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An international survey mapping practice and barriers for upper-limb assessments in movement analysis

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ABSTRACT

Background: Upper-limb movement analysis could improve our understanding of function, pathological mechanisms and inform rehabilitation and surgical decision-making. Despite the potential benefits, the use of clinical upper-limb motion analysis is not well established and it is not clear what the barriers to clinical motion analysis are.

Research question: What is current practice for assessment of the upper-limb and what are the barriers currently limiting upper-limb motion analysis being routinely used in clinical practice?

Methods: A web-based questionnaire was used to collect responses through international professional movement analysis society coordinators over an 18 month-period.

Results: A total of 55 responses were received and 75% of laboratories performed some form of upper-limb assessment. In total 44% of laboratories performed upper-limb assessments for clinical purposes and only 33% did 3D-movement analysis. The most commonly seen patient groups were those with neurological injury e.g. cerebral palsy (adults and children) and normal controls for comparative purposes. Barriers to upper-limb motion analysis were the availability of standard reference tasks, protocols, software, funding and clinical need. Practice was variable with no universally identified approaches to upper-limb movement analysis. Differences in practice were also identified between laboratories accredited by the Clinical Movement Analysis Society of the UK and Ireland and other international professional societies and affiliate laboratories.

Significance: These findings may be used to inform the development of practice standards and progress the use of clinical motion analysis in the upper-limb. This study provides a summary and describes current practice, potentially providing access to peer support and experience for laboratories with an identified clinical need looking to conduct upper-limb assessment. A national picture (UK and Ireland) for practice regarding upper-limb assessment in this sub-population is presented. We have laid out further work which is needed to establish standards of practice or consensus initiatives for enhancing clinical upper-limb motion analysis.

1. Introduction

The introduction of 3D movement analysis has driven significant improvements in clinical practice and patient outcomes [1,2]. This is most apparent in clinical gait analysis, where motion analysis is commonly used for informing treatment and surgical decisions e.g. multilevel surgical planning in children with cerebral palsy. Multilevel surgery in children with cerebral palsy proved a significant driver for technology adoption. Key factors included the heterogeneity of presentation, the complexity of movement patterns, the presence of multiple impairments and compensations, and the magnitude of the intervention. Similar factors may be prevalent in the management of upper-limb conditions e.g. tendon transfers in the upper-limb for cerebral palsy or surveillance and surgical planning for shoulder instability in young people or facioscapulohumeral dystrophy, and might provide a framework for assessing the suitability of 3D movement analysis in the upper-limb [3–8]. Despite the potential benefits the use of clinical upper-limb motion analysis is less established.

Advances in the quality and availability of measurement technology and associated software, have enhanced our ability to measure and understand human movement. A wide range of measurement technology equipment and processing software (including biomechanical and

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musculoskeletal models) is available for clinical and research purposes. This is true for both the upper and lower-limbs. Given the emergence of new technologies and methods of collecting, processing and reporting clinical movement analysis data, it was recognised that there was a need to develop standards for clinical movement analysis. Internationally several professional societies such as the European Society for Movement Analysis for Adults and Children (ESMAC) and affiliates have been established in an effort to share state of the art information and practice in clinical movement analysis [9]. In some cases, such as the Clinical Movement Analysis Society of UK and Ireland (CMAS) national societies are also responsible for setting national clinical practice standards and accrediting motion analysis laboratories. However, current initiatives are focused on the lower-limb [9].

Individual centres seeking to apply best practice to the evaluation of the upper-limb are therefore limited as there have been no equivalent standardisation exercises or consensus initiatives to date. Each centre is therefore likely developing practice on the basis of local choice leading to diversity which presents a risk and limitation to learning. An important precursor to standards or consensus initiative development is mapping existing service provision and practice. Processes related to consensus development default to informal discussions in the absence of explicitly mapped practice or sufficient evidence [10,11]. In these circumstances, consensus exercises can be disproportionately influenced by one or two group members [10,11]. There is a risk that consensus initiatives will fail to reach agreement, identify a set of minimal acceptable criteria, or follow the practices of the dominant group members which may not be equivalent to best practice.

Upper-limb movement analysis, informed by practice standards and consensus initiatives, could improve our understanding of function, pathological mechanisms and inform rehabilitation and surgical decision-making. It is therefore important to map existing practice which can be used to develop frameworks that inform consensus and standards initiatives. It is also important to appreciate the current barriers to more widespread use of upper-limb motion analysis and see where there is potential for translation. The aim of this study was therefore to map current practice for assessment of the upper-limb in international professional societies and affiliate laboratories, and identify barriers which may currently limit upper-limb motion analysis being routinely used in clinical practice.

