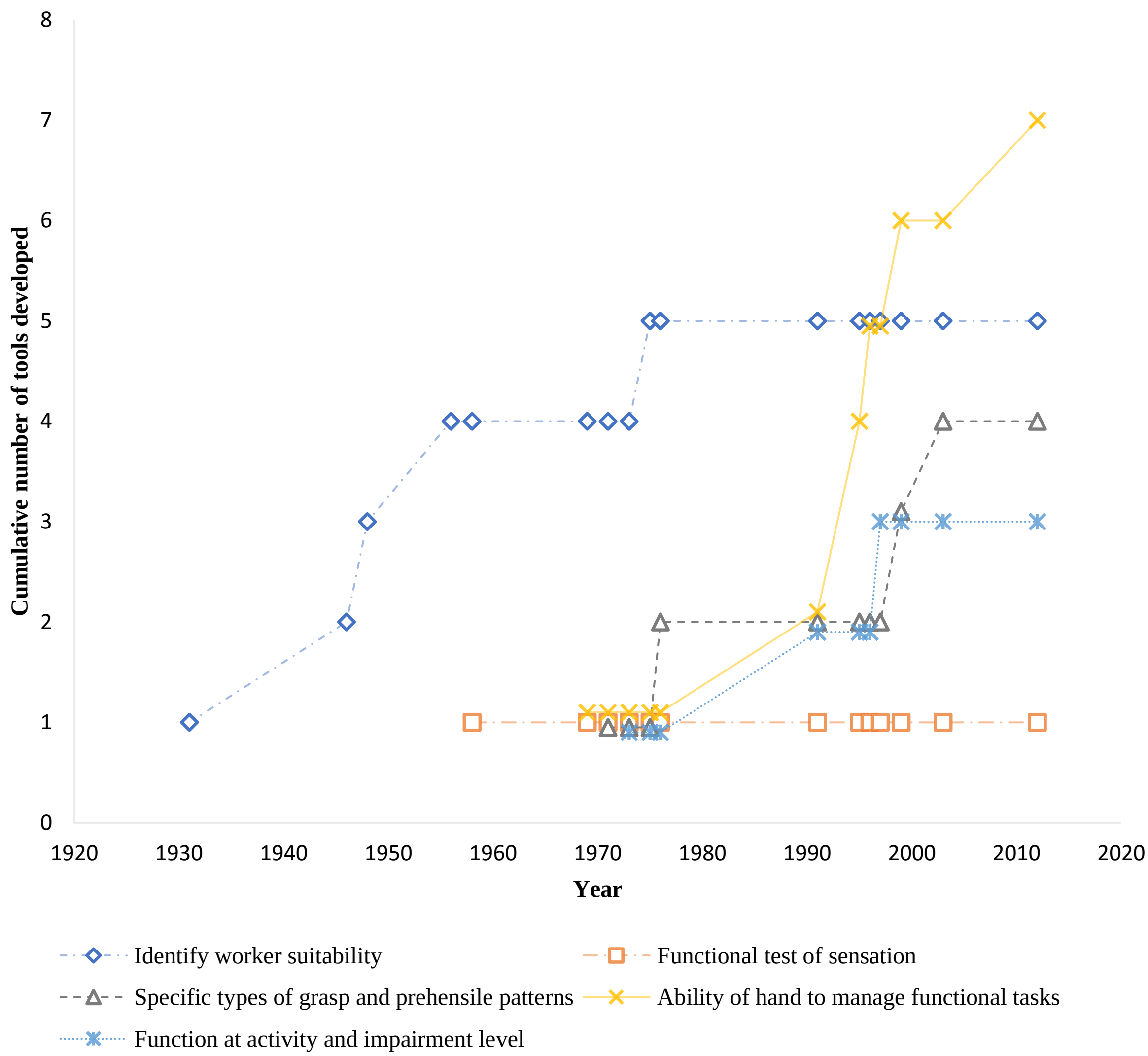


Fig. 6: Graph representing the cumulative number of developed performance-based outcome measures of dexterity and hand function (PBOMD) grouped by the original purpose of the tools, over time.

3.4 Discussion

This study highlights several key issues, including; the ambiguity and overlap in the constructs of dexterity and hand function, the diversity of potential PBOMD currently available, and the conceptual gaps in identified tools. The study findings also illustrate the shift in theory and practice over time towards function-focused items and inclusion of qualitative assessments of task performance.

3.4.1 Avoiding the Overlap in Constructs-Dexterity and Hand Function

This study identified that both the constructs- 'dexterity of the hand' and 'hand function' examined the ability to execute motor tasks, with the latter having a stronger focus on everyday activities. The shared meaning of both terms leads to an overlap between popular definitions of 'hand function' used in healthcare, and 'dexterity' of the hand and upper limb. The overlapping concepts are also suggested in previous reviews focusing exclusively on outcome measures of dexterity or outcome measures of hand function, where similar tools were included in both types of reviews.[7,9,12,28] Lack of consensus around the definition of both constructs was also reflected in a qualitative study of therapists' perceptions on the measurement of dexterity done by the principal investigator.[63]

The evolving understanding and measurement priorities of dexterity and hand function can be inferred from trends in tool development, which reflect an increased focus on attempting to account for the diversity of hand movements and grasp patterns,[51,59] while simultaneously trying to incorporate items representational of daily life.[64,65] These trends appear to support convergence in the operationalization of the constructs of hand dexterity and hand function. Studies conducting factor analysis of dexterity tools[61] and hand function tools,[66] noted that they loaded onto many common factors, which further supports the hypothesis that they measure the same construct in different ways.

It has been suggested that dexterity does not need to be restricted to the hand.[16] Dexterity refers to whether the given task was performed with respects to all indicators of success, including task efficiency, quality of movement and ability to complete the task in response to the changing environmental demands (according to Bernstein)[16]; therefore we recommend that dexterity of the hand is not limited to finger or fine movement, but can be used to consider the broader performance of purposeful daily activities. We believe the construct of dexterity is relevant to the assessment of daily tasks and congruent with the way that task performance is evaluated in actual practice. Therapists are already observing dimensions like the quality of movement and accounting for natural variation in the environment when they evaluate task performance.[63,67] This model of hand and wrist dexterity, however, requires further empirical evaluation to determine its utility in clinical practice.

While hand function is used by many to refer to the ability to perform purposeful daily activities, it can be used as an umbrella term to encompass all body function and structures of the hand. As there is currently no unified understanding of the term 'hand function,' we suggest that users should explicitly define what they mean when using this term and examine whether the PBOMD they use are congruent with the construct they are looking to measure. The model cataloguing the scope of each PBOMD with reference to their definitions (refer to fig. 2) can be used as a guide to helping users select tools that match the construct they wish to measure.

3.4.2 Establishing the Validity of PBOMD

Content validity is the cornerstone of measurement, featuring two important components; comprehensiveness (i.e. whether the key concepts of the construct is represented in the measure), and relevance (i.e. whether the items on the tool are relevant to the construct, target population and context of use).[13]

When we critically examined the comprehensiveness of the tools against dimensions of dexterity, the scope of human performance represented by 1) the functional purpose of the task in human life, and 2) biomechanical elements of the tasks, it appeared that some dimensions of the construct were absent. For example, no tool accounted for the ability to complete a task by anticipating and responding adequately to changing circumstance or environment(for example, catching a falling object).[16] This quality may be an important measure of the integration of the neurological and sensorimotor system and may be essential to daily living tasks.[68]

A more nuanced issue relates to the comprehensiveness of PBOMD in representing the breadth of human performance. Despite the wide representation of activities of daily living and grasp patterns featured by the identified PBOMD, only the Sequential Occupational Dexterity Assessment represented non-prehensile patterns, and no tool represented the hook grasp pattern or all activity domains of the ICF. While the decline of tools designed to simulate manufacturing work suggests efforts to broaden cultural relevance, there is a lack of tools representing tasks featuring domains of leisure pursuits like sports, community and social life, and modern technology. These domains have been described to be greatly affected by persons with malunited distal radius fractures in a recent qualitative study by Andreasson et al.[69] Thus, these domains should ideally be accounted for in the tools we use today as they may prove relevant to persons with HWC. Pragmatically, it may not be feasible nor clinically necessary to represent all the potential domains of function within a single tool, for example, precision handling assessments may be more responsive to persons with injuries to the thumb, the second, and third fingers. Furthermore, multiple shorter PBOMD representing different relevant dimensions or domains can be administered together if a more robust interpretation of dexterity and function is required. Thus, the relevance of the assessment should be considered based on the specific need of each targeted population.[13]

Another element of comprehensiveness and relevance relates to increasing representation of diverse dimensions of dexterity and hand function in newer tools. Task efficiency, however, is still a dominant attribute, since quantifying speed was central to 19 out of the 20 tools (90%) validated for use in persons with hand and wrist conditions. The prominence of task efficiency in the identified tools differs from the composition of tools found in a narrative review by Wang et al.[28] which included populations with central nervous system conditions like stroke, finding only 5 of 17 included tools (29.4%) were timed tests. The difference between the two reviews could reflect a pragmatic difference in the execution and interpretation of the tools between the different populations, or a different set of expectations and priorities in functional recovery between the two different populations. The number of tools found to consider the quality of movement is similar to that of Wang et al.[28] and is consistent with the knowledge that there are alterations to movement patterns and reduced reaction speed after common musculoskeletal hand injuries such as chronic wrist pain or tennis elbow.[70,71] The value of considering the quality of movement seems intuitive, but no studies to our knowledge have formally evaluated whether including this dimension improves the predictive ability of these measurement models.