2. Methods

A web-based survey (Appendix 1) was developed by the authors who were members of a UK accredited clinical gait service and CMAS. The questionnaire was developed to map the range of patient groups, assessments methods and barriers related to upper-limb movement analysis at the level of the laboratory rather than the individual patient group or stated laboratory's research or clinical purpose. It was constructed following consultation with two other member laboratories and appraised for face validity prior to dissemination. It was developed serially following feedback and piloting within the research team. Laboratories were recruited through their affiliation with ESMAC and the study questionnaire was distributed through the ESMAC and affiliated national societies and coordinators (SMALLL - Netherlands & Belgium, SOFAMEA- France, SIAMOC -Italy, CMAS – UK and Ireland, GAMMA - Germany, Switzerland, Austria and GCMAS – USA [1]). Laboratories were recruited over an 18-month period (February 2020 to August 2021). Clinical managers were asked to respond after discussion with wider team as necessary. A minimum of two reminders were requested during the recruitment period from respective national societies and coordinators. Only complete questionnaires were included in the analysis and the dataset was screened for any duplicate responses. Responses are reported as frequencies and where appropriate sub-categorised according to whether the laboratories reported carrying our upper-limb assessment for clinical purposes only, research purposes only or for clinical and research purposes. Responses were also reported separately for CMAS – UK and Ireland.

3. Results

A total of 55 responses were received from individual laboratories across 18 countries. An overview of responses from individual countries has been provided in Fig. 1.

The data set included responses from all laboratories accredited by CMAS (n = 15), giving a complete cohort of established clinical services in those nations. We are therefore able to report a national picture (UK and Ireland) for practice regarding upper-limb assessment in this subpopulation.

Overall 75% (n = 41/55) of responding laboratories reported conducting upper-limb assessments[2] and these were carried out for the following domains, 11% for clinical purposes only (n = 6/55), 31% for research purposes only (n = 17/55) and 33% for clinical and research purposes (n = 18/55). Within the subpopulation associated with CMAS, 40% (n = 6/15) reported conducting upper-limb assessments and these were carried out for the following domains, 20% for clinical purposes only (n = 3/15), 7% for research purposes only (n = 1/15) and 13% for clinical and research purposes (n = 2/15).

3.1. Results for patient groups seen for upper-limb assessment

Results for the frequency of patient groups seen for clinical and research purposes are presented in Table 1.

The most commonly seen patient groups for both research and clinical purposes were those with neurological injury e.g. cerebral palsy (adults and children) and normal controls for comparative purposes. Patient groups seen for research and clinical purposes were similar with 20 groups being common to both categories. For clinical purposes, an additional five patient groups were seen and reported as not being assessed for research purposes. For research purposes an additional 10 patient groups were seen and reported as not being assessed for clinical purposes with the majority being orthopaedic or musculoskeletal in nature.

3.2. Results for factors/ barriers to upper-limb analysis in practice across all laboratories

An overview of the barriers to upper-limb practice for all laboratories is presented in Table 2.

Overall the three most commonly identified barriers were, lack of standard reference tasks/ protocols, availability of software (e.g. biomechanical models) and capacity in service (laboratory time). Within CMAS the three most commonly selected barriers to upper-limb movement analysis were capacity in service (Laboratory time) (80%, n = 12/15), lack of standardised reference tasks/protocols (67%, n = 10/15) and clinical need (60%, n = 9/15).

[1] Full society names in respective order: Society of Movement Analysis in the Low Lands (SMALLL); Société Francophone d'Analyse du Mouvement chez l'Enfant et l'Adulte (SOFAMEA); Societa' Italiana di Analisi del Movimento in Clinica (SIAMOC); Clinical Movement Analysis Society of UK and Ireland (CMAS); Gesellschaft für die Analyse Menschlicher Motorik in ihrer klinischen Anwendung (GAMMA); The Gait and Clinical Movement Analysis Society (GCMAS)

[2] The term 'assessment' was used to encapsulate any form of upper-limb assessment, irrespective of the method of measurement or modality. Unless explicitly stated as 3D motions analysis, the term 'motion analysis' was used to encapsulate all forms of instrumented measurement which could be considered a form of motion analysis e.g. electromyography, 2D video etc.