3.4.3 Discordance Between the Shift in Tools Developed and Tools Being Used

There has been a shift in the intended purpose and characteristics of tools being developed across time. Tools have changed from tasks characteristic of the manufacturing industry, prioritizing the measuring of task efficiency; to increased representation of daily activities and grasp pattern representation, and evaluation of dimensions such as quality of movement. The identified trend in tool design, however, may not reflect the tools being used by clinicians, since the most frequently used PBOMD includes tools like the Purdue Pegboard Test and Nine-hole Peg Test, both of which measure primarily dexterity of the finger with a focus on task efficiency.[72] This lag in the uptake of newer, more comprehensive and relevant tools could be due to difficulties in accessing information about the newer tools,[63] or lack of research investigating the psychometric properties of the newer tools.[7]

3.4.4 Limitations

There are several limitations in the study design that need to be considered. In this study, only one reviewer screened the names of tools and the titles of citations during the first round of screening. The reliance on one reviewer increased the chance of omitting articles. However, the study team attempted to control for this limitation by conducting a pre-screening pilot test of the screening criteria to ensure consistency of judgement. Another potential limitation is that the potential grasp patterns used during PBOMDs were generated by the reviewers rather than directly observed. Although the reviewers had experience in rehabilitation of persons with hand and wrist injuries and attempted to identify patterns that may occur in different populations, observational studies need to be done to determine which patterns are actually used in each PBOMD. A third limitation is that the study findings are based on tools with at least one study investigating the psychometric properties of the tools in persons with hand and wrist conditions, and may, therefore, exclude tools that are used in practice but are not reflected in the peer-reviewed literature. This criterion pragmatically selects for the included tools that other researchers deem useful to investigate, but it may exclude tools that are used in other patient populations or newly developed tools that may be relevant for use with persons with hand and wrist conditions. Finally, the tool development process and psychometric properties were not evaluated; these factors need to be considered when selecting a tool for clinical use or research.

3.5 Conclusion

Valid and psychometrically robust tools are an important part of patient care. This review provides an overview of how dexterity and hand function are defined and operationalized in the management of persons with hand and wrist conditions. It also reflects the shifting perspectives around the operationalization of dexterity, the evolution of hand function relative to changing activity demands determined by societal changes over time and reveals how both constructs are intertwined. In this way, hand function can be viewed as an anthropomorphic construct. This review also serves as a resource for clinicians and a foundation for thoughtful future evaluation, development and refinement of dexterity and hand function measures.

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4 Chapter 4: Conclusion, Implications and Future Directions

Key Overall Findings of the Thesis

- The terms 'dexterity' and 'hand function' have multiple and overlapping meanings in hand and upper limb rehabilitation.

- Current measurement models of dexterity and hand function exhibit considerable variation in the scope and dimension of the represented construct. None encapsulate Bernstein's conceptual model of dexterity, nor all the domains of activity and participation in the International Classification of Function, Disability and Health.

- Occupational Therapists working in hand and upper limb rehabilitation in Singapore consider more dimensions of dexterity (for instance, the presence of abnormal movement patterns at other parts of the body) when measuring dexterity in clinical practice than current Performance-based outcome measures of dexterity and hand function (PBOMD).

- Occupational Therapists working in hand and upper limb rehabilitation in Singapore are unaware of the range and properties of PBOMD that are available currently. Most of the PBOMD that they are aware of were created before the 1990s.

- Identifying reasons for impaired task performance is one of the key goals for clinicians who want to evaluate dexterity, yet, this is not a feature of any standardized PBOMD.

- Barriers to the clinical use of PBOMD included lack of knowledge or awareness of tools, and how to interpret findings; lack of perceived benefit of PBOMD; and lack of access to tools. These are complex issues that require intervention at the therapist, organization and policy level.

4.1 Overview of Thesis

This thesis aimed to study how dexterity is measured in the rehabilitation of persons with hand and wrist conditions (HWC), to serve as a foundation to advancing measurement practices that assist in clinical decision making and accurate evaluation of treatment programmes. A qualitative inquiry approach was adopted to understand how dexterity is defined and measured by clinicians, as well as how it is defined and operationalized in current performance-based outcome measures of dexterity and hand function (PBOMD).

The first study presented in *Chapter 2: 'Measuring the elusive': A qualitative exploration of therapists' perceptions on the measurement of dexterity in hand and upper limb rehabilitation*, describes how occupational therapists in Singapore approach the measurement of dexterity in clinical practice. An interpretive description approach was adopted, with study findings highlighting the ambiguity surrounding the concept of dexterity and its measurement. The findings also describe the barriers identified by therapists to standardized evaluation, including skepticism regarding the value of PBOMD; lack of familiarity with PBOMD; and difficulty with accessing these measures. We identified recommendations that could support advances in the measurement of dexterity in the clinical practice of occupational therapists working in Singapore.

The second study in *Chapter 3: Performance-based outcome measures of dexterity and hand function in persons with hand and wrist injuries: A structured review of measure constructs*, used a systematic approach to identify PBOMD validated for use with persons with HWC. A content analysis approach was used to 1) examine how tool developers defined dexterity and hand function; 2) explore the evolving uses of PBOMD; and 3) compare conceptual linkages between what is measured in PBOMD to key concepts within a seminal definition of dexterity as well as to key dimensions of function outlined in the ICF. Several trends were noted, including overlap between the definition of dexterity and hand function; changes over time in the profile of PBOMD; and gaps in the extent to which the current PBOMD capture key dimensions of dexterity. We provided an overview of PBOMD, details of their measured constructs, and their congruence with ICF and dexterity theories. These can serve as a foundation to judge content validity.

4.2 Lay Summaries of Thesis Manuscripts

4.2.1 'Measuring the Elusive': A Qualitative Exploration of Therapists' Perceptions on the Measurement of Dexterity in Hand and Upper Limb Rehabilitation.

Dexterity is the ability to do tasks well and is an important part of day-to-day function. Unfortunately, many people with hand and arm injuries lose the dexterity of their hand. During a dexterity test, the patient typically completes a set of tasks that are graded by a health professional. Although standardized tests are considered a part of high-quality evaluation, many health professionals do not use standardized dexterity tests.

This study aims to understand how therapists measure dexterity. In this study, we focused on occupational therapists working with people with hand and arm injuries.

We interviewed twelve occupational therapists working in Singapore. Therapists were purposively selected from different work settings to get different types of opinions.

We asked these therapists to share their experiences and thoughts about measuring dexterity. Interview transcripts were analyzed to identify patterns in the therapists' responses. One key finding was that dexterity does not have a clear, common meaning to the therapists. Many therapists shared that they do not think about dexterity and that their workplaces do not have procedures for measuring dexterity. Next, therapists appeared to have opposed ideas about how to measure dexterity. Finally, therapists do not find the dexterity tests that they have at their workplace to be useful. One key recommendation is to build a clearer understanding of dexterity in order to improve the way therapists evaluate it in practice.

4.2.2 Performance-based Outcome Measures of Dexterity in Hand and Upper Limb Rehabilitation: A Structured Review of Measured Constructs

Dexterity is the ability to do tasks well. It is common to lose hand dexterity during a hand and arm injury. Losing dexterity makes it difficult to work and do the tasks that we enjoy. Currently, dexterity can take on different meanings to different people; this can make it hard for health professionals to understand each other.

The lack of common understanding makes it difficult to read and do research on dexterity. We did a review of research studies to summarize the different ways that standardized tools measure dexterity. This review focused on 1) dexterity tests that grade the patient based on how they do a task and 2) dexterity tests tested for use in people with hand and wrist injuries.

We searched four different electronic databases for studies on dexterity tests. We completed the search in August 2018. Two researchers (JY and PB) looked through the electronic records separately to find studies on the dexterity tests to include in the study. Then, we found the first published records of each of the chosen dexterity tests. Separately, two reviewers (JY and TP) 1) compared the way that dexterity was measured by the chosen dexterity tests to dexterity theories; 2) the intended purpose of the dexterity tests; 3) What the dexterity test designers meant when they used the words ‘dexterity’ and ‘hand function’ was also examined by the reviewers.

Twenty dexterity tests met our criteria. We found that dexterity test designers did not operate with a common understanding of the terms dexterity and hand function. Some test designers felt dexterity and hand function referred to different abilities. To other test designers, the two terms were identical.

The intended purpose of the dexterity tests also changed over time. The earlier dexterity tests (1931-1975) were designed to help identify persons best suited to manufacturing work. Newer tests were designed for use to monitor the patient’s recovery in healthcare. The newer tests incorporated a broader range of tasks representing daily life than the older tests. The newer tests also graded how the patient performed the task rather than just how fast the patient did the task. None of the dexterity tests included tasks that captured performance related to hobbies, or technology use (e.g. computers or smartphones). No test looked at a person’s ability to do a task while responding to changes in their surroundings. An example of completing a task by reacting to the surrounding could be balancing a tray of food when you trip on a step.

This study illustrates diversity in the way that dexterity and hand function are conceptualized and then measured across different tests. Variation in comprehensiveness and specificity of the tools may be important selection criteria for health professionals, depending on their evaluation goals. Health professionals may need to pair their chosen test with another testing method that provides information for aspects of dexterity that are missing.

4.3 Discussion on the Definition and Measurement of Dexterity in Hand and Upper Limb Rehabilitation

In this thesis, I examine how dexterity is defined and measured in hand and upper limb rehabilitation from two perspectives: 1) occupational therapists working in Singapore with persons with HWC and 2) development documents/ user manuals on PBOMD validated for use in persons with HWC. Both studies highlight the lack of clarity on how to define dexterity and describe how this lack of clarity may translate to inconsistencies in evaluation. In addition, there are PBOMD that therapists are not aware of and thus do not use in practice.

4.3.1 Different Ways to Reach the Same Destination-Common Interpretation of Dexterity by Therapists and PBOMD; Differences in the Way that Both Groups Operationalized Dexterity.

The study in *chapter 2* highlighted the different ways that therapists defined dexterity which ranged from a specific set of skills (‘fine motor skill,’ ‘skilled manipulation of objects,’) required for performing daily life tasks with the hand; to skills that encompass the whole broader spectrum of upper limb function (‘global ability of the hand’). The study in *chapter 3* showed that although there were differences in the way therapists and PBOMD measure dexterity, semantically, the documents on PBOMD that explicitly define the constructs ‘dexterity and ‘hand function’ had a similar, vague scope of definitions as the therapists. This suggests a lack of clear discourse in the field of rehabilitation and a need for more conceptual clarity. This lack of clarity around the discourse on dexterity was identified in the past but little has changed since then (Backman C, Cork S, Gibson D, & Parsons J, 1992; Poirier, 1988).

There were several important disconnects between how therapists evaluated dexterity and the approaches embedded in standardized evaluation tools. *Chapter 2* identified that therapists do not use PBOMD regularly. Instead, therapists often sought patients' subjective perceptions about their ability to do tasks; deduced the patient's ability at daily tasks from the level of impairment; or documented their subjective observations of a patient's task performance. Some therapists accounted for the time taken(speed) to complete a task in their assessment. However, it formed only part of their assessment. This multidimensional approach to measuring dexterity is congruent to the conceptual ideas of Bernstein but is contrary to many of the established PBOMD which focused exclusively on task efficiency rather than the quality of task performance. Moreover, none of the measures comprehensively cover the construct of upper limb dexterity as defined by Bernstein, for instance, the ability to successfully complete a task in the face of changing task and environmental requirements (Bernstein, 1996). The mismatch between the way clinicians and PBOMD measure task performance may be one of the reasons for the lack of popularity of PBOMD among clinicians.