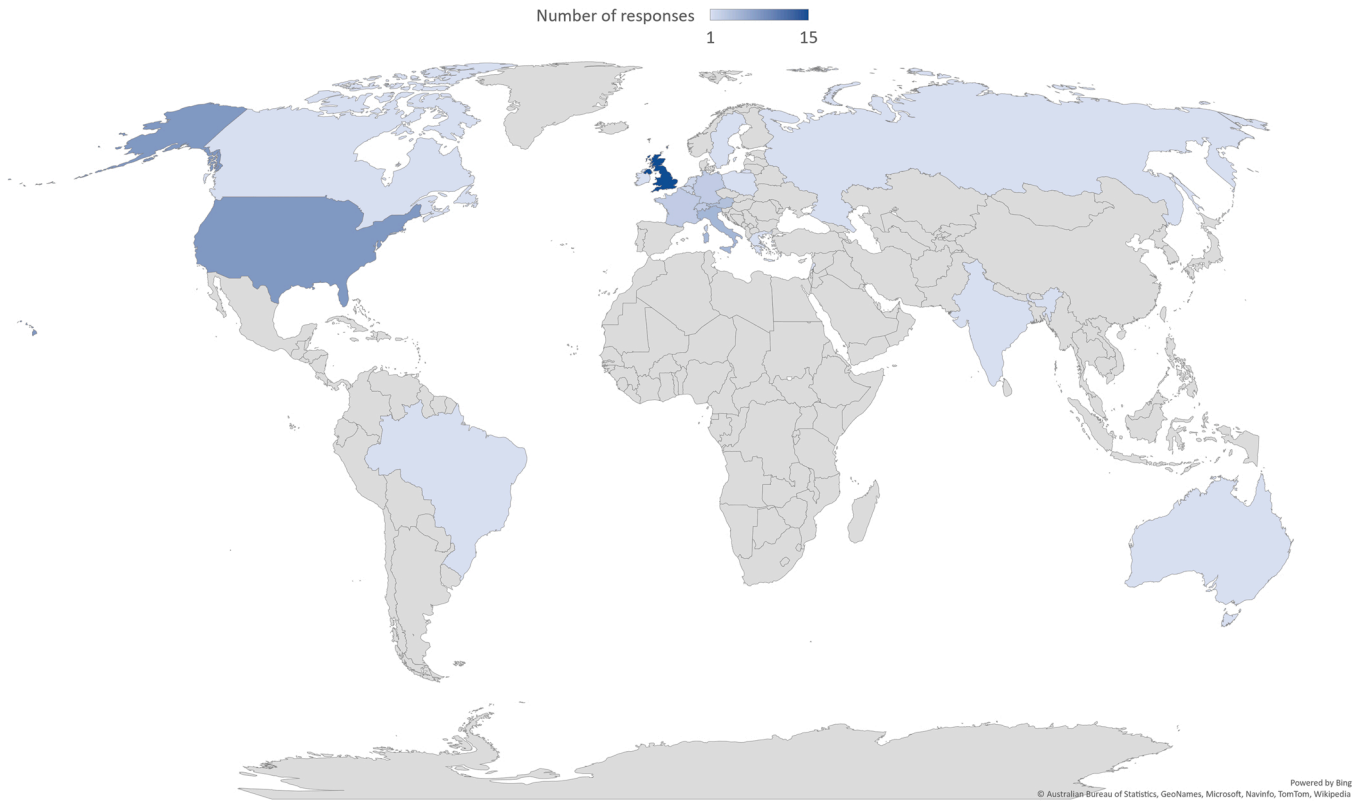

Fig. 1. A summary of responses from individual countries. Number laboratories who responded from each country (UK and Ireland (n = 16); USA (n = 8); Italy (n = 5); Austria (n = 4); France, Germany and Switzerland (n = 3); Netherlands and Belgium (n = 2); Australia, Brazil, Canada, Greece, India, Lebanon, Poland, Russia and Sweden (n = 1).

3.3. Results for assessments, outcomes, reference movements and tasks/ protocols used in laboratories who reported carrying out upper-limb analysis

3.3.1. Clinical assessments/outcomes used for measuring upper-limb function

A total of 19 clinical outcome measures were used across laboratories, a summary of which has been provided in Fig. 2.

Of the laboratories that performed any upper-limb assessment (n = 41/55), the majority did not use any outcome measures (29%, n = 12/41). The majority of outcome measures which were used were developed and validated for use in neurological populations, consistent with the patient groups reportedly seen by laboratories. There was limited use of outcome measures designed for orthopaedic and musculoskeletal conditions. Only two outcome measures were used by 20% or more of the laboratories i.e. 22% used the Box and Blocks test [12] (n = 9/41) and 20% used the Fugl-Meyer Upper Extremity Assessment [13] (n = 8/41). For CMAS laboratories which performed upper-limb assessment, the Assisting Hand Assessment (AHA) [14] and Shriners Hospital Upper Extremity Evaluation (SHUEE) [15] were the only outcome measures used by more than one lab with 50% (n = 3/6) and 33% (n = 2/6) of laboratories using them respectively.

3.3.2. Movements and functional tasks used for measuring upper-limb function

A total of 28 movements and 18 functional tasks were assessed across all laboratories (Fig. 3).

Shoulder joint movements were the most commonly assessed for both research and clinical purposes whilst isolated movements of the hand and fingers were much less frequently assessed. Functional tasks primarily focused on the retrieval and placement of objects, usually above the level of the shoulder or head.

3.4. Results for marker sets and software /biomechanical assessments used in laboratories who reported carrying out upper-limb analysis

Marker sets and biomechanical or musculoskeletal models used for upper-limb analysis between laboratories was variable, with only four marker sets and biomechanical or musculoskeletal models being used by more than one laboratory. An overview can be found in Appendix 2. Of the four marker sets identified, 27% identified those associated with the Conventional gait model [3] [16,17] (n = 11/41), followed by 12% for Rab et al., 2002 [18] and the Upper limb evaluation in movement analysis (U.L.E.M.A) [19] (n = 5/41), and 7% identifying the Evelina upper-limb model [20] (n = 3/41).

For biomechanical or musculoskeletal models, 27% identified the Conventional gait model [16,17] (n = 11/41), followed by 10% identifying U.L.E.M.A [19] (n = 4/41), and 5% identifying the Anbody model [21] and the Evelina upper-limb model [20] (n = 2/41). For CMAS the only marker set and model used by more than one laboratory was those associated with the Evelina upper-limb model (33%, n = 2/6) [20].

3.5. Results for modalities and equipment used in laboratories who reported carrying out upper-limb analysis

A ranked summary of the measurement methods used has been provided in Table 3.

[3] N = 2 laboratories explicitly identified the plug-in gait upper-body marker set and the remaining laboratories (n = 9) identified the conventional gait model associated with the Kadaba et al., 1990 source reference. We have interpreted this as the response being indicate of the upper and lower limb marker sets which are used to inform the conventional gait models that are based on the Kadaba et al., 1990 reference.

Table 1
Summary of the results for the frequency of patient groups seen for upper-limb clinical and research purposes across all laboratories.

Patient group	Number of laboratories	
	Clinical purposes	Research purposes
Adult - Cerebral palsy diplegic	2	1
Adult - Cerebral palsy hemiplegic	6	2
Adult - Cerebral palsy quadriplegic	2	1
Adult - Normal control subjects (for comparative purposes)	12	24
Adult - Orthopaedic/Musculoskeletal (not specified)	6	5
Adult - Stroke	9	11
Paediatric - Arthrogryposis	1	
Paediatric (U18) - Cerebral palsy diplegic	8	4
Paediatric (U18) - Cerebral palsy hemiplegic	12	11
Paediatric (U18) - Cerebral Palsy - quadriplegic	7	2
Paediatric - Normal control subjects (for comparative purposes)	7	12
Paediatric - Orthopaedic/Musculoskeletal (not specified)	1	2
Paediatric (U18) - Stroke	5	2
Neuromuscular dystrophy/ Neuromuscular disorders (muscular weakness due to dystrophy)	2	2
Brachial plexus palsy (Adults)	1	
Brachial plexus palsy (Children)	1	
Brachial plexus palsy (not stipulated as adult/children)		1
Spinal and head injury (Adults) / Spinal cord injury (tetraplegia)	2	2
Spinal and head injury (Children)	1	
Upper Limb Amputees	1	3
Parkinson's Disease (Adults)	1	4
Upper limb deformity	1	1
Multiple sclerosis	1	1
Alkaptonuria Adults	1	
Haemophilia	1	
Neuropathy	1	
Breast cancer adults (post treatment/ surgery)		1
Shoulder joint replacement surgery / Reverse Total Shoulder Arthroplasty		3
Shoulder instability (Children)		1
Subacromial shoulder pain		1
Humerus Fracture		1
Shoulder problems		1
Back pain		1
Paediatric Cerebral Palsy - Dystonia		1
Adults Dyskinetic Cerebral Palsy		1
Idiopathic toe walkers		1
None		1

Grey boxes indicate a zero response.

Table 2
A ranked summary of the barriers to upper-limb practice for all laboratories. Laboratories have been classified according to their stated purposes for carrying out upper-limb assessment i.e. Research only, clinical and research, clinical only, or no clinical or research. Frequency of responses is ranked in descending order.

Barriers	Number of responses				
	Research only (n = 17)	Clinical and research (n = 18)	Clinical only (n = 6)	No clinical or research (n = 14)	Ranked total (n = 55) %
Lack of standard reference tasks/ protocols	8	10	4	9	31 (56%)
Availability of software (e.g. biomechanical models)	7	9	2	11	29 (53%)
Capacity in service (Laboratory time)	5	7	3	11	26 (47%)
Funding	5	6	3	9	23 (42%)
Clear link between purpose of assessment and intervention/ outcome measure	8	4	3	5	20 (36%)
Availability of suitable experience/ expertise	7	4	1	7	19 (35%)
Clinical need	7	4	1	7	19 (35%)
Start-up investment time	3	3	3	6	15 (27%)
Start-up investment costs	3	1	3	4	11 (20%)
Lack of normal dataset for comparison	0	2	1	0	3 (5%)
None	0	2	0	0	2 (4%)
Difficulties in elimination of compensatory movements	1	1	0	0	2 (4%)
Inability to track dynamic scapular motion	0	1	0	0	1 (2%)
Upper limb assessment has not previously been explored	0	0	0	1	1 (2%)
Availability of equipment (e. g. camera speed)	0	0	0	1	1 (2%)

% representative of whole sample n = 55

Four laboratories (10%, n = 4/41) reported using no motion capture or measurement systems. A total of seven measurement or motion capture systems were used across laboratories. The most commonly identified motion capture system, identified by 60% of laboratories was Vicon systems (n = 24/41) followed by 15% for Qualisys (n = 6/41), 10% for BTS elite (n = 4/41); 5% for Codamotion, Inertial measurement unit and Opti Trak (n = 2/41) and 2% for Motion Analysis Corporation Kestrel (n = 1/41).

4. Discussion

The aim of this study was to map current practice for upper-limb assessments in international professional societies and affiliate organisations, and identify barriers which may currently limit upper-limb motion analysis being routinely used in practice. Variable practice was identified across all domains and supports the need for standardisation and consensus development. Our study has highlighted the areas of focus and provides a summary of practice which may be used for informing the next stages. Barriers to the routine use of upper-limb motion analysis in clinical practice were related to the availability of standard reference tasks, protocols, software, funding and clinical need.