However, our study in *Chapter 3* reveals that greater number of newer PBOMD (like the Sollerman hand function test or 400-point Hand Function Test) arising after the 1990s try to accommodate more dimensions of dexterity like the economy of movement and effort. However, despite the more holistic approach to measurement, these PBOMD remain less popular than the well-established measures (such as the Purdue pegboard or Jebsen Taylor Hand Function Test) with therapists working in hands and upper limb rehabilitation (Grice, 2015). The poor adoption of these newer measures could be related to some of the barriers and facilitators raised by the therapists in *Chapter 2*, such as lack of awareness and access to these PBOMD; or the therapists' impression that PBOMD that used assessor-rated scales are less objective than PBOMD that scored dexterity using the time taken; or the number of task repetitions completed under a time-limit. The considerations mentioned above need to be addressed when developing or adapting a newer measure.

In chapter 2, many of the therapists that we interviewed questioned the validity of PBOMD and whether the results can be generalized to ability in performing life roles. The therapists perceived greater validity of the tests for their patients who did industrial work reminiscent of tasks common to the 1930s-1960s. Their doubts about the validity of current PBOMD is echoed in the results of our study in chapter 3. We noticed that many of the well-used tests were developed for selection of workers in the manufacturing industry none of the identified PBOMD covered the ICF domains: 1) d7-Interpersonal, interactions and relationships; 2) d9-Community, social and civic life (World Health Organization, 2001); the PBOMD did not represent engagement in leisure, use of modern devices, nor the role of the hand as an organ of communication and expression. Empirically, there have been few studies supporting the validity of these tests (Ven-Stevens, Munneke, Terwee, Spauwen, & Linde, 2009).

4.3.2 The Differences in Reasons for Measuring Dexterity

In the study in *chapter 3,* we explored how the intended purposes of PBOMD have changed over time from aiding in the selection of workers to measuring the ability of the hand to manage functional tasks. All these PBOMD were meant to describe dexterity at the moment in time and evaluate how dexterity changes over time. However, in the study done in *chapter 2*, we found that while some therapists measured dexterity to evaluate change over time, all of the therapists we interviewed assessed dexterity (generally by observing a task relevant to the patient or via a PBOMD) in order to identify reasons for poor task performance. None of the PBOMD we identified in our review in *chapter 3* were designed for this purpose, and therefore, therapists are using tests for purposes that they were not intended.

4.3.3 Lack of Awareness of Available PBOMD

Finally, therapists interviewed in the study done in *chapter 2* shared that they felt that there was a lack of awareness of what PBOMD were available. Most of the therapists were only able to name five to seven PBOMD, and most of the PBOMD the therapists were familiar with were created before the 1990s. The review we did in *chapter 3* found that there are at least 20 PBOMD that were validated for use in HWC, confirms this lack of awareness.

Furthermore, this information is not new; there were systematic reviews on PBOMD done in the past which have listed more than seven PBOMD (Ven-Stevens et al., 2009; Yancosek & Howell, 2009). The therapists interviewed in this thesis suggested reasons such as being unable to locate information on the PBOMD as well as limited access to literature. Most of these therapists learn about new PBOMD when they attend workshops, conferences, or when they develop new treatment programmes or research projects. The lack of awareness among clinicians about the range of PBOMD available suggests that current dissemination methods are insufficient at informing clinicians about developments in the measurement of dexterity.

4.4 Limitations of the Thesis

This thesis provided new and unique insights into dexterity, but also left many unanswered questions and had limitations that should be considered when interpreting the individual studies. A qualitative approach was adopted to explore the contextual forces that shape knowledge and clinical practice; this inductive approach allowed us to gain an in-depth understanding into the complexity of clinical practice, not achievable through pre-determined hypothesis testing. The downside, however, is it is unclear if the findings can be directly generalized to other contexts. The primary data source for *chapter 2* was semi-structured interviews with a small sample of Singaporean occupational therapists working with persons with HWC. Due to ethical and pragmatic considerations, we were unable to do participant observation. The reliance on interviews as a data source means that the study presents a single, retrospective perspective of the measurement of dexterity in clinical practice. Observation, as well as interviews over time with the therapists, would have added depth of understanding of the phenomena and contributed to a more well-rounded understanding of the phenomena, allowing for a more thorough exploration of the unconscious or unsaid practices around the measurement of dexterity (Becker & Geer, 1957).

In *chapter 3*, only the principal investigator screened the titles and names of tools. The use of one reviewer may potentially result in an increased risk of selection bias and missing an article (Edwards et al., 2002). We tried to minimize this risk by doing a pilot test of the screening criteria to calibrate the judgement of the person doing the screening. In addition, all subsequent phases, which involved more complex judgement, were conducted with two reviewers.

Two reviewers who worked in hands and upper limb rehabilitation mapped out the potential grasp patterns that might be used during a PBOMD to explore the extent that PBOMD represented the human performance from a biomechanical perspective (an approach that some of the therapists we interviewed used). The reviewers made this judgement through a consensus process; however, we are unable to conclusively establish the actual grasp patterns used during the PBOMD without doing a biomechanical analysis of the performance of a PBOMD. Therefore, there may be variations between the grasp patterns that we predict will be used and the patterns used in actual task performance.

Overall, the two studies in this thesis seek to represent the way dexterity is being interpreted and measured in persons with HWC. However, we only examined two perspectives of what is a very large issue. We did not examine the use of the term dexterity in other documents (like intervention trials, studies examining measurement properties and practice guidelines), whether this perspective varies across other countries, and how other professionals (like surgeons, nurses and physiotherapists who work with persons with dexterity impairments) view the concept of dexterity. Furthermore, the concept of dexterity is relevant in different patient groups and industries (like engineering or neuroscience). These perspectives may provide further insight into the creation of a robust measurement model of dexterity, which may be useful for the care of persons with HWC.

We also limited the articles we examined to the PBOMD validated for use with persons with HWC. Thus, this thesis only represents how a subgroup of occupational therapists in Singapore perceives dexterity and its measurement; it is uncertain whether these observations can be generalized to other populations. However, I have presented the findings of this thesis to diverse groups of people, including Canadian hand therapists and physicians, who largely acknowledged that results resonated with them.

Finally, *Chapter 3* only examines one aspect of the content validity of the PBOMD. Thus, these findings cannot be used to make strong recommendations about which PBOMD is the most suitable for use in practice. A systematic review, which includes an evaluation of all psychometric properties, is required to make that judgement (de Vet, Terwee, Mokkink, & Knol, 2011).

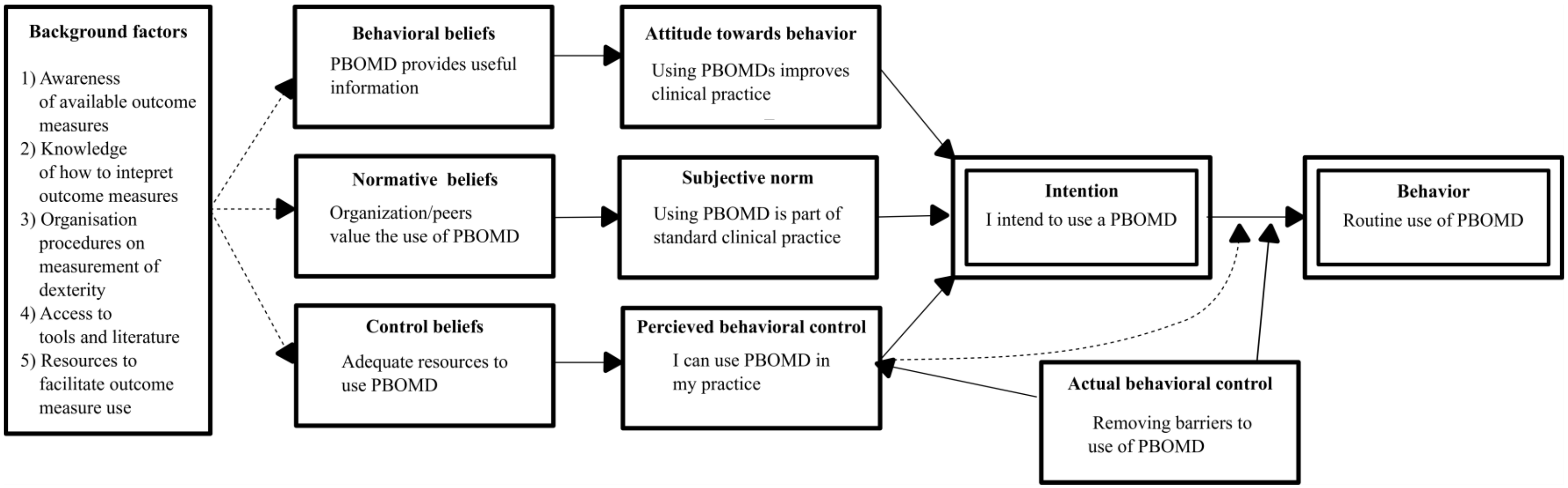
4.5 Practice implications

This thesis aims to promote awareness and reflection about the conceptual complexity of dexterity and the challenges of measuring dexterity for patients with HWC. I believe that through awareness and reflective examination of this concept, we can develop a common, shared understanding of the concept, and measurement models that are clinically useful and relevant. A comprehensive, theoretically informed definition of dexterity would help us evaluate and improve current PBOMD or develop new PBOMD if required. A unified understanding of dexterity would also aid in communication amongst clinicians. Consolidation of literature based on a shared vision of dexterity could also reduce misunderstandings, as well as promote focused research on various dimensions of dexterity and its measurement.

At this point, we are unable to make a practice recommendation on the best PBOMD to measure dexterity without further investigation. I believe that while there is currently no single PBOMD that comprehensively measures dexterity, the current measurement tools (especially those with robust psychometric properties) allow clinicians to describe the different dimensions of dexterity in a comprehensive and standardized way. This view is congruent with the benefits that some therapists articulated in the study presented in *chapter 2.*

This thesis has identified future directions that can potentially encourage the use of standardized measures of dexterity in persons with HWC. I will be explaining these implications in the following section using Fishbein and Ajzen's (2010) Theory of Planned Behaviour.

The Theory of Planned Behaviour is based on the premise that humans are rational and use available information to make decisions; therefore, the intention to perform the behaviour (the determinant of whether the behaviour is performed) is based on 1) Attitudes towards the behaviour which are the individual's beliefs about the consequence of the behaviour; 2) Subjective norms, which are opinions and expectations of the group of people that the person seeks to conform to; 3) perceived behaviour control which is the individual's perceived ability to perform the behaviour (Fishbein & Ajzen, 2010). The background factors like personality, social factors, presence of information; as well as actual behaviour control (environmental factors) indirectly contribute to these elements, thus whether the behaviour is performed (Fishbein & Ajzen, 2010). The targeted behaviour in question is the use of standardized outcome measures to measure dexterity (refer to fig 1 for diagram).



*Performance-based outcome measures of dexterity and hand function (PBOMD)

Fig. 1: Visual representation of the Theory of planned behaviour (Fishbein & Ajzen, 2010)

4.5.1 Attitudes Towards behaviour (Using of PBOMD)

In *chapter 2*, we found that therapists perceived that PBOMD were only useful under certain circumstances and may not always impact clinical decision-making. Thus, they perceived there was insufficient time to invest in executing these measures. In *chapter 3,* we ascertained that therapists were unaware of newer measures that they may potentially find useful. Duncan & Murray's (2012) survey on the barriers and facilitator of routine outcome measure use, found similar results, identifying that therapists' perception that standardized outcome measures do not provide value is a barrier to the routine use of standardized outcome measures. There is a need to challenge this perceived lack of value of PBOMD to improve the use of standardized outcome measures of dexterity. Potential benefits of standardized outcome measures like enhanced clinical decision making, assisting in setting realistic goals for the patient, and how to understand the results should be made known to therapists (MacDermid & Stratford, 2004). Hence, it is important to increase awareness of the benefits of the routine use of standardized outcome measures and increase the knowledge on how to interpret these measures in therapists working with persons with HWC. Increasing the awareness of the benefits of outcome measures may require a multi-pronged approach: increasing access to information about these outcome measures through increased literacy about finding relevant information, and advocating for open access; as well as conducting educational interventions that demonstrate the use of these measures to aid in clinical practice.

4.5.2 Subjective Norms

In *Chapter 2,* we discovered that organizational procedures did not regularly require the measurement of dexterity or the use of PBOMD. There was also an absence of dialogue on dexterity by the therapists themselves. Gaps in verbal and printed communication may contribute to the culture of non-use of PBOMD. Many of the interviewed therapists viewed the ability to document and compare the progress of their patients as a benefit of PBOMD. A PBOMD may be seen as more useful if comparisons can be made between different therapists within the same organization.

If we want to increase the use of PBOMD, we need to create a culture which uses common, high quality, reproducible measurements of dexterity and values the use of standardized outcome measures. Cultural and social norms around the value of routine, standardized outcome measures are related to the awareness of the benefits of measurement of treatment outcomes, and how the organization measures value delivered to stakeholders. In Singapore, the primary measure of the therapist's performance is the number of patients billed in a day and the amount of billable time spent with the patient. In a system that does not incentivize the use of outcome measures, the therapist does not have to prove the value of their treatment to anyone other than the patient. Changes to therapist performance metrics would need to occur at a policy level (hospital or health ministry).

4.5.3 Perceived Behavioural Control

A major theme that emerged in *chapter 2* was the lack of access to information and resources to use PBOMD. Lack of access is a nuanced issue, as it is also associated with therapists' perceptions of resources and control over their work. In our study in *chapter 2*, some therapists found ways to negotiate the limitations on time, and access to information and PBOMD, while other therapists were not able to do so despite being given the same resources. Strategies such as the use of therapist assistants to assist in the administration of the PBOMD, using environmental markers to simplify the set up of PBOMD, or planning their schedule to allocate time to administer PBOMD can be shared with other therapists to increase perceived control over the ability to use PBOMD in practice.

Ideally, we should increase the actual access to resources such as time with patients, journal articles (information), and high-quality PBOMD tools to encourage the use of standardized outcome measures. However, increasing access to these resources is also complicated as it requires proving to decision-makers at the department, organization and ministry level that increasing the access to these resources would improve patient care and/or reduce cost.

4.6 Knowledge Translation

This thesis presented a description of the current status of dexterity measurement in hand and upper limb rehabilitation. Study findings will be disseminated to stakeholders at local conferences in Singapore and Canada to raise awareness of the current ambiguity around dexterity and its measurement. In addition, the findings will be published in peer-reviewed journals, with pre-prints available so that therapists can access the overview of the content of current PBOMD in *chapter 3*, to assist them in making the decision on which PBOMD to use. Finally, I will be sharing the findings at Singapore hand therapy special interest groups to reach more knowledge end-users.

The findings in this study identify issues and priorities to improve measurement practices in the rehabilitation of persons with HWC. It is the first step in the Knowledge to Action Cycle proposed by Graham et al. (2006), and the next step would be conducting knowledge synthesis to identify, review and select a knowledge product or tool best suited to addressing the practice and policy recommendations identified in this thesis.

4.7 Future Research Directions

Developing a clearer understanding of dexterity is an ongoing priority. Through the exploration of measurement practices of occupational therapists in Singapore, I identified that dexterity (as defined by Bernstein (1996)) is congruent with the indicators of task performance that therapists measure explicitly (actual success in performance, speed, economy of effort), as well as implicitly (economy of movement patterns and ability to perform tasks in environment which has the potential to change) in clinical practice. The congruence between clinical practice and the dimensions of dexterity demonstrates that this concept of dexterity has face validity as a clinically useful measurement model. This model of dexterity has yet to be tested empirically to determine its worth, and thus, further research is required to improve our understanding of the construct of dexterity.

We can contribute to the understanding of dexterity while improving our measurement of upper limb dexterity in clinical practice, by developing dexterity measurement models and outcome measures that are grounded in an empirically supported, comprehensive understanding of dexterity. This conceptual understanding is essential for content and construct validity and is one of the most important attributes when determining the quality of a measure (Terwee et al., 2018).

Dexterity is not a unidimensional construct. The current PBOMD vary in terms of the degree to which they measure different dimensions of dexterity. A comprehensive measure of dexterity should start with a rigorous and clear conceptual framework and definition. Factor analysis of the current measures suggests that these dimensions can be classified by anatomical locations or specific types of tasks (Fleishman & Hempel, 1954; Jarus & Poremba, 1993). However, certain dexterity tasks are missing from current PBOMD, such as engaging in leisure pursuits (including sports and musical instruments); using modern technology (including smart devices and computers); and performing non-prehensile tasks such as sign language. We should examine these tasks, as not only do they appear to be biomechanically different, but they are also an essential way of representing functionally relevant, yet diverse needs of the population of people with dexterity impairments.

Furthermore, the PBOMD currently used in practice such as Purdue pegboard or the Nine-hole Pegboard Test (Grice, 2015) do not adequately represent the performance attributes of dexterity tasks such as having the economy of movement and being able to adapt to external circumstances. Studies should be done to see if these dimensions contribute to the latent construct-dexterity in a clinically meaningful way.

There is increasing interest in using sophisticated motion capture equipment, in potential treatment and assessment equipment for persons with central nervous system conditions; however, these equipment are not ready for widespread adoption. In addition, the equipment uses upper limb kinematic models that have not been thoroughly validated (Valevicius, Jun, Hebert, & Vette, 2018; Wang, Chen, & Markopoulos, 2014). Thus, the judgement of correct movement for the regular therapist working with persons with HWC remains a subjective and difficult one. We currently do not have enough information to state which set of movements are ideal for daily activities from a biomechanical/ergonomic perspective, or objectively quantify whether a patient's movement is within range of the 'correct' or 'appropriate' pattern of movement to complete the task. Further development of these technologies could aid in our understanding of these patterns and help quantify economy (quality) of movement.

In the study featured in *chapter 2*, we discovered that all therapists assess dexterity (ability to perform tasks) to identify reasons for poor task performance. This purpose is currently not supported by current PBOMD. Thus, developing a measurement which supports the identification of the reason for poor task performance will add objectivity and improve the clinical decision-making process.

4.8 Conclusion

This thesis aimed to promote and support measurement practices that will improve patient care and service delivery by exploring and describing how dexterity is defined and measured in the rehabilitation of persons with HWC. To achieve this goal, we interviewed occupational therapists working with persons with HWC, to understand their perspectives regarding the measurement of dexterity, the role of PBOMD in their clinical practice, as well as the issues they faced trying to measure dexterity. Following this interview study, we did a systematic search of the literature to identify PBOMD validated for use with HWC. We explored how PBOMD and the construct of dexterity have changed over time and compared the identified PBOMD with the current conceptual understanding of dexterity, to understand how dexterity is operationalized in current practice in comparison to theory.

The findings of this thesis support the clinical utility of Bernstein's model of dexterity. It raises awareness of the confusion surrounding the definition and measurement of the complex construct of dexterity, and the barriers that clinicians faced when trying to measure dexterity in clinical practice. Our results also serve as an overview of current constructs measured by PBOMD and can be used as a foundation for judging the content validity of dexterity outcome measures.

4.9 References

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Appendix A: Semi-structured interview guide

Primary Question	Possible prompts
1. Tell me about your current job	1. What are the types of patients seen? 2. What is the caseload like? 3. How long are the sessions? 4. Who refers these patients to you? (Are there any specific expectations?) 5. Are there specific assessments or protocols used in your setting?
2. What does a typical therapy session look like? (Could you walk me through a typical therapy session?)	1. What is the focus of your sessions with your patients? 2. Does this differ for different groups of patients/ Are there exceptions? 3. Does everyone here use a similar approach? 4. What do you need to assess?
3. How do you measure progress? -Can you relate an example of a patient to me	1. How did you decide on these outcome measures? 2. How do you use them? 3. Are there any limitations to your approach or the tools? 4. Does everyone here use a similar approach? 5. Standard outcome measures, what do you think of them? 6. Can you tell me of an occasion where you used a standardized outcome measure?

4. How do you assess dexterity in practice? 5. Do you use specific hand dexterity outcome measures?	1. How do you use these tools? 2. What information did you get from these tools? 3. Can you tell me of an occasion where used a dexterity outcome measure and found it useful? 4. Can you tell me of an occasion where they could have been useful, but you didn't manage to use the dexterity outcome measure? 5. Could you tell me of an occasion where you used a dexterity outcome measure, but it was not useful?
6. What does dexterity mean to you? 7. What would an ideal dexterity outcome measure look like to you?	1. How do you feel about current dexterity outcome measures? 2. What would encourage you to use a dexterity outcome measure? 3. Patient-rated vs performed based measure?