4.1. Overview of practice regarding upper-limb assessment

Variability in practice is to be expected in the absence of any practice standards [22] and the increased complexity associated with the upper-limb. The lack of an established activity or minimal set of activities in the upper-limb may account for some of the variability. Unlike gait analysis for the lower-limb, there is no equivalent single activity i.e. walking, which can be used as a suitable reference task for evaluating the link between activity, impairment and intervention[1,2]. Furthermore, in gait analysis there are accepted conventions that allow for the identification of deviations between and within disease conditions that are observed in the activity of walking [23,24]. The variability in upper-limb activities, which inform other components of assessment/measurement may be reflective of the search for an equivalent link. Our results suggest that laboratories are searching for this link by focusing on shoulder joint movements and tasks orientated towards object retrieval and placement in varying levels of elevation. In some cases, there were supported by outcome measures, which may overlap with some of the physiological and functional movements, but are scored ordinally and have different task constraints e.g. quality or absolute task completion. Whilst usually patients specific, the most common outcome measures were comprised of tasks of increasing complexity that required object retrieval, placement and manipulation with progressive involvement of the distal limbs. The variable use of motion analysis, outcome measures and other assessment methods, reflects exploration of measurement tools which are suitably accurate and cost-effective (time and financial) for informing impairment identification and intervention selection.

While some components of practice regarding assessment methods (modalities, movements and functional tests) were common between laboratories, the data cannot be used to reconstruct a patient or laboratory specific protocol. Commonality in practice was likely due the familiarity/availability and ease with which the markers sets and models were integrated into existing workflows such as the Plug-in-Gait model which was the most commonly used [16,17,25]. A number of factors could potentially explain the wider use of some marker sets and biomechanical models within sub-groups e.g. the Evelina upper-limb model [20] for clinical purposes in CMAS laboratories. The Evelina upper-limb marker set and model was developed by the authors to address the main impairments seen in this patient group and produce accurate joint kinematics at the joints of interest. This was identified as a pragmatic solution upper-limb 3D movement analysis i.e. fewer markers for faster data collection and less complex modelling of the proximal shoulder joint. There is an explicit link between the most prevalent impairments at the distal limb which could be measured, and possible interventions i.e. surgical release for distal limb contractures in cerebral palsy children [20,26]. These factors are similar to those which facilitated the use of motion analysis in the lower-limb and may account for why the model has been adopted by more than one laboratory in this sub-group. Existing practice for the upper-limb appears to be exploratory and research focused, where links between observed impairments and disease mechanisms are yet to be established across all disease conditions. Our research supports the need for clinical condition specific

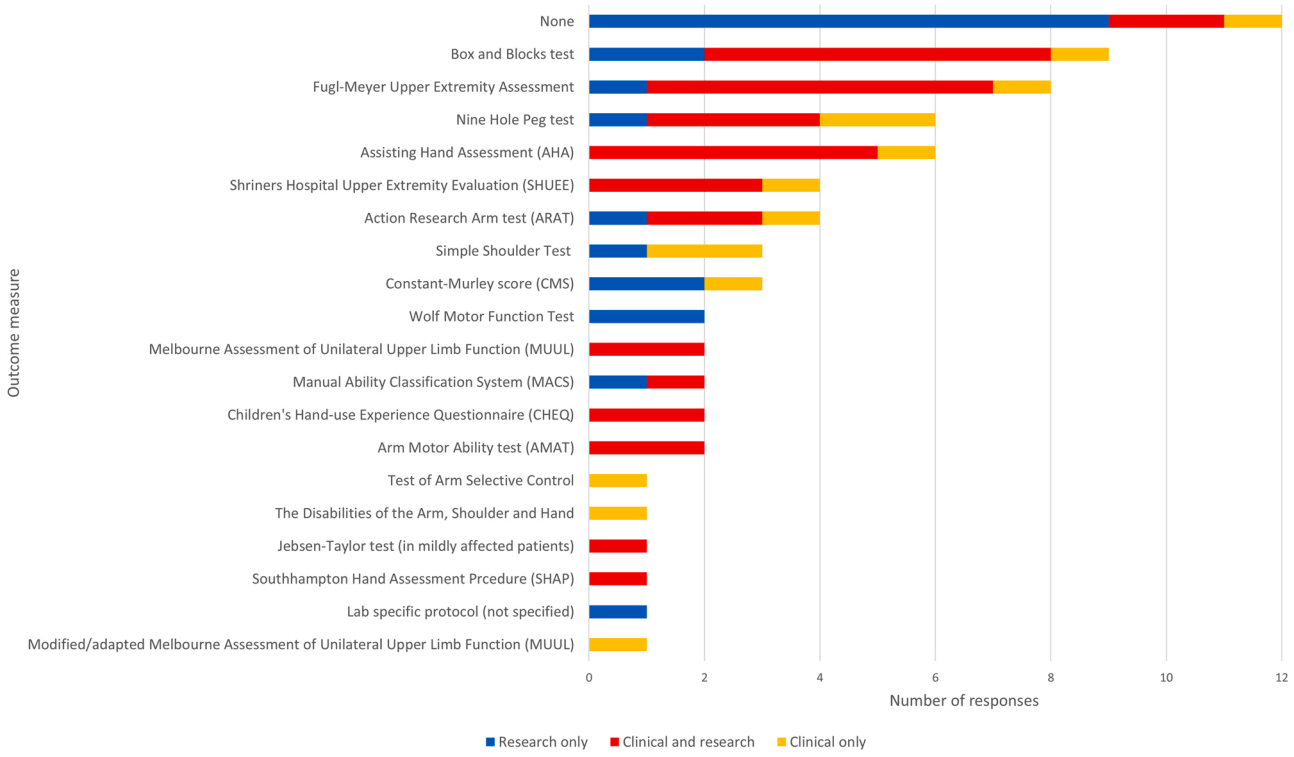

Fig. 2. Summary and number of responses for clinical outcome measures used in upper-limb assessment.

guidelines with a clear link between impairment identification, required biomechanical data, technology and methods (e.g. marker sets) and clinical outcomes or interventions.

Further variability in practice may be attributable to the different proportions of patient groups seen between CMAS and the other international professional societies and affiliate laboratories. CMAS laboratories see more children with neurological injuries and are therefore more likely to use outcome measures which are disease and age appropriate e.g. SHUEE for children with cerebral palsy[15]. Similarly, other professional societies and affiliate laboratories in which there was a higher proportion of adult neurological patients (e.g. stroke) used outcomes such as the Fugl-Meyer Upper Extremity Assessment [13]. The majority of laboratories used no outcome measures although this was predominantly in research only orientated laboratories. This is expected as research only laboratories will likely only use outcome measures in cases where their psychometric properties are being validated or explored against biomechanical measures. Limited use in clinical services may stem from limited ability in measuring or identifying activities and impairments which can inform an intervention [27].

Within the other international professional societies and affiliate laboratories, there seems to be more research into musculoskeletal/orthopaedic disorders. It seems likely that the subsequent use of motion analysis for clinical purposes would be driven by translational research outcomes [28]. It appears that there is a clinical push for use of motion analysis in the CMAS accredited laboratories and a possible research pull in the international professional societies and affiliate laboratories. Associations such as CMAS, includes many laboratories with a primary focus on clinical gait analysis in paediatric neurological populations. Understandably they tend to focus on upper-limb difficulties in their existing clinical cohorts and in some cases used 3D motion analysis. Given that cerebral palsy patients are seen across all CMAS accredited laboratories and likely present with similar upper-limb impairments, arguably use of upper-limb motion capture should be more prevalent [29]. However, it is evident that there are several barriers to more wide spread use of upper-limb assessment in movement laboratories.

4.2. *Barriers to upper-limb motion analysis*

Twenty-five percent of laboratories reported not performing any upper-limb assessment. This was proportionally higher in CMAS accredited laboratories. Upper-limb assessment for clinical purposes was carried out by less than 50% of the other international professional societies despite a higher overall proportion conducting upper-limb assessments. These differences may reflect that we were able to recruit all CMAS accredited laboratories, thus providing a representative national picture (UK and Ireland) of clinical services, whereas for the other international professional societies and affiliate laboratories we only received elective responses and clinical centres were not selectively targeted in preference to more academic laboratories.

The most common barriers to performing motion analysis were the availability of standard reference tasks/protocols and software (e.g. biomechanical models). For CMAS accredited laboratories, the most common barrier was capacity in service (Laboratory time) identified by 80% of laboratories. This was higher than for international professional societies and affiliate laboratories. The difference may be explained by other international professional societies and affiliate laboratories performing more research which is often exploratory and for which there are fewer protocols to draw on. Furthermore, given that CMAS accredited laboratories are familiar with the development of protocols as a part of the accreditation process and perform more clinical assessments, [22] this may account for the lower ranking of this component and clinical service pressures will have a greater impact on capacity issues.

There is likely to be some interplay between the identified barriers to upper-limb motion analysis. Whilst our results have identified a range of reference task/protocols and software available, use of motion analysis in the upper-limb requires suitable staff expertise/experience, a clear clinical outcome and identification of the required biomechanical evidence that would inform clinical decision making. In the absence of the latter, it is understandable that efforts (financial and of staff time) have not been made to develop or exploit existing reference tasks and protocols[28]. Whilst factors such as capacity and resources (time and