Examples of existing outcome measures would subsequently be displayed to stimulate discussion about constructs measured and usability of the measures.

1. in populations that match the occupation profile of current patients. What do you think about this measure?
    a. What do you like about this measure?
    b. What do you dislike about this measure?
2. Would you use this in your clinical practice?
    a. What would encourage you to use this in your clinical placement?
    b. What are some barriers to using these outcome measures?

Appendix B: Medline Search filter

Construct of interest

1. exp Psychomotor Performance/ OR (dexter* OR fine motor* OR "motor coordination" OR motor skill*).ti,ab,kf.

Target population

2. exp Hand/ OR exp Hand Bones/ OR exp Hand Joints/ OR exp Hand Deformities/ OR exp Hand Injuries/ OR exp Hand Deformities, Acquired/ OR exp Wrist/ OR exp Wrist Joint/ OR exp Wrist Injuries/ or upper extremity/ OR arm/ OR exp Forearm Injuries/ OR exp Finger Phalanges/ OR exp Finger Joint/ OR (hand OR wrist* OR forearm* OR thumb* OR grasp* OR grip* OR finger* OR pinch* OR upper limb* OR upper extermit*).ti,ab.

Construct of interest and target population

3. 1 AND 2

4. ("manual dexterity" OR (hand adj3 function) OR (hand adj3 dexterity) OR (hand adj3 coordination) OR (hand adj3 motor) OR (hand adj3 performance) OR (finger adj3 coordination) OR (hand adj3 coordination) OR (Limb adj3 coordination) OR (coORdinating adj3 finger) OR (finger adj3 performance) OR "in-hand manipulation").ti,ab.

5. 3 OR 4

Measurement instrument

6. exp "Task Performance AND Analysis"/ OR "Outcome Assessment (Health Care)"/ OR ("physical performance measure*" OR (performance adj3 test*) OR "performance-based test*" OR "performance based test*" OR "performance-based measure*" OR "performance instrument*" OR "performance-based instrument*" OR "performance based instrument*" OR "performance index" OR "performance-based index" OR "performance based index" OR "performance indices" OR "performance-based indices" OR "performance based indices" OR (performance adj3 assess*) OR "performance-based assessment*" OR "performance based assessment*" OR (performance adj3 eval*) OR "performance-based evaluation*" OR "performance based evaluation*" OR (performance adj3 measur*)).ti,ab. ("objective test*" OR "objective instrument*" OR "objective measure*" OR "objective evaluation*" OR "objective function*" OR "objective assessment*" OR "observational test*" OR "observational-based test*" OR "observational based test*" OR "observational instrument*" OR "observational-based instrument*" OR "observational based instrument*" OR "observational measure*" OR "observational-based measure*" OR "observational based measure*" OR "observation-based index" OR "observational based index" OR "observational-based indices" OR "observational based indices" OR "observed function*" OR "observed dexterit*" OR "observed hand function*" OR "observed hand-function*" OR "objective dexterity*" OR "objective hand function*" OR "objective hand-function*").ti,ab.

Construct of interest, population and measurement instrument

7. 5 AND 6

8. (("hand function*" adj2 measure*) OR ("hand function*" adj2 assess*) OR ("hand function*" adj2 test*) OR ("hand function*" adj2 eval*) OR (dexterity adj2 assess*) OR (dexterity adj2 test*) OR (dexterity adj2 eval*) OR (dexterity adj2 measure*)).ti,ab.

9. 7 OR 8

Measurement properties

10. (instrumentation OR methods).sh. OR exp Psychometrics/ OR psychometr*.ti,ab. OR (clinimetr* OR clinometr*).tw. or exp Observer Variation/ OR observer variation.ti,ab. OR exp "Reproducibility of Results"/ OR reproducib*.ti,ab. OR exp Discriminant Analysis/ OR (reliab* OR unreliab* OR valid* OR coefficient OR homogeneity OR homogeneous OR "internal consistency").ti,ab. OR (cronbach* AND (alpha OR alphas)).ti,ab. OR (item AND (correlation* OR selection* OR reduction*)).ti,ab. OR (agreement OR precision OR imprecision OR "precise values" OR test-retest).ti,ab. OR (test AND retest).ti,ab. OR (reliab* AND (test OR retest)).ti,ab. OR (stability OR interrater OR inter-rater OR intrarater OR intra-rater OR intertester OR inter-tester OR intratester OR intra-tester OR interobserver OR inter-observer OR intraobserver OR intra-observer OR intertechnician OR inter-technician OR intratechnician OR intra-technician OR interexaminer OR inter-examiner OR intraexaminer OR intra-examiner OR interassay OR inter-assay OR intraassay OR intra-assay OR interindividual OR inter-individual OR intraindividual OR intra-individual OR interparticipant OR inter-participant OR intraparticipant OR intra-participant OR kappa OR kappa's OR kappas OR repeatab*).ti,ab. OR ((replicab* OR repeated) AND (measure OR measures OR findings OR result OR results OR test OR tests)).ti,ab. OR (generaliza* OR generalisa* OR concordance).ti,ab. OR (intraclass AND correlation*).ti,ab. OR (discriminative OR "known group" OR factor analysis OR factor analyses OR dimension* OR subscale*).ti,ab. OR (multitrait AND scaling AND (analysis OR analyses)).ti,ab. OR (item discriminant OR interscale correlation* OR error OR errors OR "individual variability").ti,ab. OR (variability AND (analysis OR values)).ti,ab. OR (uncertainty AND (measurement OR measuring)).ti,ab. OR ("standard error of measurement" OR sensitiv* OR responsive*).ti,ab. OR ((minimal OR minimally OR clinical OR clinically) AND (important OR significant OR detectable) AND (change OR difference)).ti,ab. OR (small* AND (real OR detectable) AND (change OR difference)).ti,ab. OR (meaningful change OR "ceiling effect" OR "floor effect" OR "Item response model" OR IRT OR Rasch OR "Differential item functioning" OR DIF OR "computer adaptive testing" OR "item bank" OR "cross-cultural equivalence").ti,ab.

All four concepts

11. 9 AND 10

Exclusion filters

12. (Bibliography OR comment OR congress OR consensus-development-conference OR consensus-development-conference-nih OR current-biog-obit OR dictionary OR directory OR editorial OR festschrift OR guideline OR historical-article OR historical-biography OR legal-brief OR letter OR meeting-report OR monograph OR news OR overall OR review OR review-literature OR review-academic OR review-OR multicase OR review-tutorial OR scientific-integrity-review).pt. OR exp STROKE/ OR exp Cerebrovascular Disorders/ OR exp Brain Diseases/ OR exp Brain Damage, Chronic/ OR Hypoxia, Brain/ OR exp child/ OR exp child, preschool/ OR infant/

13. 11 NOT 12

Appendix C: EMBASE search filter

Construct of interest

1. exp psychomotor performance/ OR exp motor performance/ OR exp motor coordination/ OR exp agility/ OR exp motor control/ OR (dexter* OR "fine motor*" OR "motor coordination" OR "motor skill*").ti,ab.

Target population

2. exp hand muscle/ OR exp hand movement/ OR exp hand fracture/ OR exp hand injury/ OR hand disease/ OR exp hand transplantation/ OR exp hand function/ OR exp hand/ OR exp hand grip/ OR exp eye hand coordination/ OR hand reconstruction/ OR exp hand joint/ OR exp finger dislocation/ OR exp finger joint/ OR exp finger amputation/ OR exp finger implant/ OR exp finger fracture/ OR exp finger arthroplasty/ OR exp finger/ OR exp finger injury/ OR exp finger tip injury/ OR exp wrist/ OR exp wrist dislocation/ OR exp wrist disease/ OR exp wrist fracture/ OR exp wrist injury/ OR exp forearm fracture/ OR exp forearm injury/ OR exp forearm/ OR exp arm movement/ OR exp arm/ OR exp arm fracture/ OR exp arm injury/ OR exp arm muscle/ or upper limb/ OR exp arm/or (hand OR wrist* OR forearm* OR thumb* OR grasp* OR grip* OR finger* OR pinch* OR "upper limb*" OR "upper extermit*").ti,ab.

Construct of interest and target population

3. 1 AND 2.

4. ("manual dexterity" OR (hand adj3 function) OR (hand adj3 dexterity) OR (hand adj3 coordination) OR (hand adj3 motOR) OR (hand adj3 performance) OR (finger adj3 coordination) OR (hand adj3 coordination) OR (Limb adj3 coordination) OR (coordinating adj3 finger) OR (finger adj3 performance) OR "in-hand manipulation").ti,ab.

5. 3 OR 4

Measurement tool

6. exp outcome assessment/ OR exp treatment outcome/ OR ("physical performance measure*" OR (performance adj3 test*) OR "performance-based test*" OR "performance based test*" OR "performance-based measure*" OR "performance instrument*" OR "performance-based instrument*" OR "performance based instrument*" OR "performance index" OR "performance-based index" OR "performance based index" OR "performance indices" OR "performance-based indices" OR "performance based indices" OR (performance adj3 assess*) OR "performance-based assessment*" OR "performance based assessment*" OR (performance adj3 eval*) OR "performance-based evaluation*" OR "performance based evaluation*" OR (performance adj3 measur*)).ti,ab. OR ("objective test*" OR "objective instrument*" OR "objective measure*" OR "objective evaluation*" OR "objective function*" OR "objective assessment*" OR "observational test*" OR "observational-based test*" OR "observational based test*" OR "observational instrument*" OR "observational-based instrument*" OR "observational based

instrument*" OR "observational measure*" OR "observational-based measure*" OR "observational based measure*" OR "observation-based index" OR "observational based index" OR "observational-based indices" OR "observational based indices" OR "observed function*" OR "observed dexterit*" OR "observed hand function*" OR "observed hand-function*" OR "objective dexterity*" OR "objective hand function*" OR "objective hand-function*").ti,ab.

Construct of interest, population and measurement tool

7. 5 AND 6

8. (("hand function*" adj2 measure*) OR ("hand function*" adj2 assess*) OR ("hand function*" adj2 test*) OR ("hand function*" adj2 eval*)).ti,ab. OR ((dexterity adj2 assess*) OR (dexterity adj2 test*) OR (dexterity adj2 eval*) OR (dexterity adj2 measure*)).ti,ab.