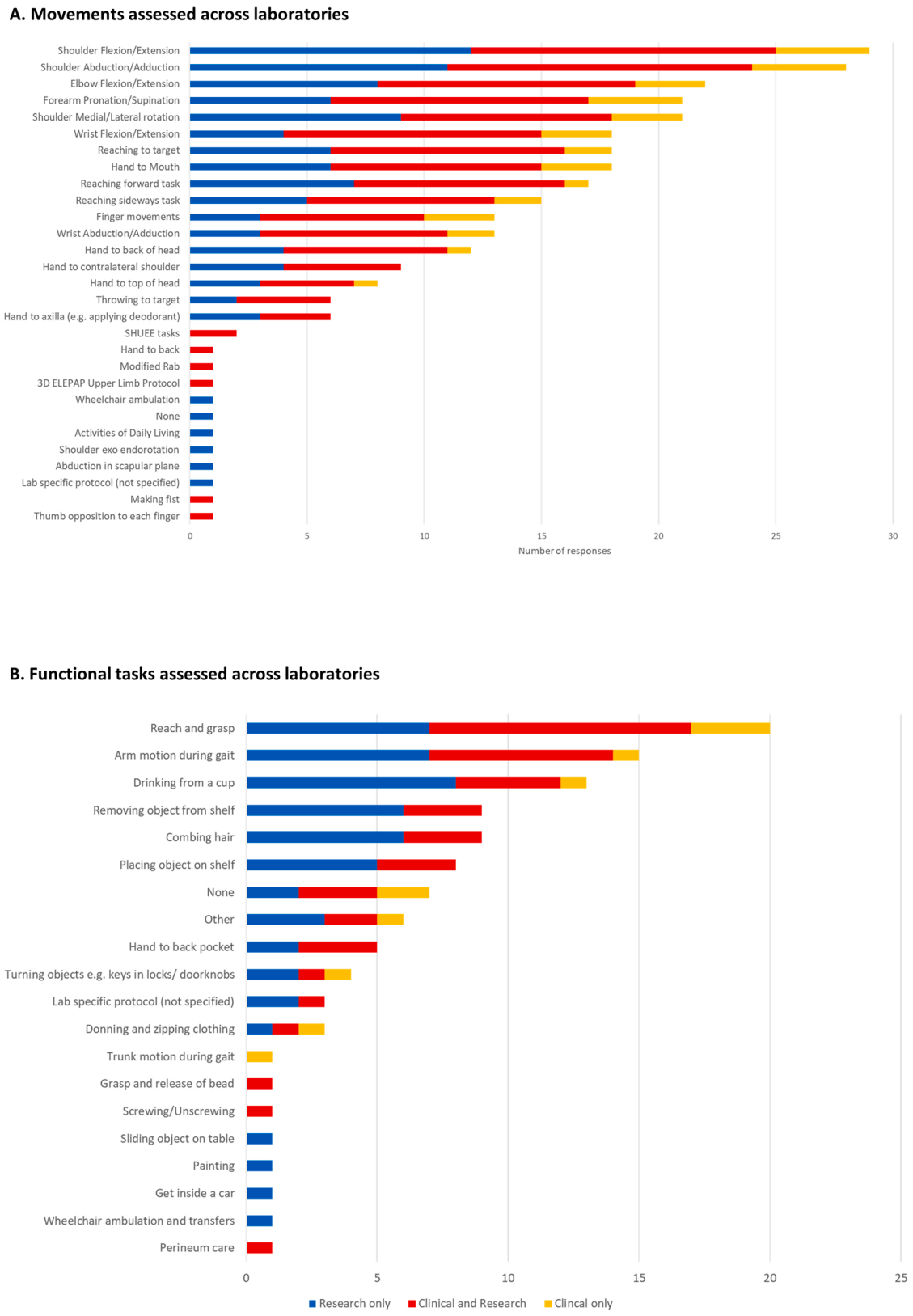

Fig. 3. Summary and number of responses movements and functional tasks used for measuring upper-limb function.

expertise) were identified as barriers, these can be considered as surrogates for funding and clinical need.

The absence of a clear clinical need and demonstrable benefits, both to the patient and funding providers, may inhibit more widespread use of upper-limb clinical motion analysis. In order to understand how these barriers could be overcome, previous experience with the lower limb may provide a good framework for evaluation. It is reasonable to assume that similar challenges were present during the emergence of motion capture for gait analysis, although there was possibly more time. Adoption of 3D motion capture was driven by the needs of a

Table 3
A summary of the measurement methods used across laboratories.

Measurement methods	Research only (n = 17)	Clinical and research (n = 18)	Clinical only (n = 6)	Ranked total (n = 41) n (%)	CMAS accredited (n = 15)	Other societies (n = 40)
3D motion analysis	16	16	2	34 (83%)	5	29
Electromyography, surface (sEMG)	12	14	3	29 (71%)	3	26
Clinical examination, visual observation*	8	14	4	26 (63%)	4	22
2D Video	8	10	5	23 (56%)	5	18
Clinical examination, supported by instrumented measures[+]	6	10	2	18 (44%)	3	15
Inertial Measurement Units (IMU's)	7	4	1	12 (29%)	0	12
Grip dynamometry	2	4	4	10 (24%)	3	7
Electromyography, fine wire (EMG)	0	4	1	5 (12%)	1	4
Pinch dynamometry	1	2	2	5 (12%)	2	3
Ultrasound	1	3	0	4 (10%)	0	4
Stereognosis	0	3	1	4 (10%)	2	2
Monofilament sensation testing	1	2	0	3 (7%)	1	2
Two-point discrimination testing	0	3	0	3 (7%)	1	2
Electro goniometers	1	1	0	2 (5%)	1	1
Electromagnetic 3D measurement system	1	0	0	1 (2%)	0	1
Lab specific protocol (not specified)	0	0	1	1 (2%)	1	0
Muscle strength test with handheld dynamometer	1	0	0	1 (2%)	0	1
Biopsychosocial questionnaires	1	0	0	1 (2%)	1	0
Blood counts	0	1	0	1 (2%)	0	1
MRI	0	1	0	1 (2%)	0	1
X-ray	0	1	0	1 (2%)	0	1
Assessment of Volkmann angle	0	1	0	1 (2%)	1	0

% representative of those who performed upper-limb analysis n = 41
*e.g. Active and Passive ROM, Manual muscle strength tests, comments on posture/ movement characteristics
[+]e.g. goniometry, myometers

heterogeneous patient population presenting with complex movement patterns which could not be adequately assessed by visual observation or 2D video. The technology allowed bespoke patient measurement and identification of individual impairments, directly informing the intervention design. In the case of surgery, the intervention was significant in terms of risk, cost, time and irreversibility. The initial effort and financial costs were justified by the benefits of minimised harm, cost and improved confidence in clinical decision-making. Services could develop sustainable business cases, attracting funding, expertise and increased clinical capacity. Whilst there are parallels with some upper-limb conditions, a clear link between impairments, required biomechanical data and clinical outcomes/interventions is not well-established and this may be limiting the wider use.

4.3. Study limitations

Whilst our study provides an overview of different practice regarding assessment of the upper-limb across international professional societies and affiliated laboratories, our data does not allow us to infer which methods of measurement (modalities marker sets and biomechanical/ musculoskeletal models), assessments (movements, functional tasks and outcomes) or reporting information is used in specific patient groups. Identification of which assessments are used in specific patient groups may be useful for informing research and clinical practice.

Information related to tracking of the scapula was provided by some laboratories although this was insufficient for codifying practice (Appendix 2). Scapula tracking presents numerous challenges which are unique to upper-limb motion analysis. It is important that in addition to the recommendations made above, future research captures practices specifically regarding scapula tracking to ensure a comprehensive understanding upper-limb movement can be achieved.

Recruitment was done through national societies to produce a group with common characteristics including access to research, peer support, networks of excellence and to eliminate outliers with more marginal interest or less developed expertise and experience. A broad overview of practice was captured; however, the ability to further subcategorise our results by region or other professional society groups is limited by the number of responses. Whilst this limits the generalisability of our findings in some cases, this work provides an overview of practice which may be used for informing future reference frameworks and consensus initiatives. We are also able to describe practice for a national (UK and Ireland) sub-population of laboratories accredited by CMAS, however it is recognised that there may be additional laboratories, both with the UK and internationally, who are conducting upper-limb assessment not included in this study.

The numbers of laboratories within some categories used for interpreting and comparing the data, e.g. CMAS laboratories with clinical purposes, whilst representative, was small and as a result when presented as a proportional representation may have been sensitive to small changes in the numbers of laboratories. We were also unable to determine a response rate for our study given that our study sample, an accurate number of affiliates at an individual or laboratory level is undetermined. Additionally, as our study investigated practice regarding upper-limb assessment, laboratories undertaking upper-limb analysis may have been more likely to respond and our sample may over represent the proportion and practices of laboratories within the affiliate groups approached during recruitment. Our study and supporting questionnaire explicitly sought to identify practice regarding upper-limb assessment and responses to the questionnaire have been interpreted as such. However, it is recognised that a very small number of responses may reflect components of practice where upper-limb activity and measurement was not the main focus but rather secondary to the lower limb. This is potentially reflected in the activities measured and selection of biomechanical models e.g. arm motion during gait and use of the conventional gait model respectively.

5. Conclusion

Overall practice was variable with no universally identified approaches regarding the patient groups seen, methods of assessment, outcomes, movements, functional tasks, marker sets and models used. CMAS accredited laboratories performed upper-limb assessment for more explicitly clinically orientated purposes compared to international professional society and affiliate laboratories who had a higher

representation of laboratories performing explicitly research orientated assessment or dual clinical and research orientated assessments. Factors which aid translation into clinical practice are likely the familiarity/availability and ease with which the markers set and models were integrated into existing workflows, or a clear link between the impairments of a patient group, selection of measurement method and possible interventions. Availability of standard reference tasks, protocols, software, funding and clinical need were identified as barriers to upper-limb analysis in practice. Whilst translational research outcomes may result in more widespread use of upper-limb motion analysis in clinic, a clear link between the impairment and clinical outcome is required. For the development of practice standards or further reference frameworks, future work should map the impairment, activities, outcomes and methods of measurement at the level of the patient population for both clinical and research purposes. Informed by our work, position statements or consensus initiatives could be developed through workshops, focus groups, Delphi technique or semi-structured interviews which are led and conducted by representatives from internationally collaborating professional societies [11]. This could be conducted remotely or at national and international conference meetings facilitating networking and sharing of current practices both within and between upper and lower limb movement analysis.

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Competing interest statement

All authors are members of the Clinical Movement Analysis Society of the United Kingdom and Ireland. None of the authors have any other financial or personal relationships with other people or organisations to disclose that could inappropriately influence (bias) their work.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2022.05.018.

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