9. 7 OR 8

Measurement properties

10. exp "psychometry"/ OR exp "reproducibility"/ OR reproducib*.ti,ab. OR psychometr*.ti,ab. OR clinimetr*.ti,ab. OR clinometr*.ti,ab. OR exp "observer variation"/ OR "observer variation".ti,ab. OR exp "discriminant analysis"/ OR exp "validity"/ OR reliab*.ti,ab. OR valid*.ti,ab. OR "coefficient".ti,ab. OR "internal consistency".ti,ab. OR (cronbach* AND ("alpha" OR "alphas")).ti,ab. OR "item correlation".ti,ab. OR "item correlations".ti,ab. OR "item selection".ti,ab. OR "item selections".ti,ab. OR "item reduction".ti,ab. OR "item reductions".ti,ab. OR "agreement".ti,ab. OR "precision".ti,ab. OR "imprecision".ti,ab. OR "precise values".ti,ab. OR "test-retest".ti,ab. OR ("test" AND "retest").ti,ab. OR (reliab* AND ("test" OR "retest")).ti,ab. OR "stability".ti,ab. OR "interrater".ti,ab. OR "inter-rater".ti,ab. OR "intrarater".ti,ab. OR "intra-rater".ti,ab. OR "intertester".ti,ab. OR "inter-tester".ti,ab. OR "intratester".ti,ab. OR "intra-tester".ti,ab. OR "interobeserver".ti,ab. OR "inter-observer".ti,ab. OR "intraobserver".ti,ab. OR "intra-observer".ti,ab. OR "intertechnician".ti,ab. OR "inter-technician".ti,ab. OR "intratechnician".ti,ab. OR "intra-technician".ti,ab. OR "interexaminer".ti,ab. OR "inter-examiner".ti,ab. OR "intraexaminer".ti,ab. OR "intra-examiner".ti,ab. OR "interassay".ti,ab. OR "inter-assay".ti,ab. OR "intraassay".ti,ab. OR "intra-assay".ti,ab. OR "interindividual".ti,ab. OR "inter-individual".ti,ab. OR "intraindividual".ti,ab. OR "intra-individual".ti,ab. OR "interparticipant".ti,ab. OR "inter-participant".ti,ab. OR "intraparticipant".ti,ab. OR "intra-participant".ti,ab. OR "kappa".ti,ab. OR "kappas".ti,ab. OR "coefficient of variation".ti,ab. OR repeatab*.ti,ab. OR ((replicab* OR "repeated") AND ("measure" OR "measures" OR "findings" OR "result" OR "results" OR "test" OR "tests")).ti,ab. OR generaliza*.ti,ab. OR generalisa*.ti,ab. OR "concordance ".ti,ab. OR ("intraclass" AND correlation*).ti,ab. OR "discriminative".ti,ab. OR "known group".ti,ab. OR "factor analysis".ti,ab. OR "factor analyses".ti,ab. OR "factor structure".ti,ab. OR "factor structures".ti,ab. OR "dimensionality".ti,ab. OR subscale*.ti,ab. OR "multitrait scaling analysis".ti,ab. OR "multitrait scaling analyses".ti,ab. OR "item discriminant".ti,ab. OR "interscale correlation".ti,ab. OR "interscale correlations".ti,ab. OR (("error" OR "errors") AND (measure* OR correlat* OR evaluat* OR "accuracy" OR "accurate" OR "precision" OR "mean")).ti,ab. OR "individual variability".ti,ab. OR "interval variability".ti,ab. OR "rate

variability".ti,ab. OR "variability analysis".ti,ab. OR ("uncertainty" AND ("measurement" OR "measuring")).ti,ab. OR "standard error of measurement".ti,ab. OR sensitiv*.ti,ab. OR responsive*.ti,ab. OR ("limit" AND "detection").ti,ab. OR interpretab*.ti,ab. OR (small* AND ("real" OR "detectable") AND ("change" OR "difference")).ti,ab. OR "meaningful change".ti,ab. OR "minimal important change".ti,ab. OR "minimal important difference".ti,ab. OR "minimally important change".ti,ab. OR "minimally important difference".ti,ab. OR "minimal detectable change".ti,ab. OR "minimal detectable difference".ti,ab. OR "minimally detectable change".ti,ab. OR "minimally detectable difference".ti,ab. OR "minimal real change".ti,ab. OR "minimal real difference".ti,ab. OR "minimally real change".ti,ab. OR "minimally real difference".ti,ab. OR "ceiling effect".ti,ab. OR "floor effect".ti,ab. OR "item response model".ti,ab. OR "irt".ti,ab. OR "rasch".ti,ab. OR "differential item functioning".ti,ab. OR "dif".ti,ab. OR "computer adaptive testing".ti,ab. OR "item bank".ti,ab. OR "cross-cultural equivalence".ti,ab.

<u>All four concepts</u>

11. 9 AND 10

<u>Exclusion filter</u>

12. (Bibliography OR comment OR congress OR consensus-development-conference OR consensus-development-conference-nih OR current-biog-obit OR dictionary OR directory OR editorial OR festschrift OR guideline OR historical-article OR historical-biography OR legal-brief OR letter OR meeting-report OR monograph OR news OR overall OR review OR review-literature OR review-academic OR review-OR multicase OR review-tutorial OR scientific-integrity-review).pt. OR exp brain disease/ or child/ OR infant/

34. 11 NOT 12

Appendix D: PsycINFO search filter

Construct of interest

1. exp perceptual motor coordination/ OR exp perceptual motor processes/ OR exp motor processes/ OR exp physical dexterity/ OR exp motor performance/ OR exp motor control/ OR exp motor coordination/ OR exp motor skills/ OR (dexter* OR "fine motor*" OR "motor coordination" OR "motor skill*").ti,ab.

Population

2.exp "HAND (ANATOMY)"/ OR exp Grasping/ OR exp WRIST/ OR exp "ARM (ANATOMY)"/ OR exp "fingers (anatomy)"/ OR exp thumb/ OR (hand OR wrist* OR forearm* OR thumb* OR grasp* OR grip* OR finger* OR pinch* OR "upper limb*" OR "upper extermit*").ti,ab.

Construction of interest AND population

3. 1 AND 2

4. ("manual dexterity" OR (hand adj3 function) OR (hand adj3 dexterity) OR (hand adj3 coordination) OR (hand adj3 motor) OR (hand adj3 performance) OR (finger adj3 coordination) OR (hand adj3 coordination) OR (Limb adj3 coordination) OR (coordinating adj3 finger) OR (finger adj3 performance) OR "in-hand manipulation").ti,ab.

5. 3 OR 4

Measurement tool

6. (instrumentation OR "outcome assess*" OR "outcome measure* " OR "treatment outcome").ti,ab. OR exp Treatment Outcomes/ OR ("physical performance measure*" OR (performance adj3 test*) OR "performance-based test*" OR "performance based test*" OR "performance-based measure*" OR "performance instrument*" OR "performance-based instrument*" OR "performance based instrument*" OR "performance index" OR "performance-based index" OR "performance based index" OR "performance indices" OR "performance-based indices" OR "performance based indices" OR (performance adj3 assess*) OR "performance-based assessment*" OR "performance based assessment*" OR (performance adj3 eval*) OR "performance-based evaluation*" OR "performance based evaluation*" OR (performance adj3 measur*)).ti,ab. OR ("objective test*" OR "objective instrument*" OR "objective measure*" OR "objective evaluation*" OR "objective function*" OR "objective assessment*" OR "observational test*" OR "observational-based test*" OR "observational based test*" OR "observational instrument*" OR "observational-based instrument*" OR "observational based instrument*" OR "observational measure*" OR "observational-based measure*" OR "observational based measure*" OR "observation-based index" OR "observational based index"

OR "observational-based indices" OR "observational based indices" OR "observed function*" OR "observed dexterit*" OR "observed hand function*" OR "observed hand-function*" OR "objective dexterity*" OR "objective hand function*" OR "objective hand-function*").ti,ab.

Construct of interest, population AND measurement tool

7. 5 AND 6

8. ((dexterity adj3 assess*) or (dexterity adj3 test*) or (dexterity adj3 eval*) or (dexterity adj3 measure*) or "hand function eval*" or "hand function test*" or "hand function measure*" or "hand function assess*" or "hand-function eval*" or "hand-function test*" or "hand-function measure*" or "hand-function assess*" or "eval* hand function" or " test* hand function" or "measure* hand function" or " assess* hand function" or "eval* hand-function" or " test* hand-function" or "measure* hand-function" or " assess* hand-function").ti,ab.

9. 7 OR 8

Measurement properties

10. exp PSYCHOMETRICS/ OR exp response bias/ OR exp Statistical Validity/ OR exp Test Validity/ OR exp Test Reliability/ OR exp Factor Structure/ OR exp Interrater Reliability/ OR exp Cross Cultural Differences/ OR exp "Error of Measurement"/ OR exp Item Response Theory/ OR exp classical test theory/ OR exp "item analysis (statistical)"/ OR exp Factor Analysis/ OR exp Adaptive Testing/ OR exp Test Items/ OR exp "Item Analysis (Statistical)"/ OR exp "Item Analysis (Test)"/ OR psychometr* OR clinimetr*).ti,ab. OR (reproducib* OR "discriminant analysis" OR reliab* OR unreliab* OR valid* OR "coefficient of variation OR discriminant analys*").ti,ab. OR (reliab* OR unreliab* OR valid* OR coefficient OR homogeneity OR homogeneous OR "internal consistency").ti,ab. OR (cronbach* AND(alpha OR alphas)).ti,ab. OR (item AND(correlation* OR selection* OR reduction*)).ti,ab. (agreement OR precision OR imprecision OR "precise values" OR test-retest).ti,ab. OR (test ANDretest).ti,ab. OR (reliab* AND (test OR retest)).ti,ab. OR (stability OR interrater OR inter-rater OR intrarater OR intra-rater OR intertester OR inter-tester OR intratester OR intra-tester OR interobserver OR inter-observer OR intraobserver OR intra-observer OR intertechnician OR inter-technician OR intratechnician OR intra-technician OR interexaminer OR inter-examiner OR intraexaminer OR intra-examiner OR interassay OR inter-assay OR intraassay OR intra-assay OR interindividual OR inter-individual OR intraindividual OR intra-individual OR interparticipant OR inter-participant OR intraparticipant OR intra-participant OR kappa OR kappa's OR kappas OR repeatab*).ti,ab. OR ((replicab* OR repeated) AND (measure OR measures OR findings OR result OR results OR test OR tests)).ti,ab. OR (generaliza* OR generalisa* OR concordance).ti,ab. OR (intraclass AND correlation*).ti,ab. OR (discriminative OR "known group" OR factor analysis OR factor analyses OR dimension* OR subscale*).ti,ab. OR (multitrait AND scaling AND(analysis OR analyses)).ti,ab. OR (item discriminant OR interscale correlation* OR error

OR errors OR "individual variability").ti,ab. OR (variability AND(analysis OR values)).ti,ab. OR (uncertainty AND(measurement OR measuring)).ti,ab. OR ("standard error of measurement" OR sensitiv* OR responsive*).ti,ab. OR ((minimal OR minimally OR clinical OR clinically) AND(important OR significant OR detectable) AND(change OR difference)).ti,ab. OR (small* AND(real OR detectable) AND(change OR difference)).ti,ab. OR (meaningful change OR "ceiling effect" OR "floor effect" OR "Item response model" OR IRT OR Rasch OR "Differential item functioning" OR DIF OR "computer adaptive testing" OR "item bank" OR "cross-cultural equivalence").ti,ab.

All four concepts

11. 9 AND 10

Exclusion filter

12. Limit 11 to (bibliography OR "column/opinion" OR editorial OR encyclopedia entry OR interview OR letter OR obituary OR poetry OR publication infORmation OR review-book OR review-media OR review-software & other OR reviews)

13. 11 NOT 12

14. exp Cerebrovascular Accidents/ OR exp Cerebral Ischemia/ OR exp Brain Damage/ OR exp Traumatic Brain Injury/ OR exp ANIMALS/ OR exp Childhood Development/

15. 13 NOT 14

Appendix E: CINAHL search filter

<u>Construct of interest</u>

1. (MH "Psychomotor Performance+") OR (MH "Agility") OR (dexter* OR "fine motor*" OR "motor coordination" OR "motor skill*")

<u>Population</u>

2. (MH "Hand Therapy") OR (MH "Hand Deformities+") OR (MH "Finger Joint") OR (MH "Stiff Hand, Post-Traumatic") OR (MH "Hand Joints+") OR (MH "Hand Deformities, Acquired+")OR (MH "Hand Fractures+") OR (MH "Hand Injuries+") OR (MH "Hand+") OR (MH "Hand Surgery") OR (MH "Upper Extremity") OR (MH "Forearm") OR (MH "Arm") OR (hand* OR wrist* OR forearm* OR thumb* OR grasp* OR grip* OR finger* OR pinch* OR "upper limb*" OR "upper extermit*")

<u>Construct of interest and Population</u>

3. 1 AND 2

4. (TI "manual dexterity" OR (TI finger N3 coordination) OR (TI finger N3 performance) OR (TI hand N3 coordination) OR (TI Limb N3 coordination) OR (TI coordinating N3 finger) OR (TI hand N3 function) OR (TI hand N3 performance) OR (TI hand N3 dexterity) OR (TI hand N3 coordination) OR (TI hand N3 motor) OR TI"in-hand manipulation") OR (AB "manual dexterity" OR (AB finger N3 coordination) OR (AB finger N3 performance) OR (AB hand N3 coordination) OR (AB Limb N3 coordination) OR (AB coordinating N3 finger) OR (AB hand N3 function) OR (AB hand N3 performance) OR (AB hand N3 dexterity) OR (AB hand N3 coordination) OR (AB hand N3 motor) OR AB"in-hand manipulation")

5. 3 OR 4

<u>Measurement tool</u>

6. (MH "Outcome Assessment") OR (TI outcome assessment OR AB outcome assessment) OR (TI outcome measure* OR AB outcome measure*) OR (MH "Health Status Indicators") OR (TI "physical performance measure*" OR (TI performance N3 test*) OR (TI performance N3 measur*) OR TI "performance-based test*" OR TI "performance based test*" OR TI "performance-based measure*" OR TI "performance instrument*" OR TI "performance-based instrument*" OR TI "performance based instrument*" OR TI "performance index" OR TI "performance-based index" OR TI "performance based index" OR TI "performance indices" OR TI "performance-based indices" OR TI "performance based indices" OR (TI performance N3 assess*) OR TI "performance-based assessment*" OR TI "performance based assessment*" OR (TI performance N3 eval*) OR TI "performance-based evaluation*" OR TI "performance based

evaluation*") OR (TI "objective test*" OR TI "objective instrument*" OR TI "objective measure*" OR TI "objective evaluation*" OR TI "objective function*" OR TI "objective assessment*" OR TI "observational test*" OR TI "observational-based test*" OR TI "observational based test*" OR TI "observational instrument*" OR TI "observational-based instrument*" OR TI "observational based instrument*" OR TI "observational measure" OR TI "observational-based measure*" OR TI "observational based measure*" OR TI "observation-based index" OR TI "observational based index" OR TI "observational-based indices" OR TI "observational-based indices" OR TI "observed function*" OR TI "observed dexterit*" OR TI "observed hand function*" OR TI "observed hand-function*" OR TI "objective dexterity*" OR TI "objective hand function*" OR TI "objective hand-function*") OR (AB "physical performance measure*" OR (AB performance N3 test*) OR (AB performance N3 measur*) OR AB "performance-based test*" OR AB "performance based test*" OR AB "performance-based measure*" OR AB "performance instrument*" OR AB "performance-based instrument*" OR AB "performance based instrument*" OR AB "performance index" OR AB "performance-based index" OR AB "performance based index" OR AB "performance indices" OR AB "performance-based indices" OR AB "performance based indices" OR (AB performance N3 assess*) OR AB "performance-based assessment*" OR AB "performance based assessment*" OR (AB performance N3 eval*) OR AB "performance-based evaluation*" OR AB "performance based evaluation*") OR (AB "objective test*" OR AB "objective instrument*" OR AB "objective measure*" OR AB "objective evaluation*" OR AB "objective function*" OR AB "objective assessment*" OR AB "observational test*" OR AB "observational-based test*" OR AB "observational based test*" OR AB "observational instrument*" OR AB "observational-based instrument*" OR AB "observational based instrument*" OR AB "observational measure" OR AB "observational-based measure*" OR AB "observational based measure*" OR AB "observaABon-based index" OR AB "observational based index" OR AB "observational-based indices" OR AB "observational-based indices" OR AB "observed function*" OR AB "observed dexterit*" OR AB "observed hand function*" OR AB "observed hand-function*" OR AB "objective dexterity*" OR AB "objective hand function*" OR AB "objective hand-function*")

<u>Construct of interest, population and measurement tool</u>

7. 5 AND 6

8. (TI "hand function*" N2 measure*) OR (TI "hand function*" N2 assess*) OR (TI"hand function*" N2 test*) OR (TI "hand function*" N2 eval*) OR (TI dexterity N2 assess*) OR (TI dexterity N2 test*) OR (TI dexterity N2 eval*) OR (TI dexterity N2 measure*) OR (AB "hand function*" N2 measure*) OR (AB "hand function*" N2 assess*) OR (AB"hand function*" N2 test*) OR (AB "hand function*" N2 eval*) OR (AB dexterity N2 assess*) OR (AB dexterity N2 test*) OR (AB dexterity N2 eval*) OR (AB dexterity N2 measure*)

9. 7 OR 8

<u>Measurement properties</u>

10.(MH "Psychometrics") OR (TI psychometr* OR AB psychometr*) OR (TI clinimetr* OR AB clinimetr*) OR (TI clinometr* OR AB clinometr*) OR (MH "Reproducibility of Results")

OR (MH "Discriminant Analysis") OR ((TI reproducib* OR AB reproducib*) OR (TI reliab* OR AB reliab*) OR (TI unreliab* OR AB unreliab*)) OR ((TI valid* OR AB valid*) OR (TI coefficient OR AB coefficient) OR (TI homogeneity OR AB homogeneity)) OR (TI homogeneous OR AB homogeneous) OR (TI "coefficient of variation" OR AB "coefficient of variation") OR (TI "internal consistency" OR AB "internal consistency") OR (MH "Internal Consistency+") OR (MH "Reliability+") OR (MH "Measurement Error+") OR (MH "Content Validity+") OR "hypothesis testing" OR "structural validity" OR "cross-cultural validity" OR (MH "Criterion-Related Validity+") OR "responsiveness" OR "interpretability" OR (TI reliab* OR AB reliab*) AND ((TI test OR AB test) OR (TI retest OR AB retest)) OR (TI stability OR AB stability) OR (TI interrater OR AB interrater) OR (TI inter-rater OR AB inter-rater) OR (TI intrarater OR AB intrarater) OR (TI intra-rater OR AB intrarater) OR (TI intertester OR AB intertester) OR (TI inter-tester OR AB inter-tester) OR (TI intratester OR AB intratester) OR (TI intra-tester OR AB intra-tester) OR (TI interobserver OR AB interobserver) OR (TI inter-observer OR AB inter-observer) OR (TI intraobserver OR AB intraobserver) OR (TI intra-observer OR AB intra-observer) OR (TI intertechnician OR AB intertechnician) OR (TI inter-technician OR AB inter-technician) OR (TI intratechnician OR AB intratechnician) OR (TI intra-technician OR AB intra-technician) OR (TI interexaminer OR AB interexaminer) OR (TI inter-examiner OR AB inter-examiner) OR (TI intraexaminer OR AB intraexaminer) OR (TI intra-examiner OR AB intra-examiner) OR (TI intra-examiner OR AB intraexaminer) OR (TI interassay OR AB interassay) OR (TI inter-assay OR AB inter-assay) OR (TI intraassay OR AB intraassay) OR (TI intra-assay OR AB intra-assay) OR (TI interindividual OR AB interindividual) OR (TI inter-individual OR AB inter-individual) OR (TI intraindividual OR AB intraindividual) OR (TI intra-individual OR AB intra-individual) OR (TI interparticipant OR AB interparticipant) OR (TI inter-participant OR AB inter-participant) OR (TI intraparticipant OR AB intraparticipant) OR (TI intra-participant OR AB intra-participant) OR (TI kappa OR AB kappa) OR (TI kappa's OR AB kappa's) OR (TI kappas OR AB kappas) OR (TI repeatab* OR AB repeatab*) OR (TI responsive* OR AB responsive*) OR (TI interpretab* OR AB interpretab*)

<u>All 4 concepts</u>

11. 9 AND 10

<u>Exclusion Filters</u>

12. PT (Bibliography OR comment OR congress OR consensus-development-conference OR consensus-development-conference-nih OR current-biog-obit OR dictionary OR directory OR editorial OR festschrift OR guideline OR historical-article OR historical-biography OR legal-brief OR letter OR meeting-report OR monograph OR news OR overall OR review OR review-literature OR review-academic OR review-OR multicase OR review-tutorial OR scientific-integrity-review)

13. (MH "Stroke") OR (MH "Stroke Patients") OR (MH "Stroke, Lacunar") OR (MH "Stroke Units") OR (MH "Brain Injuries+") OR (MH "Infant+") OR (MH "Child+")

14. 11 NOT 12 NOT 13

Appendix F: Screening outcome measures found in the initial screening of search strategy for eligibility and included in the final search strategy

Tools included			
1.	Minnesota Manual Dexterity Test	38.	Short version of Sequential Occupational Dexterity Assessment
2.	Complete Minnesota Dexterity Test	39.	Strength-Dexterity test
3.	Minnesota Rate of Manipulation Test	40.	Sollerman Hand Function Test
4.	Purdue Pegboard test	41.	Test d'Evaluation de la performance des Membres Superieurs des Personnes Agee (TEMPA)
5.	Variable Dexterity Test	42.	Pinch-holding-up activity test
6.	Functional Dexterity Test	43.	Stromberg Dexterity Test
7.	Nine-Hole Peg Test	44.	Take Five Test
8.	Dellon-modified Moberg pick-up test	45.	Roeder manipulative aptitude test
9.	Moberg Picking Up Test	46.	Greenseid and McComack Test
10.	Sequential Occupational Dexterity Assessment	47.	Work environment scale
11.	Suitcase packing activity	48.	The peg test
12.	Simple Test for Evaluating Hand Function	49.	Macquarrie test of mechanical ability
13.	modified simple test for evaluating hand function	50.	Paper and pencil dexterity test
14.	Hand-tool dexterity test	51.	Pennsylvania bimanual work sample
15.	Bennett hand-tool dexterity test	52.	Star-track test of manual dexterity
16.	Crawford Small Parts Dexterity Test	53.	upper extremity physical performance battery
17.	Grip Ability Test	54.	One-hole peg test
18.	Southampton Hand Assessment Procedure	55.	Santa Ana Dexterity Test
19.	Grooved Pegboard	56.	Nut loosening task
20.	Annett pegboard	57.	Motor capacities scale
21.	O'Connor Tweezer Dexterity	58.	AuSpinal
22.	Wire-bending test of manual dexterity	59.	eJoyce Arm and Hand Function Test
23.	400 points assessment	60.	Rapid Hand Flick Time
24.	Jebsen-Taylor Hand Function Test	61.	Capabilities of Upper Extremity Test
25.	Box and Block Test of Manual Dexterity	62.	ADL Abilities Test
26.	Smith Hand Function Test	63.	Timed Functional Arm and Shoulder Test
27.	Test of Chopsticks Manipulation	64.	Arthritis Hand Function Test
28.	NK hand dexterity test	65.	Keital Function Test
29.	NK Dexterity Small Objects Test	66.	Signals of Functional Impairment
30.	Morrisby Manual Dexterity Test	67.	Motor Performance Series
31.	MacHANd performance assessment	68.	Hand function sort
32.	O'Neill Hand Function Assessment	69.	Van Lieshout Test
33.	20 cents test	70.	Baltimore quantitative upper extremity function test
34.	Rosenbusch Test of Finger Dexterity	71.	Functional Standing Test
35.	Button Test	72.	Virtual Peg Insertion Test
36.	R-G Pegboard Test of Finger Dexterity	73.	Finger Tapping Test (FTT)
37.	Timed-revised form of the turning subtest		

Appendix G: Screening outcome measures found in other systematic reviews for eligibility

1. Combining synonyms of 1) construct of interest, 2) population, 3) psychometric properties and the name of the PBOMD using boolean operator 'AND' to get citations on the psychometric properties of the PBOMD in question
2. Title and abstracts are screened against eligibility criteria
3. This is repeated for MEDLINE, CINAHL, EMBASE and PsycINFO

Unique PBOMD identified from other systematic reviews with the number of citations found from each database, PBOMD already identified from the search strategy were excluded.

		Number of citations by databases			
No.	Tool name	MEDLINE	EMBASE	CINAHL	PsycINFO
1	"Capabilities of Upper Extremity Instrument"	1	2	1	1
2	"Wolf Motor Function Test" OR "WMFT"	53	131	25	32
3	"Action Research Arm Test" OR "ARAT"	84	151	29	39
4	"Chedoke Arm and Hand Activity Inventory" or "CAHAI"	4	10	4	5
5	"Graded and Refined Assessment of Strength Sensibility" or "GRASS"	2	7	2	0
6	"Motor Evaluation Scale for Upper Extremity in Stroke"	2	2	1	2
7	"Motor Status Scale"	2	2	1	4
8	"Stroke Upper Limb Capacity Scale"	0	0	0	0
9	"Radboud skills test"	0	0	0	0
10	"Upper extremity function test" or "UEFT"	2	3	0	1
11	"Computer Abilities Scanning and Training Test" or "CASTT"	0	0	0	0
12	"Hand Assessment"	76	119	39	32
13	"Manual Ability Scanning Test" or "MAST"	1	5	1	2
14	"Modified Motor Assessment Chart" OR "MMAC"	1	1	1	0
15	"Physical Capacity Evaluation"	1	3	1	0
16	"Standaard Observatie Ergotherapie Schrijven en Sensomotorische Schrijfvoorwaarden" OR "SOESSS"	0	0	0	0
17	"Wilson's Functional Test"	0	0	0	0
18	"Clawson test"	0	0	0	0
19	"Physical Capacities Evaluation of Hand Skill"	0	0	0	0
20	"Walker test"	0	0	0	0

None of the PBOMD met the inclusion criteria, see appendix H for reasons for exclusion

Appendix H: List of PBOMD that were excluded from the study with reasons for exclusion

Not validated in persons with hand and wrist conditions

1. Variable Dexterity Test
2. Suitcase packing activity
3. Simple Test for Evaluating Hand Function
4. modified simple test for evaluating hand function
5. Grooved Pegboard
6. Annett pegboard
7. O'Connor Tweezer Dexterity
8. Test of Chopsticks Manipulation
9. Morrisby Manual Dexterity Test
10. 20 cents test
11. Rosenbusch Test of Finger Dexterity
12. R-G Pegboard Test of Finger Dexterity
13. timed-revised form of the turning subtest
14. Test d'Evaluation de la performance des Membres Superieurs des Personnes Agee (TEMPA)
15. Stromberg Dexterity Test
16. Roeder manipulative aptitude test
17. The Peg test
18. O'Neill Hand Function Assessment
19. Macquarrie test of mechanical ability
20. Paper and pencil dexterity test
21. Pennsylvania bimanual work sample
22. star-track test of manual dexterity
23. upper extremity physical performance battery
24. one hole peg test
25. The Squares Test
26. Coin Rotation task (CRT)
27. Multiple Sclerosis Performance Test (MSPT)
28. motor capacities scale (MCS)
29. AuSpinal
30. eJoyce Arm and Hand Function Test (RAHFT)
31. Rapid Hand Flick Time (RHFT)
32. Capabilities of Upper Extremity Test (CUE-T)
33. ADL Abilities Test (ADLAT)
34. Santa Ana Dexterity Test
35. nut loosening task
36. Capabilities of Upper Extremity Test
37. Timed Functional Arm and Shoulder Test
38. Arm Motor Ability Test (AMAT)
39. Motor Performance Series
40. Van Lieshout Test
41. Virtual Peg Insertion Test
42. Finger Tapping Test (FTT)
43. Wolf Motor Function Test
44. Action Research Arm Test
45. Chedoke Arm and Hand Activity Inventory
46. Motor Evaluation Scale for Upper Extremity in Stroke
47. Motor Status Scale
48. Manual Ability Scanning Test (MAST)
49. Physical Capacity Evaluation
50. Southampton Hand Assessment Procedure

Does not measure dexterity or hand function at an activity level

1. Keital Function Test
2. Strength-Dexterity test
3. Pinch-holding-up activity test
4. Work environment scale
5. Signals of Functional Impairment
6. Functional Standing Test
7. Motor Assessment Scale
8. Rivermead motor assessment
9. Brunnstrom Fugl Meyer Test (B-FM)
10. Frenchay Activities Index
11. Extended Activities of Daily Living Scale (Extended ADL)
12. Handicap Assessment and Resource Tool (HART)
13. Simulated Activities of Daily Living Examination (SADLE)
14. Tufts Assessment of Motor Performance (TAMP)
15. Fugl-Meyer Assessment
16. Timed test of money counting
17. Finger Tapping Test (FTT)
18. One-arm hop test

Not a performance-based outcome measure

1. Hand function sort
2. Juvenile Arthritis Functional Status Index (JASI)
3. Cochin Rheumatoid Hand Disability Scale
4. Score for Assessment and Quantification of Chronic Rheumatic Affections of the Hands (SACRAH)

Measure constructs applicable only specific diagnosis

1. Southampton Hand Assessment Procedure
2. Assessment of Capacity for Myoelectric Control: Packing a Suitcase
3. Activities Measure for Upper Limb Amputees (AMULA)
4. The Prosthetic Upper Extremity Functional Index (PUFI)

Insufficient information located on psychometric properties

1. Hand-tool dexterity test
2. Bennett hand-tool dexterity test
3. wire-bending test of manual dexterity
4. Take Five Test
5. Greenseid and McComack Test
6. Baltimore quantitative upper extremity function test
7. "Graded and Refined Assessment of Strength Sensibility
8. and Prehension"
9. Stroke Upper Limb Capacity Scale
10. Radboud skills test
11. Upper extremity function test
12. Computer Abilities Scanning and Training Test (CASTT)
13. Hand Assessment
14. Modified Motor Assessment Chart (MMAC)
15. Standaard Observatie Ergotherapie Schrijven en Sensomotorische Schrijfvoorwaarden (SOESSS)
16. Wilson’s Functional Test
17. Clawson test
18. Physical Capacities Evaluation of Hand Skill
19. Walker test
20. Tactual performance test